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# Connecting plug-in vehicles with green electricity through consumer demand

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## Abstract

The environmental benefits of plug-in electric vehicles (PEVs) increase if the vehicles are powered by electricity from 'green' sources such as solar, wind or small-scale hydroelectricity. Here, we explore the potential to build a market that pairs consumer purchases of PEVs with purchases of green electricity. We implement a web-based survey with three US samples defined by vehicle purchases: conventional new vehicle buyers ( $n = 1064$ ), hybrid vehicle buyers ( $n = 364$ ) and PEV buyers ( $n = 74$ ). Respondents state their interest in a PEV as their next vehicle, in purchasing green electricity in one of three ways, i.e., monthly subscription, two-year lease or solar panel purchase, and in combining the two products. Although we find that a link between PEVs and green electricity is not presently strong in the consciousness of most consumers, the combination is attractive to some consumers when presented. Across all three respondent segments, pairing a PEV with a green electricity program increased interest in PEVs—with a 23% demand increase among buyers of conventional vehicles. Overall, about one-third of respondents presently value the combination of a PEV with green electricity; the proportion is much higher among previous HEV and PEV buyers. Respondents' reported motives for interest in both products and their combination include financial savings (particularly among conventional buyers), concerns about air pollution and the environment, and interest in new technology (particularly among PEV buyers). The results provide guidance regarding policy and marketing strategies to advance PEVs and green electricity demand.

**Keywords:** plug-in electric vehicles, green electricity, renewable electricity, consumer behavior

## 1. Introduction

This study explores the potential to build a market that pairs plug-in electric vehicles (PEVs) with 'green' electricity. Although PEVs hold the potential to benefit the environment through reductions in greenhouse gas emissions (GHGs), air pollution, and oil use, the actual source-to-wheels impacts are

uncertain (Axsen *et al* 2011). For example, GHG emissions from plug-in hybrid vehicles (PHEVs) have been estimated to be 15%–65% lower than conventional vehicles (Samaras and Meisterling 2008, Duvall *et al* 2007), with potentially little improvement over (non-plug-in) hybrid vehicles (National Academy of Sciences 2010). Kromer and Heywood (2007) reach broadly similar conclusions; the GHG emissions impacts of future PEV uptake depend on many uncertain assumptions.

Electricity carbon intensity is the largest source of variation in PEV GHG emissions calculations. The most direct method to assure large GHG emissions reductions



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from PEVs is to pair their charging with low-carbon 'green' electricity. Ideally, widespread de-carbonization of the electrical grid would achieve this goal. Some state and national jurisdictions have implemented renewable portfolio standards that require some or all electricity producers to increase their proportion of generation from lower carbon sources. However, the national US grid is a long way from achieving deep GHG reductions from electricity generation.

Here we consider another method to reduce GHGs from PEVs: providing consumers with the opportunity to purchase PEVs and green electricity as a packaged product. Green electricity options could include the purchase of residential solar panels, leasing part of non-residential photovoltaic or wind systems, or enrolling in a 'green electricity' program to support green generation by the household's electricity provider (or a third party retailer). In addition to potentially reducing the GHG impacts of PEV charging, such a pairing strategy might also serve to help build the market for PEVs. That is, some consumers may be more likely to buy a PEV if they feel assured that they will be powering it with green electricity (hereafter referred to as 'GE'). To explore this possibility, we state the following research objectives:

- (1) Assess consumer interest in PEVs and GE programs as separate products.
- (2) Assess if combining a PEV with a GE program increases demand for PEVs, i.e. see if some consumers view the two products as complementary.
- (3) Characterize consumer motivations regarding demand for PEVs, GE, and their combination.

To accomplish these objectives we developed a web-based survey and implemented it among three US samples defined by their previous vehicle purchases: conventional vehicles, hybrid vehicles, and buyers/lessees of a PEV. We summarize existing literature regarding demand for PEVs and GE, then describe our method, results and implications.

## 2. Literature review

We have not found a prior study that directly explored the potential to combine consumer demand for PEVs and GE. Here, we summarize several studies and approaches that have been applied to each product individually.

### 2.1. Demand for plug-in electric vehicles (PEVs)

To start, we differentiate between two different types of PEVs. A 'pure' electric-vehicle (EV) is powered only by grid electricity. A plug-in hybrid electric vehicle (PHEV) can be powered by grid electricity for some charge-depleting range (say, 20–40 miles), but also can use a gasoline or diesel engine to supplement power from the battery and provide most power once the battery is depleted. Further PEV technical details and distinctions can be found elsewhere (Axsen *et al* 2010).

In the last three decades, most research on PEV demand has utilized discrete choice modeling techniques in an effort to quantify consumer preferences and willingness to pay

for alternative fuel vehicles (Train 1980, Hidrue *et al* 2011, Bunch *et al* 1993, Ewing and Sarigollu 2000). This approach assumes an individual, utility-maximizing, rational actor. Results typically focus on the role of functional drawbacks of PEVs such as limited EV range, long recharge times, and high purchase price in limiting market potential.

Several inductive research approaches report that consumer valuation of PEVs is more dynamic than conventional, static choice models and preference functions assume. Kurani *et al* (1996) implemented an in-depth, repeated contact study with car buying households. The authors found that up to one-fifth of new car buying households in California were interested in their next new vehicle being a PEV—depending on the types of PEV offerings. More recent research with EV buyers supports this early finding of consumer willingness to adapt to what they see as an engaging product (Turrentine *et al* 2011, Pierre *et al* 2011). In the case of PHEVs, which are not range limited, results of a representative US survey indicated about one-third of new car buying households exhibit both an interest and requisite home electrical infrastructure to buy a PHEV (Axsen and Kurani 2009).

In-depth, inductive research methods can uncover the complexity of consumer motives relating to PEVs—which can extend far beyond the functional concerns of driving range, recharge time, and purchase price. A series of interviews with (non-plug-in) hybrid vehicle buyers discovered that most were at least partially motivated by the symbolic values communicated by such a vehicle, such as concerns regarding the environment and energy security, intelligence, and technological advancement (Heffner *et al* 2007). Similarly, many PHEV drivers associated the vehicle with environmental and other pro-societal motives (Caperello and Kurani 2012, Axsen and Kurani 2012). In another study, EV lessees described the value and excitement they associated with the 'adventure' of experiencing and mastering new EV technology (Turrentine *et al* 2011). Drawing from such empirical findings, we assume that potential PEV buyers can be motivated by more than functional characteristics of the technology—such as symbolic and pro-societal benefits including reduced environmental impact.

### 2.2. Demand for green electricity (GE)

As noted above, we use the term green electricity (GE) to refer to zero or near-zero GHG emissions sources of electricity, such as solar, wind, small-scale hydroelectric and geothermal. GE is also referred to as 'clean,' 'sustainable,' or 'renewable' electricity. The ability of any single household to use GE may take several forms. GE can include the installation and use of residential solar panels. Depending on whether their electricity provider offers such programs, GE also includes programs in which consumers can voluntarily enroll. Two forms of these are voluntary higher electricity rates to support investments in GE and leasing of specific allotments of existing GE production facilities. According to Bird *et al* (2009) programs in which customers voluntarily

enroll to support investments by their electricity provider in GE account for 0.6% of US electricity sales.

Like PEV market studies, many GE market studies are framed according to consumer willingness to pay, e.g. Roe *et al* (2001). However, GE market studies have not been limited to the more singular behavioral model of consumers followed by much PEV market research. GE researchers have frequently drawn from attitudinal models such as the new environmental paradigm and theory of planned behavior (Clark *et al* 2003, Hansla *et al* 2008, Ozaki 2011), as well as theories of consumer innovativeness and diffusion (Faiers and Neame 2006).

Across these studies (using different methods, in different regions), we identify what seem to be several key themes. Enrollees in voluntary monthly subscription programs are found to have relatively high pro-environmental values (particularly biocentric values), typically expressed as concerns about local environmental impacts rather than global impacts (Clark *et al* 2003). As with PEV adoption, GE adoption has been linked to consumer needs to symbolically communicate some aspects of their identity to others (Ozaki 2011). Further, households are more likely to be willing to pay for GE if they hold ‘liberal’ political values (Rowlands *et al* 2003), feel that they can trust the provider of GE (Diaz-Rainey and Ashton 2011), and think that other households will also participate (Wiser 2007). A lack of knowledge and understanding regarding GE programs was found to be a barrier to consumer participation (Salmela and Varho 2006). Interestingly, it is not clear if household income significantly affects consumer willingness to adopt GE—at least in the choice between designs of voluntary contribution programs (Kotchen and Moore 2007). Household interest may also vary by the particular form of GE; in one study respondents prefer solar relative to wind or a generic ‘green’ source (Borchers *et al* 2007).

### 2.3. Drawing from focus groups of PEV buyers and GE enrollees

In an earlier stage of this research project, researchers conducted a total of six focus groups with PEV lessees and GE enrollees in Los Angeles, New York and New Jersey (Kurani *et al* 2012). Focus group participants were asked about their motivations for purchasing the product that defined their group (PEV or GE), and then asked to discuss the other product which they had not (necessarily) taken up. Finally, participants talked about combining the two products. There was a general lack of consensus on a link between PEV and GE. Among PEV lessees, some had already formed this link, e.g., buying home solar panels. Still, others stated that their PEV ownership was already ‘doing enough’; they wanted to see others, specifically people still driving gasoline cars, do something about oil use and the environment before PEV drivers were asked to pay more for green electricity. GE enrollees were generally skeptical of the environmental benefits of PEVs. Interestingly, PEV lessees and GE program enrollees did share many of the same motives for their commitments to their single action, i.e., lease a PEV or

join a GE program, including air quality (especially in Los Angeles) and energy security—but with little mention of climate change. The present study utilizes these exploratory insights to explore PEV and GE demand among larger, more diverse samples of vehicle buyers.

### 2.4. Assessing demand using technology ‘design games’

Our measures of consumer interest in PEVs and GE are derived from design games. A design game differs from the choice sets offered to respondents in stated preference discrete-choice exercises typically used in other PEV market research. The latter typically collects multiple stated choice observations from each respondent in order to estimate an aggregate preference function for that sample—that is, to infer the preferences held by the market. In contrast, design games provide a ‘design space’ and allow each respondent to construct their own, unique vehicle design for their particular context. The constructive nature of the design games is consistent with notions that preferences change (Norton *et al* 1998) and that consumer preferences are constructed by the participant as they encounter and work through a novel purchase decision (Bettman *et al* 1998). We believe that this constructive process is even more likely for consumers when they encounter a novel purchase opportunity, such as design games involving PEVs, GEs and their combination. Our present PEV design exercise is influenced by previous versions used for car use (Lee-Gosselin 1990), EV demand (Kurani *et al* 1996), and PHEV demand (Axsen and Kurani 2009).

## 3. Methods

### 3.1. Survey of US car buyers

To explore our research questions, we designed a web-based survey and implemented it among these three samples:

- (1) Recent buyers of new conventional vehicles (CV buyers, or CVBs).
- (2) Recent buyers of hybrid vehicles (HEV buyers, or HEVBs).
- (3) Recent buyers or lessees of plug-in electric vehicles, including the MINI E, Chevrolet Volt and Nissan Leaf (PEV buyers/lessees or PEVBs).

The CVB sample is representative of households who buy new cars in the US. The HEVB and PEVB samples, while ‘national’ or multi-regional, are much less likely to be nationally representative given the limited geography and high lease and sale prices of PEVs during the time period of this study. The questionnaire required 20–25 min to complete. The flow of questions was customized for each respondent. Section 1 asked about household type, whether they had access to 110 and 220 V outlets where they parked their vehicle(s) at home, and the existence or feasibility of rooftop photovoltaic installation (we call this ‘solar’ for shorthand). Section 2 asked about household vehicles, and guided the

**Table 1.** Incremental prices for PEV design games.

Vehicle type	Higher price scenario				Lower price scenario			
	Compact	Sedan	Mid-SUV	Full-SUV	Compact	Sedan	Mid-SUV	Full-SUV
HEV	\$1080	\$1290	\$1480	\$1740	\$780	\$850	\$920	\$1000
PHEV-10	\$2710	\$3530	\$4120	\$5050	\$2090	\$2600	\$2950	\$3510
PHEV-20	\$3160	\$4060	\$4830	\$5880	\$2320	\$2860	\$3300	\$3920
PHEV-40	\$4070	\$5110	\$6240	\$7540	\$2770	\$3380	\$4000	\$4760
EV-75	\$5940	\$6920	\$8970	\$10 550	\$2940	\$3140	\$4010	\$4500
EV-100	\$7570	\$8790	\$11 490	\$13 510	\$3760	\$4080	\$5270	\$5980
EV-125	\$9200	\$10 670	\$14 010	\$16 480	\$4570	\$5020	\$6530	\$7460
EV-150	\$10 820	\$12 540	\$16 530	\$19 450	\$5380	\$5960	\$7790	\$8950
EV-200	\$14 070	\$16 290	\$21 570	\$25 380	\$7010	\$7830	\$10 310	\$11 910

respondent through a vehicle design game. The design space included conventional vehicles (CVs), HEVs, and PEVs. Section 3 asked about household electricity usage, and guided the respondent through a GE design game. Section 4 provided a ‘combined’ game where PEV options were explicitly linked to GE options. The design games in sections 2–4 also included follow-up questions on motivations for designing (or not) their next new vehicle to be a PEV, designing a GE program for their home, or both. The vehicle and GE design spaces and motivations were informed by the focus group study and literature review. Finally, sections 5 and 6 collected attitudinal, lifestyle and demographic information.

### 3.2. PEV design game

All survey respondents completed the vehicle design game in section 2. Each respondent first selected a ‘base’ vehicle—a vehicle they thought they would buy next if they were limited to choosing either a CV or HEV. The respondents entered their expectations of this vehicle’s body type, price, and fuel economy. Next, the respondent was provided with a one-page summary of the details of and differences between a HEV, PHEV, and EV—in part based on a PEV information package previously developed for non-expert consumers (Axsen and Kurani 2009). Respondents then completed higher and lower price versions of the vehicle design game.

Our vehicle design games presented the respondent with up to four potential vehicle types: (i) their base conventional vehicle, (ii) a hybrid version (with 33% higher fuel economy over the base), (iii) a PHEV version that could be powered with electricity for the first 10, 20, or 40 miles (achieving the same 33% increase in fuel economy until the battery is recharged), and (iv) an EV version powered only by electricity for 75, 100, 125, 150, or 200 miles of range. The incremental prices for each vehicle type and electric driving range within type differed by vehicle body size (table 1). Incremental prices are based on an electric-drive price model, influenced by several technical PEV cost studies (Delucchi and Lipman 2010, Kromer and Heywood 2007, Duvall *et al* 2002). Incremental prices include the cost of the battery as well as changes to the engine, motor, exhaust and wiring. Further, we assumed a more power dense battery is more expensive (per kWh) than a more energy dense battery (Santini *et al* 2011).

Of course, any estimates of future battery and PEV costs are highly speculative and uncertain. Our overall research question does not substantially rely on using ‘correct’ battery costs. Instead we seek to observe if consumers may value PEVs and green electricity as complementary products under certain contexts.

### 3.3. GE design game

The GE design game follows similar principles as the PEV game. Section 3 of the survey collected information about the respondent household’s electricity use. Because most households do not know their monthly consumption in kWh (as ascertained in this and prior survey work), we estimated their monthly electricity consumption based on their housing type and State using publicly available data from the US Energy Information Administration. The respondent was given an opportunity to change our estimate before they continued with the GE design game. Respondents also reported if they were already enrolled in some type of GE program. If any respondents indicated they already owned solar panels, they did not complete the GE game.

After establishing their baseline household electricity usage, respondents were shown a one-page summary of as many as four GE program types (summarized in table 2): (i) no program or their current GE program, (ii) enrollment in a monthly GE program through their electricity provider, (iii) enrollment in a 2 year GE lease program, and (iv) purchase and installation of a residential rooftop solar system. Respondents who did not have the ability or authority to install solar panels at their home location were not provided the last option (solar).

The GE design games were also completed in a high and low cost version. The type (i) GE monthly subscription and (ii) lease programs were identically priced—monthly premiums above their base kWh price were \$0.03/kWh or \$0.015/kWh for the higher and lower price scenarios, respectively. Respondents could elect to have the subscription or lease cover from 20% to 100% of their monthly electricity consumption. The subscription program required a shorter commitment than the lease (one month rather than two years), and provided more electricity source options. The source options for the lease were limited to non-residential solar or

**Table 2.** Incremental prices for Green-E design games.

	1. Monthly subscription program	2. Two-year lease	3. Install home solar
Source options	Solar, wind, tidal, geothermal, biomass, small hydroelectric, or determined by electric utility	Lease solar panels or wind turbine (non-residential)	Solar panels installed at home
Higher price scenario	Levels: 20%, 40%, 60%, 80% or 100% of household electricity use price = \$0.03/kWh	Same as levels and prices as monthly (#1)	180 kWh: \$29/month (\$5.1/W) 360 kWh: \$58/month (\$5.1/W) 540 kWh: \$68/month (\$4.0/W) 720 kWh: \$86/month (\$3.8/W) 900 kWh: \$102/month
Lower price scenario	Same levels price = \$0.015/kWh	Same as levels and prices as monthly (#1)	180 kWh: \$20/month (\$3.6/W) 360 kWh: \$40/month (\$3.6/W) 540 kWh: \$48/month (\$2.8/W) 720 kWh: \$60/month (\$2.7/W) 900 kWh: \$71/month (\$2.5/W)
Savings on electric bill	None	None	Savings = (% solar) × household bill

wind. Based on the focus groups, we anticipated the lease may be perceived as more ‘real’ than the monthly subscription program because their contribution would finance capacity at a specific facility rather than providing unspecified ‘support’ to green electricity investments by their electricity provider.

The home solar installation option was based on system size rather than percent of consumption, ranging from 180 to 900 kWh per month (table 2). Purchase and installation prices in the two scenarios were based on estimates by the Lawrence Berkeley National Lab (Barbose *et al* 2011). Price per watt varied by system size; including government incentives the higher price scenario ranged from \$5.10 to \$3.60/W, and the lower price scenario ranged from \$3.60 to \$2.50/W. This level of detail was not shown to respondents; instead, price was framed as a monthly payment based on financing at 5% interest over 20 years. Because the solar installation would generate electricity, this option also served to reduce the household’s electrical bill in proportion to the household’s consumption rate. Both the additional monthly cost to amortize the system and any monthly savings on their electricity bill was shown to respondents.

This GE design space has several limitations. As with the PEV design space, the actual costs of present and future green electricity and solar panel are highly uncertain. Further, the actual costs, availability and efficiencies of different green electricity sources vary substantially by US region. Due to the complexity of representing such regional variation, the present methodology provided the same GE design space to all US survey respondents. We also ignored the potential complexity that electric utilities might face in trying to provide such ‘green electricity’ to quickly meet such consumer demand (e.g. breaking existing supply contracts). Future research can explore these additional complexities and uncertainties.

### 3.4. Combined design game

The initial vehicle and GE design games instructed respondents to think about each product independently. Section 4 of the survey presented respondents with a

‘combined’ design game that explicitly linked the two products. Using the same design options and prices as the independent design games, the combined games consisted of a higher and lower price scenario. The respondent first selected a vehicle design then selected an electricity program. The GE design game differed in two minor ways: (i) the amount of the monthly electricity bill was increased to reflect any estimated additional consumption of electricity to charge a PEV (if the respondent selected one) and (ii) the GE design space showed respondents the percentage of their PEV’s electricity usage that would be covered by their green program (up to 100%). The latter piece of information was provided in case the respondent wanted to know how much of their vehicle’s electricity would be ‘green’.

## 4. Results

### 4.1. The US sample: buyers of conventional, hybrid and plug-in hybrid vehicles

We implemented the survey in January and February of 2012. We received useable responses from 1502 respondents: 1064 conventional vehicle buyers (CVBs), 364 hybrid vehicle buyers (HEVBs), and 74 plug-in vehicle buyers (PEVBs). The PEVBs were largely made up of previous one-year lessees of BMW’s MINI E electric vehicle. These vehicles were leased to households in Los Angeles, New York and New Jersey, as summarized in Turrentine *et al* (2011). Sixty-one of the PEVB sample were MINI-E lessees, nine owned a Chevrolet Volt (PHEV), nine a Nissan Leaf (EV), nine a BMW Active E (PHEV), and one a Tesla Roadster (EV). These frequencies add up to more than 74 because some respondents owned or leased more than one PEV.

Reported enrollment in some form of GE program was higher than expected: 6–8% of respondents across the three samples. Reported ownership of home solar was also higher than expected for CVBs (8%), and even higher for HEVBs (37%) and PEVBs (32%). These higher than

**Table 3.** Demographic characteristics by sample.

Characteristic	Category	Segment <sup>a</sup>		
		Conventional vehicle buyer (CVB)	Hybrid vehicle buyer (HEVB)	Plug-in electric vehicle buyer (PEVB)
Sample size		1064	364	74
Electricity	Green electricity program	6.3%	7.7%	8.1%
	Owens home solar	8.3%	36.8%	32.4%
Luxury make		9.9%	13.2%	N/A
Number of vehicles	1	23.9%	19.5%	9.5%
	2	56.0%	58.8%	40.5%
	3 or more	20.1%	21.7%	50.0%
Education	High school or less	42.6%	30.5%	12.2%
	University/college graduate	43.3%	47.3%	45.9%
Age	Graduate degree	14.1%	22.3%	41.9%
	19–29	20.4%	30.5%	9.6%
	30–39	25.5%	26.4%	9.6%
	40–49	16.6%	14.4%	16.4%
	50–59	20.3%	15.5%	43.8%
Income	60 or older	17.3%	13.2%	20.5%
	<\$50k	26.9%	20.1%	4.1%
	\$50–69k	24.0%	20.3%	5.4%
	\$70–99k	23.2%	23.4%	12.2%
	\$100–150k	16.4%	24.2%	10.8%
	>\$150k	4.6%	9.1%	50.0%
	No answer	5.0%	3.0%	17.6%
Median income category	\$60–69k	\$70–79k	\$>150k	
Housing type	Detached house	73.6%	71.7%	91.9%
	Attached house	13.1%	17.0%	1.4%
	Apartment	10.3%	10.2%	4.1%
	Mobile home	3.0%	1.1%	2.7%
Owens home		80.9%	84.1%	93.2%

<sup>a</sup> Differences between the three segments are significant at 99% confidence level ( $p < 0.01$ ) for all variables shown.

expected percentages, especially for the HEVB and PEVB samples, could have been a result of errors in some respondents’ reporting (or misunderstanding of the questions) or a differential interest in completing the questionnaire by those already interested in the topics of PEVs and GE. Regardless, interpretations of our specific results will be generalized cautiously.

The three samples differ by demographic and attitudinal factors. The PEVB respondents were most different from the other two samples: PEV buyers/lessees were more likely to: have higher income, be older, have more education, own more vehicles per household, live in a detached home, and own their home (table 3). Further, we note that PEVB respondents were largely made up of MINI E leasers, which may not represent owners of other electric-vehicle models. Relative to the CVB segment, HEVBs were slightly more likely to have higher income, have more education, and be younger. In terms of lifestyle patterns, PEVBs were most likely to report that they explore new technologies and are open to change. HEVBs were most likely to engage in pro-environmental activities, where PEVBs were not significantly more likely to do so than CVBs.

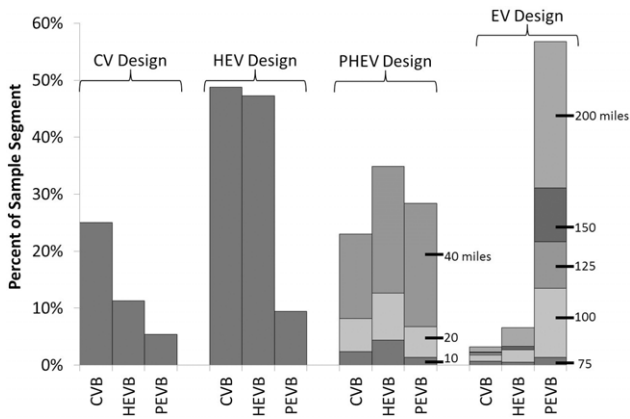
#### 4.2. PEV designs

Figure 1 portrays the distributions of vehicle designs by the three segments from the higher price version of the initial vehicle design game. The majority of PEVBs (57%) selected

some form of EV for their next vehicle; counting PHEVs, more than 80% select some form of PEV. Of those who select an EV, 26% select the most expensive EV with the highest offered range of 200 miles. In contrast only 3% and 7% of CVBs and HEVBs selected any EV design. The CVBs and HEVBs were most likely to select an HEV followed by PHEVs. Even among the CVBs only about one-fourth elected to stay with their initial base conventional vehicle design. This overall pattern—the PEVBs overwhelmingly favoring PEVs and EVs in particular and the CVBs and HEVBs favoring HEVs and to a lesser extent PHEVs—were nearly identical for the ‘lower’ price scenario, with a slightly higher prevalence of PEV designs across all three segments.

#### 4.3. GE designs

GE designs also differed across the three vehicle segments (figure 2). Though the majority of all samples selected some form of GE program, participation markedly increases going from the CVB, to HEVB, to PEVB segments. This result excludes the more than one third of the HEVBs and PEVBs who reported they already owned home solar panels, and thus did not complete the GE design game. Of the respondents that did select some form of GE program, the most popular program across all three segments was the home solar installation (particularly popular among PEVBs), followed by the monthly GE program (14%–18%). The two-year GE lease was only selected by 6–9% to nine percent of respondents.



**Figure 1.** Vehicle designs from ‘higher price’ game (CVBs = 1064, HEVBs = 364, PEVBs = 74).

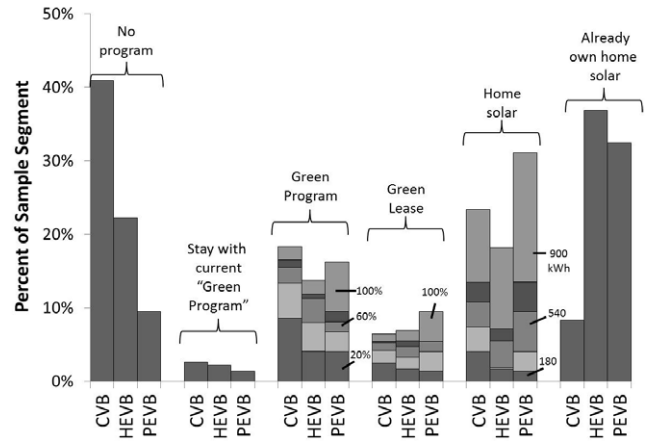
Results followed similar patterns in the lower price games, with slightly higher proportions of respondents selecting each form of GE program.

4.4. Combining PEV and GE designs

Following the first two games, respondents were asked if they thought about the source of electricity when they completed the first vehicle design game. Consideration of electricity varied by segment and was highest among PEVBs (PEVBs = 74%, HEVBs = 52%, CVBs = 40%). PEVBs were also most likely to think about electricity prices (PEVB = 68%, HEVB = 57%, CVB = 51%). Responses to these questions can serve as one indicator of the level of inherent conscious linking of PEVs and GEs among different consumer groups.

The final design game integrated the PEV and GE design options into a joint vehicle-GE design game. Figure 3 portrays the proportion of each sample that elected to combine some form of PEV (PHEV or EV) with some form of GE (monthly subscription, two-year lease, or home solar installation). Figure 3 excludes respondents that already owned a home solar system because they did not complete this design game. In the higher price scenario, some PEV–GE combination was selected by less than one-third of CVBs, about one-half of HEVBs, and almost nine-tenths of PEVBs. The most popular combination among the PEVBs was an EV with a home solar system. In comparison, among CVBs and HEVBs their combinations were more likely to involve a PHEV and to be more even split between a monthly subscription program and home solar installation. These results followed a similar pattern for the ‘lower’ price scenario.

One of our research objectives was to assess if the addition of a GE option could increase demand for PEVs. We get one measure of such a potential complementarity by comparing the distributions of PEV designs in the vehicle-only design game with those from the combined vehicle-GE design game. Figure 4 shows that in all three respondent segments, PEVs were selected more frequently in the combined game. The highest percentage increase was observed among CVBs, whose proportion of PEV



**Figure 2.** GE designs from ‘higher price’ game (CVBs = 1064, HEVBs = 364, PEVBs = 74). Note: respondents that already owned home solar did not complete game 2.

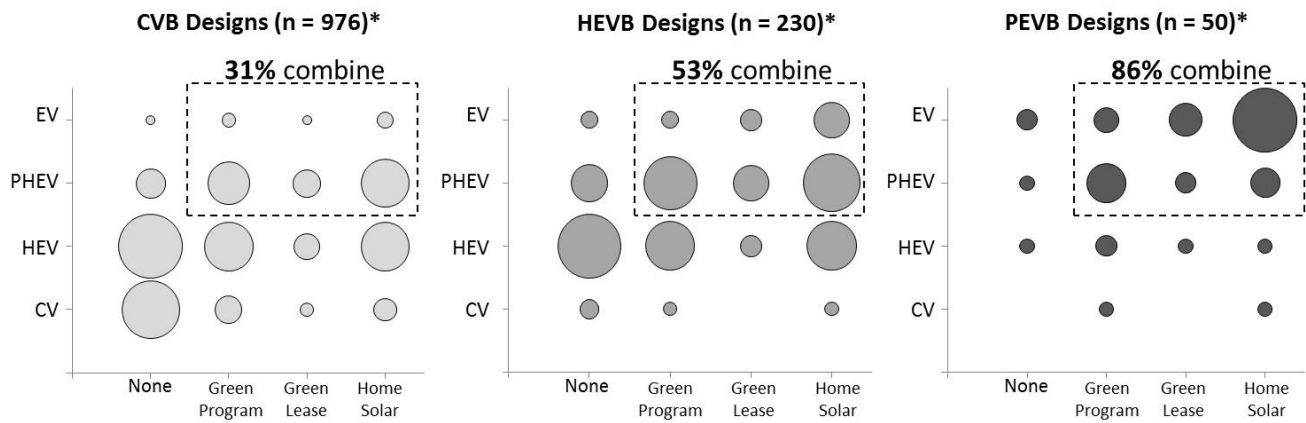
designs increased from 25% to 31% (a 23% increase). The proportional increase was slightly less among HEVBs, and significantly less among PEVBs as the vast majority of the PEVBs had already designed some form of PEV for their next vehicle.

4.5. Motivations for respondents’ vehicle and GE designs

Each of the three design games was followed with a question about respondent motivations for their selecting or rejecting a PEV or GE program. Researchers selected from a list of 11–12 statements representing potential motivations, which were informed by the previous focus groups study as well as the literature review. Respondents could add one additional open-ended response. Respondents were provided with a limited number of points (30 for the first two games, 15 for the third) that they could assign to each motivation up to a maximum of five points per motivation; they did not have to assign any points to any motivation nor did they have to spend all their points. The exercise requires respondents to prioritize among their most important motivations without having to produce an exact rank order. It allows them to rank some items as being of equal importance—whether that is of utmost important, some importance, or of no importance. In a simple rating exercise, i.e., if respondents had been asked to rate 11 or 12 statements on a five-point scale, they in effect would have up to 55 or 60 points to spend (with a maximum of five on any item). Because they have much fewer points than this to allocate, any mean score above 2.5 points (=30 pts/12 items) represents a high average score for a motivation.

Table 4 summarizes results for the top motivations in each exercise. The most highly rated motivation for selecting a PEV among CVBs and HEVBs was saving money on both fuel and overall vehicle ownership. PEVBs were more likely to be motivated to select (another) PEV by environmental concerns and interest in new technology. ‘Concerned about the environment’ was among the highest motivations for all three segments in all three games; concern about climate change was absent in all cases.



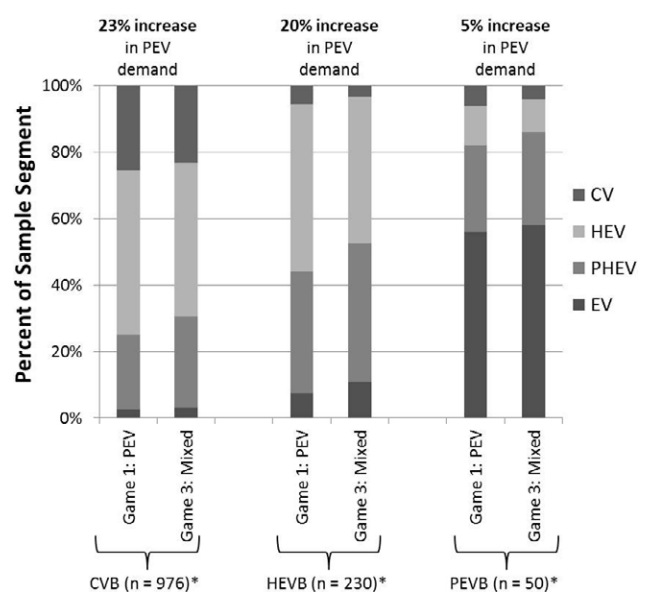


**Figure 3.** Combining vehicle and electricity designs in the ‘higher’ price combined game. Note: respondents that already owned home solar did not complete game.

In the GE design game, CVBs and HEVBs were again more likely than PEVBs to report interest in saving money on their monthly household electrical bill. PEVBs were more likely to be driven by interests relating to technology exploration, and the politics of oil. All three groups were similarly motivated by the environment, support for renewable energy, and control regarding electricity sources. The combined design game yielded similar patterns for motivations. As a final step, we conducted a binary logistic regression analysis (not shown), finding that a respondent was more likely to select a PEV–GE combination if they: are under 60 years of age, live in a detached home, previously bought an HEV or PEV, frequently engage in technology-oriented activities, or score highly in pro-environmental attitude.

**5. Discussion and conclusions**

As policymakers and automakers attempt to initiate electrification of light-duty automobiles, questions of consumer acceptance and motivation loom. The specific question we explored with US car-buyers in this study was whether their interest and motivation regarding PEVs is affected by explicitly linking PEVs with green sources of electricity to recharge them. To establish a baseline, we first assess respondent interest in each product independently through a series of design games. In the first, respondents design their next new vehicle within a design space that spans from the conventional vehicles most of them are presently driving (and imagine they will buy next), to hybrids, plug-in hybrids, and electric vehicles. In the second, they design their home electricity ‘program’, deciding whether to keep their present electricity plan, volunteer to enroll in a monthly subscription program to pay extra to their electricity provider for investments in green electricity production, lease a specific amount of solar photovoltaic or wind turbine capacity for two years, or install solar on their home. Both design spaces are limited in that they provide a hypothetical setting for consumer valuation, and clearly do not represent all the complexity of these two products. However, the method does provide one perspective on how demand patterns for such products might develop.



**Figure 4.** Effect of combination game on PEV demand. Note: respondents that already owned home solar did not complete game 3.

Most conventional vehicle buyers (CVBs) abandon conventional vehicles, even under the higher vehicle price conditions: only one-fourth retained a conventional vehicle design for their likely next new vehicle. Just under half the CVBs redesigned their next new vehicle to be a hybrid and about one-fourth designed a PEV of some kind—the vast majority of these being PHEVs. Both the HEVs and PHEVs that the CVBs design have significantly higher gasoline-equivalent fuel economy than their conventional variants. This observed general interest in much higher fuel economy matches findings gathered through a similar method for a different sample of US new car buyers in 2007 (Axsen and Kurani 2009). In the present study, PEV interest was slightly higher among hybrid buyers (HEVBs) than among CVBs, and overwhelmingly higher among previous PEV buyers (PEVBs).

Across all three groups of respondents, i.e., CVBs, HEVBs, and PEVBs, most selected some form of green

**Table 4.** Motivations (mean on zero-to-five scale; standard deviation in brackets).

	CVB	HEVB	PEVB
(A) PEV design exercises (12 statements total) <sup>a</sup>			
I designed a PEV because I...	<i>n</i> = 336	<i>n</i> = 184	<i>n</i> = 64
... think it will save my money on gasoline <sup>b</sup>	<b>4.1 (1.6)</b>	<b>3.7 (1.8)</b>	3.2 (1.8)
... am concerned about the environment <sup>b</sup>	3.1 (1.9)	2.9 (2.0)	<b>3.5 (1.9)</b>
... think it will save money on the total cost of a vehicle <sup>b</sup>	<b>2.7 (2.1)</b>	<b>2.5 (2.1)</b>	1.3 (1.7)
... am concerned about local air pollution	2.7 (2.0)	2.7 (2.1)	2.8 (2.1)
... am interested in new technology <sup>b</sup>	2.6 (2.0)	2.9 (1.9)	<b>3.4 (1.7)</b>
(B) Green-E design exercises (12 statements total) <sup>c</sup>			
I joined a green electricity program I...	<i>n</i> = 611	<i>n</i> = 172	<i>n</i> = 45
... think it will save money on my electricity bill <sup>b</sup>	<b>3.2 (2.1)</b>	<b>3.3 (2.0)</b>	2.0 (2.2)
... want to be part of a movement toward renewable energy	3.1 (2.0)	3.3 (1.9)	3.6 (1.9)
... am concerned about the environment	2.9 (2.1)	2.8 (2.1)	3.5 (2.0)
... want some control over my electricity sources	2.7 (2.1)	2.9 (2.0)	2.3 (2.1)
... am concerned about the politics of oil <sup>b</sup>	2.1 (2.1)	2.1 (2.1)	<b>2.9 (2.1)</b>
... am interested in new technology <sup>b</sup>	2.0 (2.1)	2.5 (2.1)	<b>2.9 (2.0)</b>
(C) Combined design exercises (11 statements total) <sup>d</sup>			
I would combine the purchase of a PEV with a green electricity program because I...	<i>n</i> = 162	<i>n</i> = 65	<i>n</i> = 18
... am concerned about the environment	2.2 (1.9)	2.4 (2.0)	1.8 (2.1)
... want to be part of a movement toward renewable energy	2.1 (1.9)	1.9 (1.8)	2.1 (2.2)
... want to control my PEV's electricity source	1.8 (1.9)	1.6 (1.8)	1.4 (1.9)
... am concerned about the politics of oil	1.7 (1.9)	1.4 (1.8)	1.9 (2.2)
... am interested in new technology	1.5 (1.9)	1.5 (1.8)	2.3 (2.4)

<sup>a</sup> All respondents that selected PEV in 'lower' price scenario. Respondents had 30 points and could assign 0–5 points to each of 12 possible 'motivations'. Zero indicates 'no importance' while a 5 indicates 'high importance'.

<sup>b</sup> Significant difference between segments at 95% confidence level ( $p < 0.05$ ).

<sup>c</sup> All respondents that selected Green-E in 'lower' price scenario. Respondents had 30 points and could assign 0–5 points to each of 12 possible 'motivations'.

<sup>d</sup> Respondents that selected a PEV and Green-E and in 'lower' price scenario of combined game. Due to a survey programming error, responses were only recorded for about half of respondents in each segment (245 of 459 total). Respondents had 15 points total and could assign 0–5 points to each of 11 possible 'motivations'. Observed means for each response do not significantly differ across segments at a 95% confidence level ( $p > 0.05$ ). Seemingly, the reduced sample sizes are not sufficient to view significant differences.

electricity (GE) program. One reason may be that some GE programs required little financial or temporal commitment. For example, enrollment in a voluntary, monthly GE program to cover only 20% of one's electricity requires far less commitment than buying a new kind of vehicle. On the other hand, among those respondents that selected any GE program (across all three vehicle samples), the most popular option was to finance for 20 years the installation of a residential solar system. The residential solar option was the only GE program that could reduce the respondents' monthly electricity bill, which may help to explain its relative popularity. The leasing option is rare in the real world, which may explain its relative lack of support in the games—it may be the most unfamiliar. Certainly our expectation that leasing might appeal to people because it was an investment in a specific renewable energy producing facility rather than payment into a less tangible investment fund did not raise the appeal of leasing above any other type of GE program.

Having established these baseline measures of interest, we move to our central question, 'Does forging a connection between PEVs and GE increase interest in both?' The answer to the question appears to be generally positive. Among CVBs, the combination increased the stated PEV demand by 23%, with a similar increase among HEVBs. PEVBs saw less

of an increase, but most had already selected PEV and GE designs in the prior independent games or in fact in their real lives had already combined both. As important as any increase in the percentage of the CVB who designed their next new vehicle to be a PEV in the final game is the insight that prior to our explicitly framing the question as one of co-designing a PEV and a source of household electricity, most CVB respondents did not think about electricity sources when initially playing the initial vehicle-only design game.

Motivations for selecting a PEV, a GE program, or both yielded both consistencies and variations across the respondent samples. Environmental concern was consistently important across samples and across design games, and pro-environmental attitude and lifestyle were strong predictors of respondent selection of a PEV–GE combination. This finding of pro-environmental association is well established for electric-drive vehicle interest (Heffner *et al* 2007, Caperello and Kurani 2012, Turrentine *et al* 2011). Further, the focus of all three samples on local environmental concerns (air pollution) rather than global concerns (climate change) echoes results from previous research (Clark *et al* 2003). Relative to the other groups, CVBs were much more likely to be motivated by financial savings, while PEVBs were more likely to be driven by technical interest. The latter point is

consistent with findings that many of the MINI-E lessees recruited for this PEVB sample demonstrated very high interest in exploring new technologies (Turrentine *et al* 2011). An interesting and perhaps new insight was the relatively consistent selection of ‘control over electricity sources’ as a motivator for all three respondent segments.

Across these results, we see clear differences between the CVB, HEVB and PEVB segments. CVBs are least likely to select PEVs or GE, but demonstrate the highest proportional increase in PEV demand when the two products are combined. HEVBs are generally more likely to select a PEV, GE program, or both. PEVBs are far more likely to select a pure EV design (with higher range at a higher price), and are more likely to already own solar, or to select a home solar design.

Our results hold interesting implications for the combination of PEV and GE products. Shorter-term marketing opportunities exist with HEVBs, and even more so with PEVBs. These segments are already more likely to be aware of PEVs and GE, and seem to be more readily able and willing to link the two—if they haven’t already. PEVBs already demonstrate a very strong interest in the combination of a pure electric vehicle with a home solar photovoltaic system (as demonstrated by actual purchase behavior). But PEVBs represent a small proportion of the total new vehicle market; marketing techniques that are effective with this segment may not work be effective with CVBs.

Although the PEV–GE link is not presently strong in the consciousness of most general consumers, our results indicate the combination may be attractive to some consumers if clearly explained and appropriately framed according to motivations of overall cost savings, air pollution reductions and control over energy sources. The motivation for overall cost savings speaks to alternative financing instruments for either or both GE and the combination of PEVs and GE. If this link is effectively made, GE program offerings—with their generally much lower cost of entry—could possibly serve as an accelerant for the PEV market. As shown in other research, consumer perceptions are not static and can be shaped through learning and the construction of new social norms and values (Axsen *et al* 2009, Norton *et al* 1998, Axsen and Kurani 2012). Even if consumers do not presently link two products, policymakers, automakers, electricity providers, consumer and environmental groups, and others can feasibly work to create this link. Actions could include more detailed product labeling (e.g. showing the effects of different electricity sources on expected PEV emissions), offerings of PEV–GE combined packages by automakers, or cross-marketing by the automobile and electricity sectors. Further research is needed to better explore potential policies and strategies that could effectively build such a market on a broad scale. For now, we conclude that there appears to be some promise in doing so.

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