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Potential Consumer Response to Electricity Demand Response Mechanisms: Early Plug-in Electric Vehicle Drivers in San Diego, California

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ABSTRACT

This report summarizes findings of household interviews and focus groups conducted with plug-in electric vehicle (PEV) drivers on the effects of demand response management (DRM) strategies on the time of day of PEV charging. The research was conducted in the spring and fall of 2012 with PEV drivers in San Diego County, CA. The DRM strategies were of three basic types. First, electricity pricing included intentional and carefully designed time-of-use (TOU) price signals as part of a household PEV customer rate experiment by San Diego Gas & Electric (SDG&E), as well as uncontrolled implicit TOU signals resulting from differences between home and away-from-home prices of electricity. Home and away-from-home charging had independent price structures—including an initial period lasting several months during which much of the away-from-home charging was free. Second, technology, in this case timers on-board PEVs and in the electric vehicle service equipment (EVSE), i.e., the “chargers” were available to support PEV drivers adherence to a chosen time to start vehicle charging. Third was exhortation—often implicit or indirectly tied to PEVs—about the private and social benefits of shifting electricity demand to off-peak periods. It is not possible to entirely disentangle the effects of the individual DRM strategies. The aggregate effect is a widely told story by our respondents of their goal to maximize the amount of their PEV charging done during the “super off-peak” period from midnight to 5am. Given the qualitative research reported here, this stated behavior should be corroborated with quantitative measures of vehicle charging when they are reported at the end of SDG&E’s TOU rate experiment. Our PEV drivers reveal different comparative standards for whether any electricity price is perceived to be “high” or “low.” Their behavior, in aggregate, suggests the effect of TOU prices may be more like an off-on switch than the continuous change implied by the most common measure of such prices, i.e., own-price elasticity of electricity. This may be because TOU prices convey both a private price signal and a public exhortation to heed a social narrative about the susceptibility of the electrical grid to service interruption during periods of peak demand. PEV drivers with home photovoltaic systems are the most likely to say they charge their PEV at their convenience throughout the day—despite also being on a TOU rate—because of the mistaken belief that their PV system insulates the grid from their vehicle charging. A series of questions is posed about the generlizability and longevity of these findings, in particular as additional PEVs and PEV buyers enter the market.

Keywords: plug-in electric vehicle (PEV), demand response management (DRM), consumer response.

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EXECUTIVE SUMMARY

Early PEV Buyers Reaction to Demand Response Management

There are large time-of-day differences in present electricity demand. The uptake of plug-in electric vehicles (PEV) by large numbers of consumers would represent large new demand for electricity to charge the vehicles. Even more modest early PEV sales could produce local electricity distribution problems if those sales are geographically clustered. Thus, it is desirable to implement systems to manage the new total demand for electricity in a way that at least does not exacerbate the present time-of-day distribution of electricity demand and at best utilizes the new PEV demand to produce a more desirable total demand curve. A rubric for programs and methods for shaping demand according to some system-optimum—as opposed to the optimum of any individual—is Demand Response Management (DRM). While DRM is generally thought of in terms of pricing and technology, we add here a social component we will call exhortation. The question we address is whether PEV buyers' vehicle charging behavior can be shaped so as to avoid new electricity demand during the existing evening peak, but rather fills the existing valley of electricity demand during the hours from midnight to 5am. Impacts on spatial clustering are left to other research.

This report presents findings regarding the behavior of recent buyers and lessees of PEVs to DRM measures. Twenty-eight PEV owners and lessees were interviewed in their homes in April and May, 2012. Four focus groups were conducted with a second sample of PEV drivers in November, 2012; a total of thirty-three participated. All 61 of these PEV buyers and lessees reside in San Diego County, CA; they were drawn from the population of people eligible for a California Clean Vehicle Incentive (CVI) in 2011 and early 2012. Notably this population largely excludes early buyers and lessees of Chevrolet's Volt because that vehicle was not eligible for the CVI during the Volt's first model year. This means our samples of PEV buyers are made up almost solely of buyers and lessees of the Nissan Leaf. (A handful of Volt drivers were included because they were also Leaf buyers or because they were in an additional sample drawn from participants in Ecotality, Inc.'s EV Project to supplement the focus group recruiting list. One participant owned a Tesla Model S; another, a Toyota RAV4-EV.)

DRM in San Diego, CA

Three basic DRM strategies were deployed in San Diego: pricing, technology, and exhortation. Pricing was complex in that price signals differed by location type over the study period, i.e., not just the intended pricing by time-of-day. Some form of time-of-day pricing was deployed for at-home charging consistently over the study period with the exception of those households who had a tariff based on a pre-existing, i.e., before they purchased or leased their PEV, solar-photovoltaic (PV) system. As no pricing structure for away-from-home charging was consistently implemented for the study period, it follows that no time of use (TOU) rate structure was either. Any single household faced a variety of possible transitions away from a non-TOU rate to a TOU rate. As much away-from-home charging occurred and is anticipated to occur during daytime and early evening hours (when PEV drivers are more likely to be driving), whether or not that service is free or priced, it carries an implicit time-of-use signal.

One of several of San Diego Gas & Electric's (SDG&E) TOU tariff structures might be available to a given household. The primary distinction between the single-meter (whole house plus PEV)

EV-TOU rate and the EV-TOU2 rate (in which the PEV has its own meter and TOU rate) is that the transition from peak to off-peak pricing occurs earlier in the evening for EV-TOU2. The domestic solar energy system rates (DR-SES) for those with PV systems are generally slightly higher than the EV-TOU rates and the timing of transitions between rates generally differ by one or two hours.

In addition to these rates, SDG&E is conducting a TOU rate experiment specifically for PEV charging. Participants were all screened to assure they could (and did) install an EVSE at their home and had a second meter specifically for their PEV. Further, they all were drawn from Ecotality's EV Project, so all had a Blink brand EVSE. All their PEVs were Nissan Leafs. Participating households were randomly assigned to one of three experimental TOU rates. These rates were designed to study the elasticity of PEV drivers time-of-day vehicle charging; they were not designed according to the usual rate design principles used to set non-experimental rates. The experiment was designed to test for 1) differences between the experimental rates, and 2) the persistence of time-of-day effects within experimental rates over time. The experimental rate X most closely matches the EV-TOU rate, with slightly lower super-off peak and slightly higher on-peak prices. Going from rate X to rates Y and Z, the super-off peak rates are even lower, and the on-peak prices higher.

The technological approach to DRM deployed in the study setting was the timer on-board the vehicle and another timer in the electric vehicle service equipment (EVSE), i.e., the "charger," itself. Exhortation took two primary forms. First, there is an ongoing narrative in California about the electrical grid being subject to brownouts and blackouts and the role of peak electricity demand—especially from air conditioning on hot summer afternoons—in these service interruptions. This narrative is generally supported by electric utilities in California, including SDG&E, through public service announcements and other education and outreach efforts. Second, the TOU rates themselves not only price electricity differently, but also symbolize the importance of protecting the electrical grid.

Early PEV Buyers' Reactions

We first summarize the findings, and then elaborate on them in subsequent sub-sections. DRM strategies in San Diego have produced a widely (but not universally) shared set of beliefs and behaviors that accomplish the goal of assuring that high percentages of PEV charging occur during the valley, or "super off-peak" time period of midnight to 5am, especially on weekdays. However, the wide variety of specific non-PV tariff structures, i.e., EV-TOU, EV-TOU2, DR-SES and the experimental rates X, Y, and Z make very little difference in the stated beliefs and behaviors of these PEV owners and lessees. It appears that the existence of any price reduction (at least within the range of reductions in this research context) for electricity during the desired "super off-peak" PEV charging period is enough to prompt the desired outcome—with a few notable exceptions discussed below.

The role of DRM technologies, timers in this case, are to aid in making behaviors routine: set a timer, plug-in the PEV upon returning home, don't think about it until the next morning. This technology and these routines are not foolproof and produce unintended outcomes—almost always in the form of a "missed" charge.

The effect of TOU tariffs is not solely through price alone. Rather, the TOU tariff structures are part of a narrative about electricity demand in California that the PEV drivers recount: the susceptibility of the grid to service interruptions. That is, the system or social benefit behind the prices differences is accepted and the goal of grid reliability is supported. The TOU price signals also support another narrative about PEVs—that they are inexpensive to drive because electricity is a cheaper fuel than gasoline. Part of this narrative is the elevation of cost-effectiveness, or frugality as virtues. As one of our respondents said, "That's part of the lure of the whole thing… the frugality of it because we're cheap." Thus, the effects of TOU tariffs are difficult, and may be impossible, to disentangle from the effect of exhortation.

Charging behavior in response to TOU tariff schedules

Home charging

The descriptions of almost all respondents who were on any TOU tariff were similar, whether for their home and PEV combined (EV-TOU), their PEV only (EV-TOU2), or any of the experimental rates: "Super-off peak (midnight to 5am) is cheapest. Why wouldn't I charge then?" In short, that there was any price signal was enough for almost all the PEV drivers without a home PV system to do all their at-home charging during the least expensive price period. Motivations were linked to both the direct effect of pricing on (private) costs and social or system benefits.

The savings from using electricity as fuel rather than gasoline was an important motivation for off-peak charging. Households went so far as to calculate individual trips. "My wife did the math. She said it costs her 86 cents to go round trip—that would've been $12 in gasoline." Several participants were able to recount their average miles driven per month and connected this with the cost of their electricity bill, in comparison to what they estimated they would have spent on gasoline. Many drivers were proud of their savings and the cost differential represented a reason for charging at home

Respondents differed in their assessment of whether the TOU rates were essential to achieving their purported cost savings. One of the respondents who thought the super-off peak price was essential to cost savings said, "[You] start thinking about if the EV is really so much cheaper with electricity compared to gasoline, and it may not be, unless if you charge at home for the very low rate time, which is midnight to the morning..." Contrary statements included, "The difference between the super off-peak and the off-peak is only two cents per kilowatt. It's not a big deal." (It is essential to recall that these drivers may have faced different TOU rates from each other. Further, the second statement is either a simple misstatement or the informant doesn't know their price difference between peak and super-off peak since in no case is it less than 12¢ per kWh.)

Their vehicles, i.e., mostly the Nissan Leaf, are capable of attaining a "full" charge during this five-hour period. Thus no Leaf driver faced the question of whether to fully charge (at a slightly higher cost) or partially charge (to keep all charging in the super-off peak period). We qualify "fully" charge because virtually all the Leaf drivers follow the vehicle manufacturer's suggestion to charge the battery to 80 percent in order to protect battery life.

Who was not responsive to TOU rates?

There are two notable exceptions to this responsiveness to super-off peak pricing. One is PEV drivers who can charge at work for free during the day, "Usually when I drive in my driveway [the PEVs estimated remaining driving range] is usually in the teens and it charges for between four and four and a half hours every night and then I go to work and I charge for two." Drivers with short commutes may do all their weekday PEV charging during the morning hours just after arriving at work (and perhaps in the early afternoon after returning from lunch). They typically would charge at home during the period from midnight Friday to 5am Saturday so that the PEV is available for weekend driving.

The other exception is households who had PV systems; they were more varied in their time-of-day charging behaviors. Some believed that their home and PEV were completely insulated from the grid (or rather, that the grid was completely insulated from them) by their PV system; they would plug their PEV in at most any time of day they returned home. "When you have solar, you're generating power during the day so you're always paying the lowest per-kilowatt rate no matter because you pay based on how much you use and if you're never using more than the minimum you're never paying more than the minimum." This belief encouraged on-peak charging among some of the PV owners. Others reasoned that they made the most money by producing as much net power during the peak period, thus they would delay their PEV charging until their cheapest price period, beginning at 10pm. For these respondents the low cost of fueling an electric vehicle on SDG&E's DR-SES TOU rates for households with solar energy systems offered enough financial incentive to motivate off-peak and super off-peak charging.

Away-from-home charging

Away-from-home charging is not presently on any formal TOU tariff. This may be due in large part to the fact that providers of away-from-home PEV charging services cannot re-sell electricity. When we conducted household interviews in Spring 2012 all away-from-home charging reported by our respondents was free. By the Fall 2012 focus groups, some away-from-home charging locations were billing users, but were billing them for connection time, not kWh of electricity. The advent of billing for away-from-home charging services seems likely to have some of the effects of DRM strategies—even in the absence of explicit TOU tariffs for the electricity provided. While some PEV drivers continue to find value for paid away-from-home charging, many PEV drivers tell us that paid away-from-home charging is now an emergency back-up, not the perquisite it was when it was free. One driver explains, "I always look at the public charging things as an emergency. I never charged and paid for it other than…in desperation." As PEV drivers are most likely to be driving during peak and off-peak electricity use times and parked at home during super off-peak periods, any reduction in their away-from-home charging has the effect of reducing peak or off-peak charging, whether or not it increases their super off-peak charging.

When and where it was available (and continuing at those locations where it still is available), free away-from-home charging presented a powerful price signal, and also an implicit time of day signal. For example, several interview respondents in Spring 2012 discussed using public charging stations because they were free even when they did not need to charge the PEV, "On a weekend especially where Balboa Park is almost always on the map, I'm plugging into that run. Even if it only took two bars to get down there, I'm plugging in. Because it's free and because it's parking that I wouldn't otherwise have." That away-from-home charging carries an implicit TOU signal is part of the transition from free to paid service. One focus group participant explained his response to now being billed for connection time at PEV chargers, "A dollar an hour isn't that big of a deal, but there's a big gap between $1 an hour and free. You know, $1 to $2 is not that big of a deal, but $1 to free [group laughter] that's what's motivates people: free."

Some public charging systems introduced a flat access fee regardless of whether the vehicle is actively drawing a charge. Several drivers found that this system presented a disincentive for public charging, "Yeah, the thing I don't like about the way the system is going is that it's based on time and the connection time which is ridiculous because I should be billed by the kilowatt hour, not the amount of time I'm plugged in." Other drivers approved of connection charges as a way to ensure the availability of charging stations; "Maybe that's not such a bad thing if it's encouraging people not to leave their cars there longer than necessary."

Comparisons between gasoline and electricity costs and between home charging and public charging constituted the primary method of cost-savings analysis among respondents. One focus group participant discussed how the new expense of paid public charging access compared to the cost of charging at home confined his charging to home (and thus, largely to super off-peak), "So basically the calculations that go through my mind currently are I'm not going to rely on [away-from-home] charging at all. I will not take the Leaf out of the driveway unless I know perfectly well I can come back. Even if it's with a couple miles left on the gauge, I will not take the car out unless I'm almost positive that I can make it back." Several other participants shared his sentiment, "As far as relying on the [away-from-home] infrastructure to charge, it really is not economically viable to charge any place that charges more than twice as much as what you would pay at home."

On the other hand, some participants believed the shift away from free public charging represented a necessary step and were comfortable paying for public charging. Within this group, many expressed the opinion that so long as public charging remained cheaper than gasoline, they would be willing to pay for public charging. One driver explained, "It depends on how you did the comparison. If you're comparing the charging at home on the super cheap rate—midnight to five—it's probably four times as much. But it is still, as you pointed out, half as much as buying gas." This driver, like many others compared the price of public charging to the cost of charging at home.

Though these sorts of comparative costs remained a central factor in the discussion of whether drivers would use public charging, time and convenience emerged as influential factors on drivers' PEV charging and willingness to pay. Several participants found public charging to be an inconvenience and limitation due to charging times, parking, and billing systems. Several participants found public charging to be an inconvenience and limitation due to the length of time required to fully charge their vehicle. For some this was because the time constraints required additional planning; "It puts a big obstacle on your planning of your day. I may not want to spend two hours at whatever hotel. I mean what am I going to do there? It doesn't seem to fit my life anyway." Like this participant, several PEV drivers chose not to use public charging because it did not fit into their lifestyle or routine; "I don't really see charging public and paying for it like a regular part of my day just because I don't want to see my bars too low or something. I would rather just drive with as low [a charge] as I can to home or get stranded trying." This driver, amended that they would use public charging, "if my lifestyle changes so that I have to have charge in my route or along the way of my route."

Some drivers talked about using charging stations because of the free parking, or premium parking made available to them as PEV drivers. Others talked about the problem of parking in a different way, citing the disincentive of paying for parking on top of paying for a charge. "They have six charging stations right over here at 4th and B but they charge you $10... There's a fee for parking because I work downtown and so…it's $10 plus the Blink fee." "Sea World has them [chargers] but you have to pay to park though…" One participant explained the difficulties of parking at the San Diego airport. "If I'm going to the airport, I'll park across the way on those spaces and take the free parking." For these participants free charging was restricted and pay-to-park charging was made unappealing by additional parking costs.

The complications of different charging services and billing systems presented another challenge. Several focus group participants complained of the complication and confusion of having to manage multiple memberships, billing cards for different EVSE provider networks, and rate structures. One driver suggested streamlining the payment process citing the system of charging used in Houston, TX; "As far as pricing models I've kind of been interested in doing what they're doing, I think it's in Houston, where it's just billed [to] your home electric bill. You're in a plan and you use as much juice as you want and I guess all those are owned by the utility company though. And you can plug in anywhere in town and you're not worrying about…" Other drivers offered similar suggestions and many agreed payment methods for public charging need simplification.

For other PEV drivers, public charging represented a convenience despite the associated costs and complications. One driver with three children explained, "I think differently because I think of the public charging stations as, 'I don't have to go home.' I can charge up while I'm running errands, then I can pick up my kids, run my kids around and then get [home]…" Another driver described his first public charging experience, "My alternative would be to drive the Prius down and back [from north San Diego County to the City of San Diego], and it would have cost a lot more than a dollar. A dollar would just get me a quarter gallon of gas. So I had no problem justifying paying a dollar [for an hour of public charging] to have the assurance of getting home." For these drivers the convenience and comfort offered by public charging offset the cost.

On weekdays, the PEV drivers are far more likely to be away-from-home outside the hours of midnight to 5am; thus, free away-from-home electricity was a strong inducement for those drivers who could, to charge their PEV outside the desired off-peak period. Participants in one focus group outright rejected the notion that away-from-home charging would need to be priced according to a time-of-use (TOU) schedule because they imagined no benefit to less expensive, late-night, away-from-home charging—they would always be home during super off-peak hours. "Time of day is kind of irrelevant because it's always going to be during the day for the most part because at night you're charging at home…You'll rarely ever use it at night so it would only be peak power."

Timers

Some PEV drivers (across the home TOU tariffs) agreed that establishing a routine played a role in when they charge their cars; the primary role of timers was to enable these routines. Price may have been an initial motivator; timers enable a routine to enact that motivation (and any other). One respondent said, "SDG&E sends a thing out that tells you when your lowest rate is. So once you just set up all the timers, it's just standard." Another agreed, describing their routine, "I just set the timer for midnight…it charges up the next morning and I get in and go." The combination of TOU rates and a timer turned charging into a routine, "For those of us who are on TOU it's so easy. You plug it in when you get home and you don't think about it until you get out the next morning." For households with such routines, charging during peak times, including public charging, happened only rarely because it represented a deviation from their standard PEV charging behavior.

However, some households established more flexible routines; when to charge included lifestyle or household schedules, not adherence to a single, simple routine. Though most of the PEV drivers spoke with tried to limit their PEV charging to off-peak times, most could recite emergencies and disruptions in daily routines (such as a second driver using the PEV) as reasons for charging during peak periods. One driver explains, “Too many things come up unexpectedly. But, yeah, usually we plan. And sometimes I forget to hit the ‘don't charge during the day’ button.” For many, weekends were when the household required changes from their weekday routines of PEV charging, “The thing is sometimes on the weekend, in the morning I would have a bunch of errands and I’d come home with almost no charge at midday. Occasionally I do [plug in during the day on weekends] because I have to make another trip.”

The downside of using the timer technology to establish and sustain a routine is that it separates the driver from the actual charging of their PEV; the driver merely connects the EVSE to the car—the timer starts the charging. This is problematic when the drivers charge their PEVs at a place or time that is not the primary place and time of the routine. For example, a PEV driver may enact a routine to connect their EVSE to their PEV in their garage when they arrive home from work. Charging anywhere else or at any other time—both in the sense of clock time and in the sense of the flow of events in their day—is a break in that routine. In the new situation, they may connect the EVSE to their PEV—and walk away forgetting to override their timer. The usual consequence is a missed charge. Several people offered such examples, “We forgot to push the timer button to turn the timer off. So we were [billed] for two hours and didn’t get any electricity at all.”

Exhortation

The PEV drivers recount numerous reasons why charging during the super off-peak period provides “civic” benefits to all electricity users. That these PEV drivers are able to recount these benefits is evidence of a social narrative about electricity. This narrative existed before the sales of PEVs in exhortations from electricity providers for electricity users to moderate their peak electricity use. As one driver said, “…ever since I have been in California, I’ve been conditioned that between 11[am] and 6pm are flex hours and that ‘s when they have the blackouts and that’s when the fires start.” Some drivers explained their choice to charge their PEVs during off-peak and super off-peak periods as a sort of civic duty or a way to contribute to the electric grid infrastructure. One driver discussed his belief that charging his PEV at night not only supports the grid, but the local economy, too.

> “Well, electricity is so much cheaper if you're charging at night, you have more money to spend on the local economy, and you're not sending money overseas. So it's good for the local economy…it's also we're supporting the infrastructure because we're paying the infrastructure cost, so we're bringing the cost down for the system for everybody else.”

This civic-mindedness was present even among drivers with home PV systems and those who reported not being on a TOU rate structure; “Charging during off-peak times reduces emissions and infrastructure costs, its just better for society. It's the right thing to do anyway… it’s just being a good citizen."

However, some participants with home PV systems charged anytime, explaining that not only was it always the same price to charge but also that they were generating power and did not feel guilty charging at peak times; "We have the solar panels so they do it kind of differently. We charge more when it's peak."

Part of the focus group discussion centered on several challenges to home charging during off-peak time periods. Participants offered suggestions that would improve the ease of charging and encourage drivers to take advantage of the TOU rates. One driver said,

> "It really should all be done in a way that encourages [super off-peak charging], because in the long run, like he said, if we're plugging in at night and we're paying something, we're helping support the grid, you know, the overhead, and all the other positive things that are happening."

Many of the drivers agreed that utility companies should encourage PV use for electric vehicle drivers but also find a way to encourage plugging in at night. They believed this approach would benefit both the utility, by alleviating demand and providing more energy, while also benefiting the drivers with decreased costs.

Guidance for future policy and research

As the findings reported here are specific to a time, a place, and a more limited variety of PEVs than are already available to consumers, questions about the generalizability (across electricity infrastructure and pricing, households, and vehicles) and longevity of these results require further research to inform robust policy making. A few of these questions are unexpected—either because they confound prior expectations or because we simply had not formed expectations at all.

1. Is there an electricity price difference too small to prompt super off-peak charging?
    a. Our specific findings suggest that pricing mechanisms do shift PEV charging to desired time periods, but the smallest effective price signal may be smaller than any presented to the PEV drivers who spoke with us. Much of the prior research on DRM discussed in the literature review purports to estimate own-price elasticities of demand for electricity, implying larger price differences produce larger response. The discussions with PEV drivers in San Diego suggest that price differences act more like an on-off switch.
2. How durable is the effect of DRM (more generally than pricing) on charging behavior?
    a. To date, the experience of these PEV drivers is that they establish routines that tend to reinforce over time patterns of charging during super-off peak periods.
        i. Deviations tend to be mostly by people who have home PV systems. What is necessary to assure that these people understand that, in general, they are part of the "grid" too and that charging their PEV at night is important.
    b. Future PEV owners: will they respond differently to price signals? How? Why?
        i. One reason may be more of the future PEVs may have larger batteries that cannot be fully charged within the five hour super-off peak period in SDG&E's present tariffs. Even at a faster charging rate of 6.6kW (double

the 3.3kW of the Nissan Leaf vehicles driven by most of our respondents), a five hour period allows for a maximum charge of approximately 30kWh. Given this, some of these PEV drivers may have to complete at least a portion of their charge during off-peak rather than super-off peak times. Whether they do, how many have to, how often they have to, and the aggregate effects on total electricity demand are subject to future research.

3. Effects of TOU rates for away-from-home charging arose in the study setting mostly because of the correlation between the timing of those rates and the timing of most of these households daily schedules.
    a. We did not study the use of Car-2-Go PEVs in the study area; what is the time of day distribution of demand for car-sharing and charging of shared cars?
    b. If PEVs make inroads into markets—younger people?—who may have different daily routines than the predominately employed families and retired persons in our sample, what will the time of day distributions of activities, travel, and PEV charging demand be for them? And, how susceptible will they be to DRM strategies to push their PEV charging into specific timer periods?
    c. As markets for PEVs grow—regardless of the sort of differences just mentioned—will demand for away-from-home charging grow enough to warrant the application of TOU pricing?
4. What we have called exhortation—the positioning of TOU pricing for PEV charging within ongoing social narratives, social marketing campaigns, and other efforts to create a sense of civic duty—is part of effective DRM strategies to shape PEV charging. The question is whether it is possible to separate the effect of pricing from the effect of what pricing means or symbolizes in order to create more effective DRM campaigns.

CHAPTER 1: Plug-in Electric Vehicle Buyers' Responses to Electricity Demand Response Management

1.1 Background and Research Questions

There are large time-of-day differences in present electricity demand. The uptake of plug-in electric vehicles (PEV) by large numbers of consumers would represent large new demand for electricity to charge the vehicles. Even more modest early PEV sales could produce local electricity distribution problems if those sales are geographically clustered. Thus, it is desirable to implement systems to manage the new total demand for electricity in a way that at least does not exacerbate the present time-of-day distribution of electricity demand and at best utilizes the new PEV demand to produce a more desirable total demand curve.

A rubric for programs and methods for shaping demand according to some system-optimum—as opposed to the optimum of any individual—is Demand Response Management (DRM). While DRM is generally thought of in terms of pricing and technology, we add here a social component we will call exhortation. As part of the market launch of PEVs in San Diego, CA. San Diego Gas & Electric (SDG&E) secured permission from the California Public Utilities Commission to conduct an experiment with different time-of-use rates for PEV owners. SDG&E is conducting a large-scale, long-term analysis of this experiment. The electric vehicle service equipment (EVSE), i.e., vehicle chargers, and each PEV are equipped with timers to control when the PEV charges. The effect of charging PEVs on electricity grid reliability was part of the public discussion and marketing of PEVs and of a much longer-term narrative told about electricity in California by the electric utilities, and the PEV owners who participated in the research that is the basis for this report.

The research question we address is whether early PEV buyers' vehicle charging behavior has been shaped so as to avoid new electricity demand during the existing evening peak, but rather fills the existing valley of electricity demand during the hours from midnight to 5am. The impact of spatial clustering of PEV markets is left to other research.

This report presents findings regarding the behavior of recent buyers and lessees of PEVs in San Diego County, CA to DRM measures. Twenty-eight PEV owners and lessees were interviewed in their homes in April and May, 2012. Four focus groups were conducted with a second sample in November, 2012; a total of thirty-three more PEV drivers participated. All 61 of these PEV buyers and lessees reside in San Diego County, CA; they were drawn from the population of people eligible for a California Clean Vehicle Incentive (CVI) in 2011 and early 2012. Notably this population excludes early buyers and lessees of Chevrolet's Volt because that vehicle was not eligible for the CVI during its first model year. This means our samples of PEV buyers are made up almost solely of buyers and lessees of the Nissan Leaf. (A handful of Volt drivers who were included because they were also Leaf buyers or because they were in an additional sample drawn from participants in Ecotality, Inc.'s EV Project to supplement the focus groups. One participant owned a Tesla Model S; another, a Toyota RAV4-EV)

1.2 Literature Review

The existing literature on demand response varies from large programmatic reviews to detailed descriptions of individual experiments. Of particular interest to this report are studies that explore the potential effect of demand response on household PEV charging behavior—there is however very little literature specific to this topic. The more general literature on residential demand response programs yields a fairly unified approach to measuring "behavior" but varied results. The behavioral measure commonly used is the own-price elasticity of electricity, i.e., for a unit change in the price of electricity, how much does demand for electricity change? These measures are typically offered as averages or aggregates, sometimes for sub-sets of the study samples. A few recent studies try to reconceptualize charging behavior as something other than a price response, hoping to uncover clues to means to shape demand other than prices. Regardless of the measure, the literature appears to span results from no effect of DRM on time-of-day demand electricity to moderate effects.

Of interest to the present report, past results notably don't address whether on-peak electricity demand was shifted to another time period, or whether those energy-using services were simply forgone. In fact, given that most of the prior literature reviewed here focuses on residential building demand, an actual reduction in overall electricity use counts as a benefit. For example, air conditioning services not consumed at the contemporaneous peak temperature and peak electricity demand period may simply be forgone. For PEVs though, while many PEV drivers may be willing to delay charging their vehicle, they will want it charged before they leave home the next day.

1.2.1 National Programmatic Reviews

The United States Department of Energy (USDOE) (2006) offers the following definition of demand response:

> "Changes in electric usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized."

They categorize mechanisms of demand response as either price or incentive-based. Pricing strategies include TOU, real-time pricing (RTP), and critical peak pricing (CPP). TOU prices, while variable over the day, vary according to a fixed schedule. RTP prices vary according to demand; in practice, customers with RTP may have as little as one hour to adapt to a new (higher or lower) price. CPP is essentially TOU with the highest price being variable (as in RTP) rather than fixed (as in TOU). Incentive-based demand response strategies pay customers to participate in, as examples, direct load control or interruptible/curtailable service.

This USDOE review cites studies of voluntary participants in a variety of demand response programs. The reported point own-price elasticities for three different residential studies range from -0.04 for the least elastic participants in a residential CCP program in CA to -0.21 among the most elastic participants in a five-utility TOU program. Across the three residential studies cited, the mid-value elasticities varied from -0.08 to -0.14. These may be characterized as inelastic responses, i.e., behavior does not change greatly with changes in price. In the cases cited, the behavior of interest was total on-peak electricity consumption.

While the Federal Energy Regulatory Commission (2011) conducts a survey of utilities and grid operators, they primarily take physical measures of demand response, e.g., counts of entities with demand response programs, estimates of potential peak load reductions by regions and customer types, but no discussion of actual customer behavior in response to these programs.

1.2.2 Residential DRM; without PEVs

The formation of the United States Department of Energy in 1977 was one sign of the rapidly increasing interest in managing energy demand in addition to private production of energy supplies. DRM of electricity prompted much research at this time, including residential electricity demand (see for examples Lifson and Miedema (1981) and Faruqui and Malko, 1983). This research does not appear to have included the specific question of managing new electricity demand from PEVs. However, Lifson and Miedema (1981) foreshadow the apparent results of the present TOU rate experiment in San Diego: "Results indicated that if the TOU rates had an effect on usage, the effect was virtually identical for each TOU rate." Faruqui, A. and J.R. Malko (1983) review twelve pricing experiments. Their overall conclusion is that residential peak-period electricity consumption is generally price-sensitive; TOU rates generally reduced peak period—and daily—electricity use. However, they report short-run own-price elasticities of peak consumption range from 0 to -0.45. These two studies do not necessarily contradict each other; Lifson and Miedema are not saying TOU rates have no effect; rather, differences in TOU rates don't seem to have different effects.

The more recent chapter on customer response to dynamic pricing (RTP rather than TOU) of electricity in Borenstein et al. (2002) characterizes buildings as the "customers." The authors report from one study in Georgia that one-hour-ahead price increases of 20¢ per kWh achieve reductions of zero to 20 percent across groups of increasingly motivated customers, i.e., customers defined *a priori* as more motivated to change showed large reductions in electricity use for the same price signal.

Thorsnes et al. (2012) described an experiment to measure the response of 400 households in New Zealand to weekday differentials in peak and off-peak electricity prices. Much as was done in the present SDG&E TOU experiment, each household was assigned randomly to one of four experimental groups: no change in peak or off-peak prices, low price differential, medium price differential, and large price differential. They report TOU rates had no statistically significant effect on either average daily electricity consumption or on-peak consumption when averaged over an entire year. Additionally there was no significant variation in peak conservation with price across experimental groups.

Faruqui and Sergici (2010) reviewed residential DRM experiments from 2001 to 2005, mostly in US states, though one each also in France, Australia, and Canada. In contrast to Thorsnes et al. (2012), Faruqui and Sergici claim there is "conclusive evidence that households respond to higher prices by lowering usage. The magnitude of price response depends on several factors, such as the magnitude of the price increase, the presence of central air conditioning and the availability of enabling technologies…." Still, the estimates of own-price elasticity of demand for electricity can be generally characterized as being in the range defined as inelastic.

1.2.2.1 DRM, Smart Meters, and Smart Grids

Some stakeholders view the deployment of DRM and smart meters as steps toward the smart grid. Whether or not one achieves the benefits of smart grids may then depend on the acceptance by electricity customers of these building blocks. Krishnamurti et al. (2012)

combined in-depth interviews and a general survey to investigate the perceptions of potential smart meter customers. The authors first elaborated a normative analysis of smart meter installation, consisting of an examination of the potential effects on individual households both from the smart meter itself and effects that might arise from implementing smart meter technologies. Second they conducted descriptive research into how individuals actually view and make decisions about smart meters. This was achieved through the in-depth interviews and a subsequent structured survey.

In both interview and survey responses, participants generally reported wanting smart meters. However, this desire was often based on incomplete or incorrect information about the purpose and function of smart meters. According to the authors, respondents confused smart meters with in-home displays and other technologies and expected to realize immediate savings. They also perceived risks, including less control over their electricity usage, violations of their privacy and increased costs. To bridge from the normative analysis of smart meter installation to the everyday reality of consumers, the authors suggested two possible avenues of smart meter implementation. The first is to scale back consumer expectations for smart meters and the second is to bring the technology in-line with expectations of consumers.

Verbong et al. (2013) conduct a series of in-depth interviews with stakeholders and smart grid projects in an attempt to reveal how stakeholders perceive and enact the inclusion of users in the transition process toward smart grids. The research was conceived and conducted within a Strategic Niche Management (SNM) framework, i.e., focusing on experiments and user niche developments during transitions in socio-technical systems. For many of the respondents, smart grids represent a shift toward demand management. Consequently a focus on electricity users, specifically on encouraging behavioral change, emerged as a unifying theme among stakeholders and smart grid projects. Many stakeholders identified a need for long-term engagement of users, achieved by changing their routines through the use of feedback mechanism and incentives. There was widespread consensus that users need to be actively involved in their energy use. The most common perspective was that offering price incentives would trigger and sustain this involvement. Rather than only use high prices as disincentives, some stakeholders suggested that users might be motivated by ideas such as self-sufficiency and environmental image.

The authors maintain that stakeholders placed too much focus on technology and economic incentives. They argued that though sustainability and costs are relevant they are often not decisive in how electricity demand management is embedded in everyday household practices. In their opinion social variables like daily routines, individual preferences and social relations in a household seem to be more important for energy demand and efforts to influence this demand. This view points to alternative models of "user," "consumer," and "household" behavior.

1.2.3 TOU and PEVs

One recent discussion of TOU and PEVs by Faruqui et al. (2011) reviews the rational actor rationale for why pricing would affect PEV charging. Their simulation results suggest a small average elasticity = -0.04; "Using this price elasticity with the high TOU rate…we find that the percent of customers charging during the peak period would drop from 60 percent to 55 percent." They do recognize that early PEV buyers may be motivated by more than the modest private cost savings the authors estimate for any driver adhering to the off-peak charging period compared to what the authors call "convenience charging" starting at whatever time the PEV arrives home.

1.2.4 Alternate Behavioral Models

The reliance on elasticities as the measure of the effect of DRM reveals a pervasive underlying model of electricity users as rational actors who will respond in a predictable manner to changes in prices. A few studies have pursued alternate behavioral models in an effort to improve explanation for the relative success or failure of DRM to achieve its stated goal. Strengers (2012) reviews current theories of behavioral choice emphasizing individual consumers and their beliefs, values, and attitudes. These theories frame consumers as rational, self-interested and autonomous agents, and technology as an impartial instrumental tool.

Strengers then introduces *practice theor*y as a way to reframe the debate around peak electricity demand management. Rather than offer empirical analysis of demand response technology, she examines the production of knowledge and how paradigms of reality influence the practices of professions charged with managing energy demand. Practice theory posits that practices are the source and carrier of meaning, language, and normativity. In this sense, any individual's beliefs, attitudes, and values arise from practices. Individuals are simultaneously constrained and directed by practices even as those same individuals constitute those practices by enacting them. From the perspective of practice theory, energy consumption patterns arise not from beliefs, attitudes, and values of individuals but from the expectations and conventions associated with everyday household practices.

The author argues that changing the conceptualization of peak electricity demand as arising from social practices directs demand managers toward different means of creating change. If demand is a product of fluctuating social practices, change agents must understand the elements and reproduction of problematic practices. Such a change in perspective would re-orient the purpose and function of change agent professions (such as demand managers) in three significant ways. First would be a rethinking of provider-consumer relationships. In a practice theory approach, consumers become active participants in the management of their own practices rather than passive recipients of new information—including new prices. Second would be a re-examination of the scale of demand. That is, change agents would increasingly identify a wider range of human and non-human stakeholders who are involved in shaping and shifting the elements of practices. Third, demand managers could promote new wants and needs by actively challenging taken for granted lifestyle practices.

This theoretical argument elaborates on earlier empirical work by the same author. Strengers (2010) examined the causes behind the impact of a Dynamic Peak Pricing (DPP) on households' electricity consumption. The author explains that international DPP trials have demonstrated a significant reduction in electricity use. Citing research that demonstrates the effectiveness of DPP, the author set out to answer the questions of how and why households change their cooling practices in response to DPP signals through semi-structured and conversational group interviews with households, attempting to include as many members of the household as possible.

She believes the findings challenge the assumption of rational action on the part of consumers. Though there was some evidence that households weighed the benefits of practices against the high cost of electricity during DPP and modified their demand, increased cost did not often feature in their explanation of why or how they responded to DPP signals. The author explains that DPP trials engage households as co-managers of their cooling practices through a series of notification signals. Significantly many respondents expressed a sense of social responsibility in responding to DPP signals. The fact that households communicated with one another led to increased sense of responsibility and accountability. Furthermore, being monitored by the utility led to new behaviors, in response to participation in a trial.

These results, the author argues, suggest that price signal may be less of a motivator for behavior change than of consumer engagement. The electric utility enables consumers to act as co-managers of specific practices thereby linking new social and cultural meanings to those practices.

1. 3 The Present Study Setting

1.3.1 Home electricity pricing

There was an array of six TOU electricity pricing possibilities in the study setting. We describe these six in some detail as consumer experience with their pre-PEV home electricity tariff structure will be shown to be related to their discussion of their PEV tariff structure—or whether they moved to any of the PEV specific tariffs.

SDG&E has several types of residential electricity rate schedules:

- one four-tiered price structure for most present residential customers (Table 1);
- one time-of-use price (TOU) structure for domestic residential services (DR Domestic Time of Use) (Table 2);
- two TOU rate structures for domestic residential services specific to households with electric vehicles (EV-TOU and EV-TOU2) (Table 2);
- three experimental TOU price structures for plug-in electric vehicle service (Table 3), and,
- one TOU price structure for households with solar energy systems (DR-SES) (Table 4).

Most domestic residential service is priced according to a tiered system (Table 1); the more electricity a household uses per month the more they pay per kilowatt-hour (kWh) as they cross certain thresholds, i.e., tiers. For example, once a consumer uses more than their baseline number of kWh (the first or baseline tier) the cost per kWh increases from $0.14344 to $0.16580 per kWh. This step size is independent of the season; the steps from tier 2 to 3 and 3 to 4 are larger in the summer (May through October) than in the winter (November through April). To the extent that a consumer pays attention, this is akin to a "time-of-use" tariff over the time span of one month.

Table 1: SDG&E Residential Electricity Tariffs

DR Domestic Service	Summer (May 1 to Oct. 31)	Winter (Nov. 1 to April 30)
Cost $/kWh: Baseline	0.14334	0.14334
101% to 130% of Baseline	0.16580	0.16580
131% to 200% of Baseline	0.27982	0.26239
Above 200% of Baseline	0.29982	0.28239

Source: http://www.sdge.com/sites/default/files/regulatory/010113-schedule_dr.pdf

More typically, TOU rate structures are thought of as those changing over the period of a single day. As implemented to-date in the study area, once a household has a TOU rate plan, the specific prices and the time schedule for changes in prices are, hypothetically, knowable in advance. (There is as yet no RTP or dynamic time-of-day pricing in which the price may change by any amount at any time in response to real-time demand.) The households' electricity meters communicate to the utility company the time of day at which electricity is used. Higher TOU prices apply during periods of high electricity demand and lower rates during periods of low electricity demand.

The TOU rate structure for domestic residences without electric vehicles is a hybrid tiered and TOU system where the rates are based on designated high (Peak) and low (Off-Peak) periods of demand for electricity (Table 2). This means that the cost per kWh for each of the four tiers differs based on the time or day and whether it is a weekend, weekday, or holiday.

SDG&E provides two TOU price structures for households with PEVs that divide the day into three periods of demand for electricity: high (Peak), low (Off-Peak), and super-low (Super Off-Peak) with corresponding rates. For both TOU price structures the Super Off-Peak period is from midnight to 5:00 A.M. But each offers different prices and times for the Peak and Off-Peak periods. Similarly, SDG&E offers customers with solar energy systems a TOU rate with three price periods: Peak, Semi-Peak, and Off-Peak.

In an effort to better understand the relationship between PEV charging and time-of-use rates, SDG&E is conducting a TOU rate experiment. Participating households were all screened to assure they could (and did) install an EVSE at their home and had a second meter specifically for their PEV. Further, they all were drawn from Ecotality's EV Project, so all had a Blink brand EVSE; all their PEVs were Nissan Leafs. Participating households were randomly assigned to one of three experimental TOU rates. These rates were designed to study the elasticity of PEV drivers time-of-day vehicle charging; they were not designed according to the usual rate design principles used to set non-experimental rates. The experiment was designed to test for 1) differences between the experimental, and 2) the persistence of time-of-day effects within experimental rates over time.

Table 2: Electric Tariff TOU - Residential Rates

	Summer *(May 1 -Oct 31)*			**Winter** *(Nov 1 - Apr 30)*		
	On-Peak	**Off-Peak**	**Super Off-Peak**	**On-Peak**	**Off-Peak**	**Super Off-Peak**
DR: Domestic Time-of-Use Service						
	Noon - 6:00 p.m. Weekdays	All Other Hours; Weekends; Holidays	N/A	Noon - 6:00 p.m. Weekdays	All Other Hours; Weekends; Holidays	N/A
Baseline Energy	0.15957	0.14063	N/A	0.14285	0.14063	N/A
101% to 130% of Baseline	0.17128	0.15234	N/A	0.15456	0.15234	N/A
131% to 200% of Baseline	0.2811	0.25357	N/A	0.24045	0.23738	N/A
Above 200% of Baseline	0.39039	0.27774	N/A	0.28851	0.27874	N/A
EV-TOU: Domestic Time-of-Use for Electric Vehicle Charging						
	Noon - 8 p.m.	All Other Hours	Midnight - 5 a.m.	Noon - 8 p.m.	All Other Hours	Midnight - 5 a.m.
Total Electric Rate	0.26183	0.16288	0.13878	0.17214	0.16519	0.14079
EV-TOU-2: Domestic Time-of-Use for Households with Electric Vehicles						
	Noon - 6:00 p.m. Excld Holidays	All Other Hours	Midnight - 5 a.m.	Noon - 6:00 p.m. Excld Holidays	All Other Hours	Midnight - 5 a.m.
Total Electric Rate	0.26179	0.16289	0.13878	0.1721	0.1652	0.14079

Sources for Table 2: Electric Tariff TOU
Domestic Time of use Service http://www.sdge.com/sites/default/files/regulatory/010113-schedule-dr-tou.pdf
EV – TOU: Domestic Time of Use for Electric Vehicle Charging http://www.sdge.com/sites/default/files/regulatory/010113-schedule_EV.pdf
EV – TOU: Domestic Time of Use for Households with Electric Vehicles http://www.sdge.com/sites/default/files/regulatory/010113-schedule_EV.pdf

Table 3: Domestic Experimental Plug-In Electric Vehicle Service

	Summer (May 1 -Oct 31)			Winter (Nov 1 - Apr 30)		
	On-Peak	Off-Peak	Super Off-Peak	On-Peak	Off-Peak	Super Off-Peak
-	Noon - 8 p.m.	8 p.m. - Midnight 5 a.m. - Noon	12 Midnight - 5 a.m. Daily	Noon - 8 p.m.	8 p.m. - Midnight & 5 a.m. - Noon	Midnight - 5 a.m. Daily
X-Group	0.26753	0.16313	0.1334	0.1724	0.16577	0.13903
Y-Group	0.28836	0.18136	0.07529	0.24286	0.16191	0.08015
Z-Group	0.37802	0.15121	0.0662	0.33171	0.13268	0.06868

Source for Table 3: Domestic Experimental Plug-In Electric Vehicle Service
X - http://regarchive.sdge.com/tm2/pdf/ELEC_ELEC-SCHEDS_EPEV-X.pdf
Y - http://regarchive.sdge.com/tm2/pdf/ELEC_ELEC-SCHEDS_EPEV-Y.pdf
Z - http://regarchive.sdge.com/tm2/pdf/ELEC_ELEC-SCHEDS_EPEV-Z.pdf

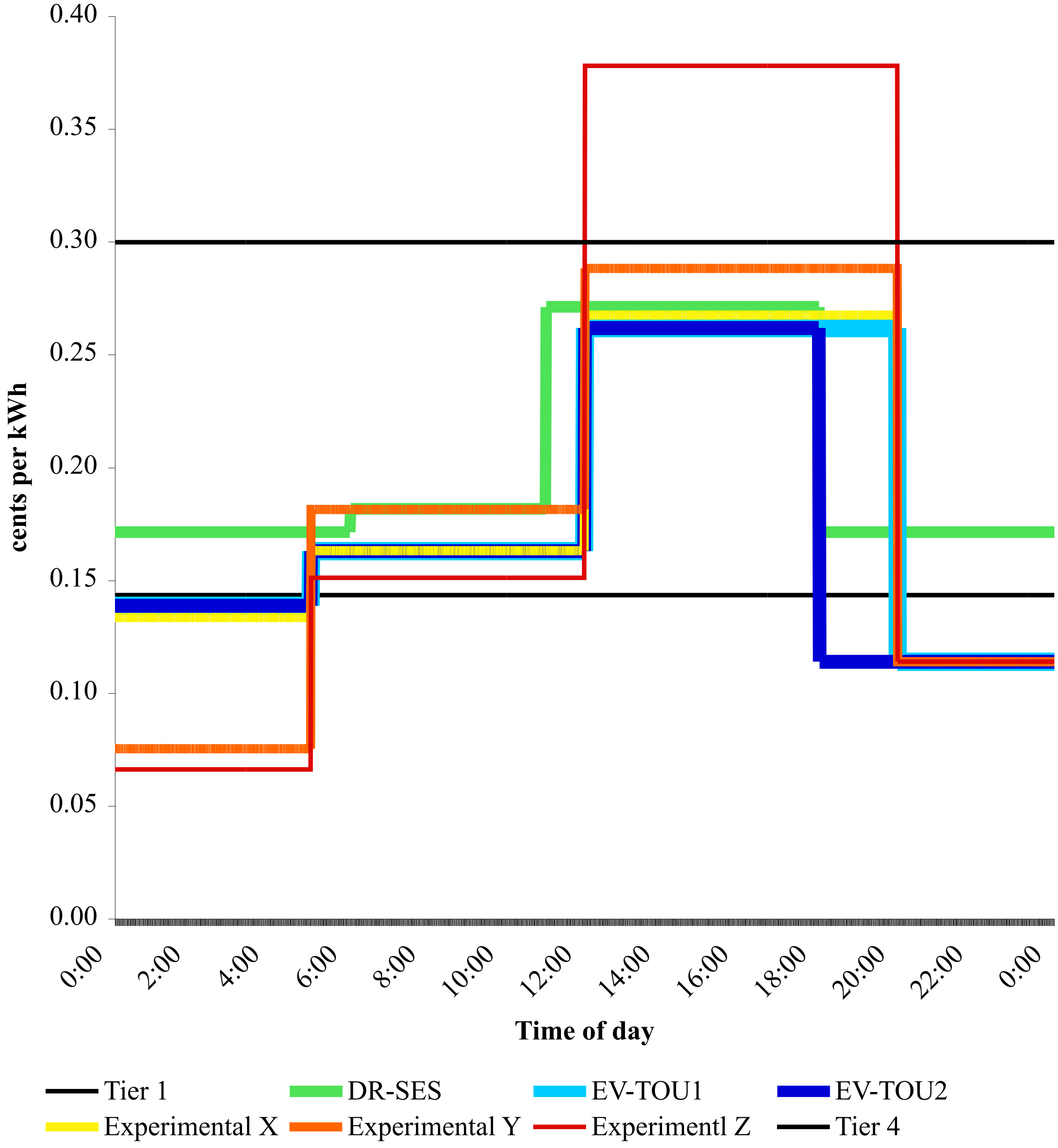
Table 4: Electric Tariff With Solar Energy System – Residential Rates

	Summer (May 1 -Oct 31)			Winter (Nov 1 - Apr 30)	
	On-Peak	Semi-Peak	Off-Peak	On-Peak	Semi-Peak
-	11 a.m. - 6 p.m. Mon - Fri, excld Holidays	6 a.m. – 11 a.m. 6 p.m. – 10 p.m. Mon - Fri, excld Holidays	10 p.m. – 6 a.m. Mon-Fri; all hours on weekends; Holidays	6 a.m. – 6 p.m. Mon - Fri, excld Holidays	6 p.m. – 6 a.m. Mon-Fri; all hours on weekends; Holidays
Total Electric Rate	0.27128	0.18758	0.17138	0.18172	0.17311

Note: Data are from San Diego Gas & Electric Company's web site: http://www.sdge.com/sites/default/files/regulatory/010113-schedule_dr-ses.pdf

Figure 1 illustrates the six summer TOU rate structures, bracketed by the lowest and highest rates within the tiered tariff structure. In the tiered rate plans, all kWh are charged the lowest price until monthly demand exceeds the lowest price tiers allocation. All electricity use up to the third tier is billed at the second tier price, and so on.

Figure 1 San Diego Gas & Electric Summer Residential Tariffs, cents per kWh



Note: Data are from San Diego Gas & Electric Company's web site.

1.3.2 Away-from-home pricing

In the interim between the household interviews in Spring 2012 and the focus groups in Fall 2012, PEV drivers had begun to be billed for PEV charging services, though at the time of the focus groups there still existed both pay-to-charge and free public charging. The operators of these charging locations cannot resell electricity; they typically bill for connection time, regardless of whether the vehicle is actually drawing power.

ChargePoint is a service that connects electric vehicle drivers with independently owned charging stations. The owners of ChargePoint stations have the option to offer free charging or to set up an access fee. Electric vehicle drivers may choose to become members of ChargePoint to receive services that help them locate and use chargers and streamline the payment process. ChargePoint chargers are available for use to PEV drivers regardless of whether or not they are members of ChargePoint.

Blink is a service that provides electric vehicle charging stations that drivers may access for a fee. There are three fee options: Blink Plus, Blink Basic, and Blink Guest. The Blink Plus membership costs $30 annually, though as of the time of the focus groups the company was waiving the membership fee. The access fee for Blink Plus members, for level 2 (L2) charging stations is $1.00 per hour. The Blink Basic membership does not require a yearly fee and the access cost for L2 charging is $1.50 per hour. Similar to ChargePoint, the public chargers managed by Blink are available for use to PEV drivers regardless of whether they have a membership with the company. The access cost for a Blink Guest to L2 charging is $2.00 per hour. For all three fee options, billing occurs at the beginning of each hour and is not pro-rated.

These various price structures will affect PEV drivers both because they may think these prices are "high" or "low," but also "fair" or "unfair." The drivers' evaluations will depend on whether they use their home electricity prices or the price of gasoline as the standard for comparison.

1.3.3 Vehicles

Virtually all of the PEVs in this study are Nissan LEAFs. The LEAF has a 3.3KW charger; other PEVs, including the small number of Chevrolet Volts, a Tesla Model S, and Toyota RAV4-EV driven by our respondents charge at higher power, i.e., they charge faster. One of the relevant factors shaping the charging behavior that is possible to observe in our samples is this: the Nissan LEAF, even with it's relatively slower charging will fully recharge within the five hour super-off peak electricity price period. One proviso insures that this is true for most LEAF drivers we spoke with: Nissan recommends that the LEAF battery be routinely charged to only 80 percent state of charge to protect long term battery life. Almost all of our respondents report they follow this advice. Thus while the LEAFs 24kWh battery might nominally require nearly eight hours to fully charge, in practice few of our respondents would ever require a charge larger than 15kWh. The relevant point for the effectiveness of DRM pricing, timers, and exhortation is that few of our respondents must routinely choose between a full charge and paying anything more than the lowest price for electricity; we do describe some of those few who do pay the higher prices because they will charge outside the super-off peak period.

1.4 Research Methods

The primary methods for this research are qualitative. Therefore this study is characterized as an exploration of why PEV drivers charge when (and where) they do; the large-scale quantitative research being done by SDG&E on their PEV charging TOU experiment will detail the measures of when charging occurred.

1.4.1 Interviews

1.4.1.1 Interview sampling

The PEV owner and lessee population from which we sampled was those households who had received a free charger through Ecotality's EV Project as of early 2012. This population had to own their home and have a suitable parking and charging location for their PEV on their premises. This population of PEV drivers in San Diego was sampled as part of a project to study PEV drivers throughout California in early 2012. The survey yielded 1,201 respondents statewide; 336 were from San Diego County. It is from this 336 that the respondents for the interviews were drawn. The PEV owners and lessees, whether from the more general California survey or San Diego specifically, had on average higher income, age, and education levels than the general San Diego population. Previous research identified similar socio-demographic differences between samples of general populations and new-vehicle buying households (Axsen and Kurani, 2009).

The goal of the interview sampling was to cover the range of several household and driver attributes. Households for the interviews were selected based on household income, gender of the primary PEV driver, age of the survey respondent, households made up of employed or retired households, and whether the home had a solar photovoltaic systems or not. While sampling across the available range of income and socio-economic measures may seem obvious choices to stratify the interview sample, the solar/no-solar one may be surprising. We thought it a desirable criterion as approximately one-third of households buying or leasing a PEV in the study area had a home PV installation.

1.4.1.2 Interview Protocol and Analysis

Interviews were conducted in March and April, 2012. The interviews were conducted by four researchers; two for each interview. Most interviews were conducted at the participant's home and consisted of the primary driver of the PEV. Every attempt was made to include spouses and partners, especially if they drive the PEV, too. Interviews lasted between one and two hours. The discussion was guided by a list of specific topic areas: purchasing the PEV, charging, information sources including the vehicles' instrumentation, and their sense of a community forming around PEVs. Questions were open ended and participants were encouraged to discuss items they found important to further allow the research team to understand each driver's experiences. Interviews were audio recorded and supplemented by field notes and observations made during the interviews.

The interview team conducted meetings every few days while conducting interviews to discuss preliminary themes that were arising to determine if additional questions should be added or emphasized in future interviews. Upon completion of the interviews, each researcher reviewed the audio recordings and compiled a review of households in which they had been an interviewer. These reviews included the major themes discussed in the interview and specifics of each person's experience with their PEV. These household reviews were then compared against each other to locate themes across households representing common experiences, ideas, and valuations across interviews (Braun, 2006). To identify themes in the data, the researcher conducted a three-step coding process that included (a) open coding on the first reading to locate themes and assign initial codes, (b) axial coding to review and examine initial codes, and (c) selective coding to look for examples to illustrate themes.

1.4.2 Focus Groups

1.4.2.1 Group design and sampling

Four focus groups consisting of PEV owners and lessees recruited from the households participating in Ecotality's EV Project were convened in San Diego, CA in November, 2012. None of the interview households from Spring 2012 were included. Each of the four groups had between seven and ten participants. The goal of focus groups is to engage small groups of people in conversation to elicit stories and in-depth explanations of people's thoughts and experiences in relation to a specific topic or set of related topics. The focus group format, unlike the in-depth interview method empowers participants to share particular feelings and opinions through the understanding that others share theirs. For this to occur, group participants must have enough in common to engage in conversation with one another, to speak and share freely. The sampling process of categorizing participants into focus groups is called segmentation. Segmentation benefits focus group research in two ways. First, it encourages discussion by creating groups of similar participants within groups. Second, it allows for a comparative aspect during data collections and analysis, i.e., between groups (Morgan 1996).

The focus groups were segmented according to gender and degree of technological interest and reported ability. Women and men tend to have very different social roles and consequently driving needs and vehicle perceptions. Moreover, men's and women's travel behavior continues to be distinctly different in commuting times, trip times and distances, the number of non-work trips, automobile occupancy, and the propensity to trip-chaining.

General interest in technology and specific interest in PEV technology are thought to be both attributes of early PEV drivers and to affect PEV drivers ability to understand how and why PEVs "act" as they do, as well as interest in seeking out information and like-minded people. To sample for degree of technological interest and reported ability participants were screened with a series of questions related to their interest in the technological aspect of their vehicle, technology in general, and how others perceive their technological ability.

As discussed in the section on sampling for the interviews, other factors that might affect PEV related practices and perceptions include income, age, prior ownership of home PV systems, and employment status (employed or retired). Though the focus groups did not directly represent our sample population, we made an effort to increasing the diversity of our sample by recruiting participants who varied across these characteristics.

The focus groups were moderated by one researcher and observed by three additional researchers, unseen by the participants. All of the groups were guided by a protocol—an outline of topics with possible prompts and follow-up questions. The protocol, designed by the researches who conducted the previous in-depth interviews emerged from the themes extracted during the analysis of interview data. For comparative purposes, the protocols remained the same across each type of group. The protocol addressed a list of specific topic areas informed by the interview results: opening anecdote from each participant about how they came to be a PEV driver, home charging, away-from-home charging, how PEV charging has changed with the advent of billing for away-from-home charging, charging etiquette, and information sources.

Each focus group lasted two hours and the researchers reconvened after each group to discuss themes and share observations. The moderator introduced participants to the research and opened the conversation. As, the primary focus of the research was to assess how participants understood and experienced their vehicles, the focus groups were relatively self-managed by the participants. That is, the, moderator provided initial introduction and subtly guided the conversation toward topics of interest but in general allowed the participants to determine the direction of discussion.

1.4.2.2 Analysis

In focus groups, data is generated through the interaction that takes place among group members. Consequently the focus groups were videotaped with participants consent, transcribed, and coded for analysis. Additional field notes and observations made during the focus groups by the observing researchers supplemented the recordings. Upon completion of the focus groups, each researcher reviewed transcripts of all four groups and compiled a summary of thematically relevant statements. Topically relevant statements were selected, categorized, and interpreted by the researchers. Statements may be a single word of agreement or disagreement with a prior more extensive statement, a phrase within a longer sentence, or several sentences. The organizing themes represented the protocol topics as informed by the coding and analysis of the interview data.

CHAPTER 2: Early PEV Drivers Reactions to DRM

We first summarize the findings, and then elaborate on them in subsequent sub-sections. DRM strategies in San Diego have produced a widely (but not universally) shared set of beliefs and behaviors that accomplish the goal of assuring that high percentages of PEV charging occur during the valley, or "super off-peak" time period of midnight to 5am, especially on weekdays. However, the wide variety of specific non-PV tariff structures, i.e., EV-TOU, EV-TOU2, and the experimental rates X, Y, and Z make very little difference in the stated beliefs and behaviors of these PEV owners and lessees. It appears that the existence of any price reduction (at least within the range of reductions in this research context) for electricity during the desired super-off peak PEV charging period is enough to prompt the desired outcome—at least among our respondents.

The role of DRM technology, a vehicle and EVSE timer in this case, is to aid in making behaviors routine: set a timer, plug-in the PEV everyday when you arrive home, don't think about it until the next morning. This technology is widely but not universally used and these routines are not universally practiced. When used, they most often produce the desired outcome. A PEV driver arrives home and plugs in immediately while they are making their way from their car into their home. The timer insures that charging commences only after the super-off peak period has started. However, they are not foolproof. Unintended outcomes occur occasionally when the routine is disrupted and are almost always in the form of a missed charge.

The effect of TOU tariffs is not solely through price alone. Rather, the TOU tariff structures are part of a narrative about electricity demand in California that the PEV drivers recount: the susceptibility of the grid to service interruptions during periods of peak demand. That is, the public good behind the TOU price differences is widely accepted and the goal of grid reliability is widely supported. The TOU price signals also support another narrative about PEVs—that they are inexpensive to drive because electricity is a cheaper fuel than gasoline. Part of this narrative is the elevation of cost-effectiveness or frugality as virtues. As one of our respondents put it, “It’s still that mental barrier of six cents [per kWh]… That’s right. That’s part of the lure of the whole thing… the frugality of it because we’re cheap.” Thus, the effects of TOU tariffs are difficult, and may be impossible, to entirely disentangle from the effect of exhortation.

Names used throughout for our participants are aliases.

2.1 Charging behavior in response to TOU tariffs

2.1.1 Home charging

The descriptions of almost all respondents who were on any TOU tariff were similar, whether for their home and PEV combined (EV-TOU), their PEV only (EV-TOU2), or any of the experimental rates; “Super-off peak [midnight to 5am] is cheapest. Why wouldn’t I charge then?” In short, that there was any price signal was enough for almost all these PEV drivers to report that most of their at-home PEV charging was done during the least expensive price period. Motivations were linked to both the direct effect of pricing on (private) costs and social or system benefits. Deviations from this behavior were do due the use of some other standard than peak electricity prices for the comparative price of electricity or a “broken” mental model that a PEV driver’s home PV system (should they have one) insulated the grid from their PEV charging behavior.

The savings from using electricity as fuel rather than gasoline was an important motivation for off-peak charging. Households went so far as to calculate individual trips. “My wife did the math. She said it costs her 86 cents to go round trip—that would've been $12 in gasoline.” Several participants were able to recount their average miles driven per month and connected this with the cost of the energy bill, in comparison to what would have been their gasoline costs. Many drivers were proud of their savings and the cost differential represented a reason for charging at home

Respondents differed in their assessment of whether the TOU rates were essential to achieving their purported cost savings. One of the respondents who thought the super-off peak price was essential to cost savings said, “[You] start thinking about if the EV is really so much cheaper with electricity compared to gasoline, and it may not be, unless if you charge at home for the very low rate time, which is midnight to the morning...” Contrary statements included, “The difference between the super off-peak and the off-peak is only two cents per kilowatt. It’s not a big deal.” (It is essential to recall that these two drivers may have faced different TOU rates than each other. Further, as can be seen in Figure 1 the second statement is either a simple misstatement or the informant doesn’t know their actual price difference between peak and super-off peak since in no case is it less than 12¢ per kWh.)

A notable exception to this adherence to the lowest priced, super-off peak home electricity is PEV drivers who can charge at work for free during the day. “Usually when I drive in my driveway [the PEVs estimated remaining driving range] is usually in the teens and it charges for between four and four and a half hours every night and then I go to work and I charge for two.” Drivers with short commutes may do all their weekday PEV charging during the morning hours just after arriving at work (and perhaps in the early afternoon after returning from lunch). They typically would charge at home during the period from midnight Friday to 5am Saturday so that the PEV is available for weekend driving.

Households who had PV systems were more mixed in their time-of-day charging behaviors. Some believed that they were completely insulated from the grid (or rather, that the grid was completely insulated from them) by their PV system; they would plug their PEV in at most any time of day they returned home. “When you have solar, you’re generating power during the day so you’re always paying the lowest per-kilowatt rate no matter because you pay based on how much you use and if you’re never using more than the minimum you’re never paying more than the minimum.” Similar beliefs encouraged on-peak charging among some of the PV owners.

However, some other PEV drivers with home PV systems reasoned that they made the most money by producing as much net power during the peak period, thus they would delay their PEV charging until their cheapest price period, beginning at 10pm (Figure 1). For these respondents the low cost of fueling an electric vehicle on SDG&E’s domestic residential TOU rates for households with solar energy systems offered enough financial incentive to motivate off-peak and super off-peak charging.

2.1.1.1 Comparative prices

Within some of the examples cited, we can hear alternative standards of comparison, i.e., what is inexpensive or expensive is not judged on its own, but in comparison to some other price: this is after all, the essence of the belief that TOU tariff structures will shape behavior. But whether or not the PEV drivers we studied do charge in accordance with this assumption depends on the other “prices” to which they compare the price of electricity. These other prices may be quite specific, e.g., the price of gasoline, or more general, e.g., the cost of being mobile.

For some people, a comparison of electricity to gasoline prices reinforces their super off-peak charging behavior. Because Harold has just done taxes, he has a sheet of paper prepared for us with his total PEV miles and total electricity cost: 3,500 miles (through the end of 2011); $79.68. He compares this to the cost of gasoline for his Honda CRV which the LEAF replaced. Using 20 mpg and $4.40 per gallon of gasoline, he makes the comparison, "It's roughly $80 vs. $800. It's like 10 to 1…It's huge. It's more than I ever thought it would be." He thinks that as of the time of his interview in Spring 2012, he may be saving closer to $1,500 per year compard to buying gasoline for his CRV. He thinks the savings may be due to how the electricity rates are structured to be inexpensive after midnight. He starts charging at midnight to "get those more favorable rates." He says that even if he didn't, at the worst case it would [have been] $200 to charge the [LEAF]. While that is still 4 to 1 in favor of the LEAF over the CRV, he says, "4 to 1 vs. 10 to 1. That's an incentive to charge at midnight. And, it doesn't interfere with my lifestyle. I've never started a charge at an off peak hour." He qualifies this later because he remembers a couple of trips where he needed to charge during the off-peak period. It follows that charging his PEV at peak times is even more rare.

In contrast, for other people the comparison of electricity to gasoline prices undermines the effect of TOU electricity tariffs. AJ not only ignores the TOU prices, he eschews the use of a timer. This is related to the driving range capability of his LEAF and the fact that he nearly exhausts that range every day. He says that if he had a PEV that had a 300-mile range, he would charge only off-peak. As it is, he plugs in—and starts to charge—his LEAF as soon as he arrives home in case he needs to go somewhere. By the time he returns home, he exhausts the LEAF’s battery almost every day, so he wants it to be charged again if he needs to take it out later. To him, it is cheaper to drive on electricity rather than gasoline; he says his gasoline miles cost more than his electricity miles—even if he charges at peak times, he believes it is cheaper than driving on gasoline.

2.1.2 Away-from-home charging

Away-from-home charging is not on any formal TOU tariff at the time these PEV driver interviews and focus groups were conducted. This may be due in large part to the fact that providers of away-from-home PEV charging services cannot re-sell electricity. When we conducted household interviews in Spring 2012 all away-from-home charging was free. By the Fall 2012 focus groups, some away-from-home charging locations were billing users, but were billing them for connection time, not kWh of electricity. The advent of billing for away-from-home charging services seems likely to have some of the effects of DRM strategies—even in the absence of explicit TOU tariffs for the electricity provided. While some PEV drivers continue to find value for paid away-from-home charging, many PEV drivers tell us that paid away-from-home charging is now an emergency back-up, not the perquisite it was when it was free. One driver explains, "I always look at the public charging things as an emergency. I never charged and paid for it other than…in desperation." As PEV drivers are most likely to be driving during peak and off-peak electricity use times and parked at home during super off-peak periods, any reduction in their away-from-home charging has the effect of reducing peak or off-peak charging, whether or not it increases their super off-peak charging.

When and where it was available (and continuing at those locations where it still is available), free away-from-home charging presented a powerful price signal, and also an implicit time of day signal. For example, several respondents revealed using public charging stations because they were free even when their vehicle did not need a charge. "On a weekend especially where Balboa Park is almost always on the map, I'm plugging into that run. Even if it only took two bars to get down there, I'm plugging in. Because it's free and because it's parking that I wouldn't otherwise have." That away-from-home charging carries an implicit TOU signal is part of the transition from free to paid service. One focus group participant explained his response to now being billed for connection time at PEV chargers, "A dollar an hour isn't that big of a deal, but there's a big gap between $1 an hour and free. You know, $1 to $2 is not that big of a deal, but $1 to free [group laughter] that's what's motivates people: free."

Some public charging systems introduced a flat access fees regardless of whether the vehicle is actively drawing a charge. Several drivers found that this system presented a disincentive for public charging, "Yeah, the thing I don't like about the way the system is going is that it's based on time and the connection time which is ridiculous because I should be billed by the kilowatt hour, not the amount of time I'm plugged in. If I'm plugged in and I hit max capacity I'm still being billed." Other drivers approved of this system as a way to ensure the availability of charging stations. "Maybe that's not such a bad thing if it's encouraging people not to leave their cars there longer than necessary."

Comparisons between gasoline and electricity costs and between home charging and public charging constituted the primary method cost-savings analysis among respondents. One driver discussed how the expense of paid public charging access compared to the cost of charging at home confined his charging to home (and thus, largely super off-peak);

> "So basically the calculations that go through my mind currently are I'm not going to rely on extra charging at all. I will not take the Leaf out of the driveway unless I know perfectly well I can come back. Even if it's with a couple miles left

> on the gauge I will not take the car out unless I'm almost positive that I can make it back."

Several drivers shared this sentiment, "As far as relying on the infrastructure to charge, it really is not economically viable to charge any place that charges more than twice as much as what you would pay at home."

On the other hand, many expressed the opinion that so long as public charging remained cheaper than gasoline they would be willing to pay for public charging. One driver explained,

> "It depends on how you did the comparison. If you're comparing the charging at home on the super cheap rate – midnight to five – it's probably four times as much. But it is still, as you pointed out, half as much as buying gas."

This driver, like many others compared the price of public charging to the cost of charging at home.

Though cost remained a central factor in whether drivers would use public charging, time and convenience emerged as influential factors on drivers' charging choices and willingness to pay. Several participants found public charging to be an inconvenience and limitation due to charging times, parking, and billing systems. For some this was because the time constraints required additional planning; "It puts a big obstacle on your planning of your day. I may not want to spend two hours at whatever hotel. I mean what am I going to do there? It doesn't seem to fit my life anyway." Like this participant, several drivers chose not to use public charging because it did not fit into their lifestyle or routine. "I don't really see charging public and paying for it like a regular part of my day just because I don't want to see my bars too low or something. I would rather just drive with as low [of a charge] as I can to home or get stranded trying." This driver, amended that they would use public charging, "if my lifestyle changes so that I have to have charge in my route or along the way of my route."

Some drivers talked about using charging stations because of the free parking, or premium parking made available to them as PEV drivers. Others talked about the problems of the connections between charging parking, citing the disincentive of paying for parking on top of paying for a charge; "They have six charging stations right over here at 4^{th} and B but they charge you $10... There's a fee for parking because I work downtown and so…it's $10 plus the Blink fee." Another noted, "Sea World has [chargers] but you have to pay to park too…" One participant explained the difficulties of parking at the San Diego airport, "If I'm going to the airport, I'll park across the way in those spaces and take the free parking." For these participants, pay-to-park charging was unappealing because of the "additional" parking costs.

The complications of different charging services and billing systems presented another challenge to some of the drivers. Several complained of the complication and confusion of having to manage multiple memberships, charging cards for different EVSE networks, and rate structures. One driver suggested streamlining the payment process citing the system of charging used in Houston, TX;

> "As far as pricing models I've kind of been interested in doing what they're doing, I think it's in Houston, where it's just billed [to] your home electric bill. You're in a plan and you use as much juice as you want and I guess all those are

> owned by the utility company though. And you can plug in anywhere in town and you're not worrying about…"

Other drivers offered similar suggests and many agreed that the payment methods for public charging needed simplification.

For other PEV drivers, public charging represented a convenience despite the associated costs and complications. One driver with three children explained,

> "I think differently because I think of the public charging stations as, 'I don't have to go home.' I can charge up while I'm running errands, then I can pick up my kids, run my kids around and then get [home]…"

Another driver described his first public charging experience,

> "My alternative would be to drive the Prius down and back, and it would have cost a lot more than a dollar. A dollar would just get me a quarter gallon of gas. So I had no problem justifying paying a dollar to have the assurance of getting home."

For these drivers the convenience and comfort offered by public charging offset the cost.

On weekdays, the PEV drivers are far more likely to be away-from-home outside the hours of midnight to 5am; thus, free away-from-home electricity was a strong inducement for those drivers who could, to charge their PEV outside the desired off-peak period. Participants in one focus group outright rejected the notion that away-from-home charging would need to be priced according to a time-of-use (TOU) schedule because they imagined no benefit to less expensive, late-night, away-from-home charging—they would always be home during super off-peak hours;

> "Time of day is kind of irrelevant because it's always going to be during the day for the most part because at night you're charging at home…You'll rarely ever use it at night so it would only be peak power."

2.3 Charging behavior in response to DRM-supporting technology: timers

Some PEV drivers from across the TOU tariffs agreed that establishing a routine played a role in when they charge their cars; the primary role of timers was to enable these routines. Price may have been an initial motivator; timers enable a routine to enact that motivation (and any other). One respondent said, "SDG&E sends a thing out that tells you when your lowest rate is. So once you just set up all the timers, it's just standard." Another agreed, describing their routine, "I just set the timer for midnight…it charges up the next morning and I get in and go." The combination of TOU rates and a timer made turning charging into a routine easy; "For those of us who are on TOU it's so easy. You plug it in when you get home and you don't think about it until you get out the next morning." For households with set routines charging during peak times, including public charging happened only rarely because it represented a deviation from standard charging behavior.

However, some households established more flexible routines; when to charge included lifestyle or household schedules, not simple adherence to a single, simple routine. Though most drivers tried to charge during off-peak times they cited emergencies and disruption in daily routine (such as a second driver using the PEV) as reasons for charging during peak periods. One driver explains, "Too many things come up unexpectedly, but, yeah, usually we plan. And sometimes I forget to hit the 'don't charge during the day' button." Another driver acknowledged that both cost and schedule determined charging between weekdays and weekends, "I don't use the car on the weekends so much because, you know, I don't go out so much." For many the weekend represented a time when the household required changes from their weekday routines of PEV charging, "The thing is sometimes on the weekend, in the morning I would have a bunch of errands and I'd come home with almost no charge at midday. Occasionally I do that [plug in] because I have to make another trip."

The downside of using the timer technology to establish and sustain a routine is that it separates the driver from the actual charging of their PEV; the driver merely connects the EVSE to the car—the timer starts the charging. This is problematic when the drivers charge their PEVs at place or time that is not the primary place and time of the routine. For example, a PEV driver may enact a routine to connect their EVSE to their PEV in their garage when they arrive home from work. Charging anywhere else or at any other time—both in the sense of clock time and in the sense of the flow of events in their day—is a break in that routine. In the new situation, they may connect the EVSE to their PEV—and walk away forgetting to override their timer that does not allow charging to occur until after midnight. The usual consequence is a missed charge. Several people offered such examples, "We forgot to push the timer button to turn the timer off so we were charged for two hours and didn't get any electricity at all."

2.3 Charging behavior in response to exhortation

The PEV drivers recount numerous reasons why charging during the super off-peak period provides "civic" benefits to all electricity users. That these PEV drivers are able to recount these benefits is evidence of a social narrative about electricity. This narrative started before the sales of PEVs in exhortations from electricity providers for electricity users to moderate peak electricity use. As Jane said,

> "…ever since I have been in California, I've been conditioned that between 11[am] and 6pm are flex hours and that 's when they have the blackouts and that's when the fires start."

Some drivers explained their choice to charge their PEVs during off-peak and super off-peak periods as a sort of civic duty or a way to contribute to the electric grid infrastructure. One driver discussed his belief that charging his PEV at night not only supports the grid, but the local economy, too.

> "Well, electricity is so much cheaper if you're charging at night, you have more money to spend on the local economy, and you're not sending money overseas. So it's good for the local economy…it's also we're supporting the infrastructure because we're paying the infrastructure cost, so we're bringing the cost down for the system for everybody else."

This civic-mindedness was present even among for drivers with solar energy systems or who reported not being on a TOU rate structure. “Charging during off-peak times reduces emissions and infrastructure costs, its just better for society. It's the right thing to do anyway… it’s just being a good citizen." Some participants with home PV systems, however, charged anytime, explaining that not only was it always the same rate to charge but also that they were generating power and did not feel guilty charging at peak times. “We have the solar panels so they do it kind of differently. We charge more when it’s peak.”

Part of the focus group discussion centered on several challenges to home charging during off-peak time periods. Participants offered suggestions that would improve the ease of charging and encourage drivers to take advantage of the TOU rates. One driver said,

> “It really should all be done in a way that encourages [super off-peak charging], because in the long run, like he said, if we're plugging in at night and we're paying something, we're helping support the grid, you know, the overhead, and all the other positive things that are happening.”

Many of the drivers agreed that utility companies should encourage solar system use for electric vehicle drivers but also find a way to encourage plugging in at night. They believed this approach would benefit both the utility, by alleviating demand and providing more energy, while also benefiting the drivers with decreased costs.

CHAPTER 3: Discussion and Conclusions

The primary finding is that a suite of DRM strategies appears to produce the desired effect to shift most PEV charging by households to a super-off peak period between midnight and 5am. Or rather, our samples of early PEV owners and lessees talk about their vehicle charging behavior as if they are doing most vehicle charging during this desired period. When they are available, analysis of the PEV charging data from SDG&E’s TOU rate experiment as well as Ecotality’s EV Project will have to be compared to the findings reported here.

The suite of DRM strategies included TOU pricing, timers, and exhortation. TOU pricing is commonly interpreted within a narrow calculus of private cost savings. Indeed, many of our respondents tell us the cost savings that accompany super-off peak pricing are important to them. However, TOU prices also fit a narrative that every PEV driver seems able to recount: the electricity grid in California is susceptible to collapse during periods of peak use. Thus many PEV drivers feel they are acting within a framework of civic duty when limiting their PEV charging to after midnight. Timers, typically the one on-board the vehicle, serve the purpose of making charging after midnight a routine. The driver does not have to remember to go back out to the garage in the middle of the night to start charging; they simply plug-in the car on their way into their home—the timer does the rest.

That we hear the same story about charging during super-off peak periods from households across all the electricity tariff structures (with the exception of DR-SES rates as we will discuss next) suggests that the most common metric of the effect of DRM pricing strategies may be misleading. The economic model of behavior that underlies the calculations of own-price elasticity of electricity implies that higher price differentials should produce greater changes in behavior. Yet our respondents sound alike in their descriptions of charging. Our conclusion cannot be definitive as any PEV driver we interviewed faced only one TOU rate rather than several.

The other result that contradicts both the stated goals of PEV drivers and perhaps expectations is that the PEV drivers who have made the largest financial commitment are the most likely to confound the effect on TOU rates for PEV charging: households who had purchased both a PEV and a home PV system were the most likely to report charging their PEV whenever they wanted. This seemed to be based most often on the mistaken belief that the electrical grid was insulated from their PEV charging behavior and their electricity costs were insulated from TOU pricing by their PV system. Thus people who might be the most committed to clean energy and mobility were likely to decrease the potential private and public benefits.

As the findings reported here are specific to a time, a place, and a more limited variety of PEVs than are already available to consumers, questions about the generalizability (across electricity infrastructure and pricing, households, and vehicles) and durability require further research to inform robust policy making. A few of these questions stand out as unexpected—either because they confound prior expectations or because we simply had not formed expectations at all.

1. Is there an electricity price difference too small to prompt super off-peak charging?
    a. Our specific findings suggest that pricing mechanisms do shift PEV charging to desired time periods, but the smallest effective price signal may be smaller than any presented to the PEV drivers who spoke with us.
2. How durable is the effect of DRM (more generally than pricing) on charging behavior?
    a. To date, the experience of these PEV drivers is that they establish routines that tend to reinforce over time patterns of charging during super-off peak periods.
        i. Deviations tend to be mostly by people who have home PV systems. What is necessary to assure that these people understand that, in general, they are part of the "grid" too and that charging their PEV off-peak is important.
    b. Future PEV owners: will some respond differently to price signals? How? Why?
        i. One reason may be that some future PEVs may have larger batteries that cannot be fully charged within the five hour super-off peak period in SDG&E's present tariffs. Even at a faster charging rate of 6.6kW (double the 3.3kW of the Nissan Leaf vehicles driven by most of our respondents), a five-hour period allows for a maximum of approximately 30kWh. Given this, some of these PEV drivers may have to complete at least a portion of their charge during off-peak rather than super-off peak times. Whether they do, how many have to, how often they have to, and the aggregate effects on total electricity demand are subject to future research.
3. Effects of TOU rates for away-from-home charging arose in the study setting mostly because of the correlation between the timing of those rates and the timing of most of these households daily schedules.
    c. We did not study the use of Car-2-Go PEVs in the study area; what is the time of day distribution of demand for car-sharing and charging of shared cars?

d. If PEVs make inroads into markets—younger people?—who may have different daily routines than the predominately employed families and retired persons in our sample, what will the time of day distributions of activities, travel, and PEV charging demand be for them? And, how susceptible will they be to DRM strategies to push their PEV charging into specific time periods?

e. As markets for PEVs grow—regardless of the sort of differences just mentioned—will demand for away-from-home charging grow enough to warrant the application of TOU pricing?

4. What we have called exhortation—the positioning of TOU pricing for PEV charging within ongoing social narratives, social marketing campaigns, and other efforts to create a sense of civic duty—is part of effective DRM strategies to shape PEV charging. The question is whether it is possible to separate the effect of pricing from the effect of what pricing means or symbolizes in order to create more effective DRM campaigns.

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