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An Assessment of Causes of PEV Success Across U.S. Metro Areas

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Short Abstract

Using 2014 U.S. light duty PEV registrations by make and model, this paper assesses the causes of Plug-in Electric Vehicle (PEV) success across U.S. states focusing on areas that had incentive and utility programs supporting PEV adoption. Market segments investigated were (1) luxury/performance (>$60,000 list price), (2) mid-market ($40-50,000), (3) mass market (<$40.000), and (4) total. States with either exclusive or preferential BEV incentives are a focus. BEV-biased incentives proved to be very effective in promoting mass market BEVs. After controlling for these attributes, case studies for several utility service areas were conducted to gauge whether PEVs were more or less successfully implemented via outreach by those utilities. These investigations suggest ways that utilities can successfully increase PEV registrations, after taking local climate and state incentives into consideration.

1. Introduction

Using 2014 U.S. light duty PEV registrations by make and model, for model years 2014 and 2015, this paper assesses causes of PEV success across selected U.S. metro areas focusing on those with incentive and utility programs supporting PEV adoption. Regional, state, metro, and center city PEV market shares are examined, controlling for location attributes and ambient temperature in January and August. Three market segments are examined — (1) luxury/performance (>$60,000 list price), (2) mid-market ($ 40-50,000), and (3) mass market (<$40,000). States with BEV only incentives are compared with those that relatively equally incentivised both PHEVs and BEVs. Case studies of several utility service areas are conducted to assess whether PEVs were successfully promoted, controlling for location specific factors. The utilities examined include public utilities Austin Energy and the Sacramento Municipal Utility District, and private utilities Southern California Edison, Detroit Edison and Duke Energy. The two public utilities serve core cities only. Southern California Edison largely serves cities and suburbs outside of Los Angeles, while Duke Energy serves large segments of four states.

2. Structures of Incentives vs. Plug-in Vehicle Attributes

States and the federal government adopted different strategies with respect to provision of incentives for battery electric vehicles (BEVs) and plug-in hybrids (PHEVs). When discussing sums of registrations of all types of plug-in vehicles in this paper, we use the term PEV.

In 1990 California was the first state to develop an incentive structure to encourage sales of battery electric vehicles by 1998. These were the so-called ZEV regulations. The first efforts at introducing BEVs to meet the original ZEV regulations were primarily based on nickel metal hydride battery technology. The BEVs that were introduced in the 1990s did not sell well and were confined to California. However, the Toyota Prius hybrid-electric-vehicle (HEV), which successfully used the nickel metal hydride battery technology to dramatically improve gasoline powertrain efficiency, was introduced in 1997. Lithium-ion battery technology, which Nissan had used in its 1990s BEVs for California, continued to improve.

An extension of the HEV technology to include a plug-in feature was studied by the Electric Power Research Institute, California regulators, and U.S. Department of Energy National Laboratory staff at the turn of the century [1]. The report evaluated hypothetical PHEVs that varied in range from 20 to 60 miles. Nickel metal hydride batteries were assumed.

A few years later, Federal and state hybrid vehicle incentives followed the introduction of the Prius and Honda's Insight HEV, as U.S. manufacturers began to develop their own versions of the technology. Initial $2000 federal incentives began in 2002 and were increased to $3500 in the Energy Policy Act of 2005. Sunset provisions were included, up to a maximum of 60,000 vehicles along with a step function decline in subsidy amount at phase-out. A subsidy with a defined end is used to support a "policy goal of technology diffusion" [2]. Toyota's subsidies ended in 2007. The goal of the policy was realized, as HEVs are now a common, though hardly dominant, powertrain technology. Several states also adopted incentives such as rights to drive on high occupancy vehicle lanes, income tax credits, excise tax exemptions, and sales tax exemptions. Ten of the thirteen states that Riggieri [2] lists as having subsidies in 2005 had PEV subsidies in force in 2014

Between 2004 and 2008 technical feasibility of both plug-in hybrids and pure battery electrics was illustrated, using improved lithium-ion battery technology. Aftermarket conversions of Toyota Prius HEVs were demonstrated to be able to provide about 10 miles of all-electric range, if driven very gently. Plug-in conversions of the Ford Escape HEV with a similar range and all-electric operations capability (i.e. limited) were also produced and evaluated. A new corporation, Tesla, demonstrated a prototype high performance BEV roadster and indicated plans to ultimately produce passenger car BEVs [3]. General Motors responded to the possible competitive threat from Tesla and began developing the Chevrolet Volt plug-in hybrid, which was expected to be capable of about 40 miles of range.

In 2007 EPRI and the Natural Resources Defense Council (NRDC) released a "comprehensive assessment that found that widespread use of plug-in hybrid electric vehicles (PHEVs) in the United States could reduce greenhouse gas (GHG) emissions and potentially improve ambient air quality" (http://www.nrdc.org/media/2007/070719.asp). In 2015 these partners released another study of the same type, including BEVs, quantifying the same general conclusion, with only slightly greater optimism about GHG reduction due primarily to projections of more renewable electricity use (http://www.nrdc.org/media/2015/150917.asp). The addition of BEVs to the analysis had little effect in comparison to the prior analysis of PHEVs.

By 2009 [3], the plug-in hybrid developments led the California Air Resources Board (CARB) to incorporate provisions for both Prius-type PHEVs and Volt-type PHEVs (hereafter EREVs) into revised ZEV regulations. Though not using this terminology, varying amounts of ZEV credits were incorporated for PHEVs with tested (equivalent all-electric) range from 10-40 miles, and for EREVs for tested ranges from 20-40 miles. The difference between an EREV and PHEV is that the EREV has the ability to operate all electrically in all driving conditions, including very aggressive driving.

The federal government kept track of the PHEV and EREV experiments and production interest of General Motors and Ford, as well as the CARB regulations creating new credits for the technologies. To keep these domestic plug-in programs on track, the American Recovery and Reinvestment Act of 2009 (stimulus bill), created tax credits, essentially for these two classes of PEV. A tax credit starting at $2500 for a 4 kWh battery, scaling linearly up to $7500 for a 16 kWh battery pack was provided. In effect, a minimum

equivalent all-electric range of about 10 miles was incentivized. The credits are on a per vehicle basis, ending after 200,000 PEVs have been produced. All BEVs available in 2014 qualified for the maximum credit, as did the Volt, with a pack size of 16kWh. The next largest pack size was 7.6 kWh in the Ford Energi PHEVs. The Plug-in Prius had 4.4kWh.

In 2011 [5] CARB proposed that a new subclass of BEV be created, called the BEVx. This BEV would be allowed to have an "auxiliary power unit" (APU) that would allow driving on gasoline (or other future low greenhouse gas (GHG) fuels for a range equal to or less than the range of electric operations. These vehicles must have an electric range of 80 miles in a rather undemanding driving test. The APU could not be operated until the battery pack was completely empty. Thus a tested total range of 160 miles would be the maximum allowable. Limited top speed on gasoline was requested by CARB. Such vehicles were said to allow "improved regional driving capability" but "not use for long-distance driving". Half of a manufacturers' full ZEV credits could be met with such vehicles. In 2012 this was made a part of California regulations applicable to 2017 [6]. BMW, the leader in advocating this technology, produced and is selling both a BEV (i3) and BEVx (i3 REX) version. The REX federal window sticker estimated range under more aggressive testing than for CARB certification, is 72 miles. Total range is 150 miles. When operated on electricity alone, the i3 and i3 REX are capable of more aggressive driving than any of the 2014 PEVs with suggested retail prices less than $40,000.

A comparison of the incentive structures in the CARB ZEV regulations and in the U.S. tax credit subsidies shows considerably more effort to incentivize particular technologies in the former case. Under the federal subsidies, a Tesla with more than 200 miles of electric range gets the same incentive as any of the mass market BEVs. In effect, the federal subsidies treat every BEV and GM EREVs equally, while CARB provides a range of credits that are higher for 200 mile plus BEVs such as a Tesla than for mass market BEVs. GM EREVs earn less than mass market BEVs, while PHEVs earn less than GM EREVs.

Under section 177 of the Clean Air Act, it has been possible for many years for other states to adopt CARB ZEV regulations. Many have. As of 2014 seven states east of the Mississippi had done so [8]. We include these 7 states as a group. These states are north and east of Maryland, which is included. New England states other than New Hampshire are included, as are Delaware, Maryland, New Jersey and New York. All are in our cold states climatic grouping. Manufacturers who sell PEVs in California are required to make them available in all section 177 states, so these states should have a higher rate of registrations per capita due to higher numbers of PEV models made available. Recent research by the Union of Concerned Scientists concludes that in these states and Pacific Coast states electric drive has very favourable GHG benefits [9], so section 177 CARB regulations tend to promote the best geo-spatial U.S. applications for PEVs, with respect to GHGs. Manufacturers introducing PEVs under CARB regulations can trade and bank ZEV credits across states under complex formulas [4-7].

States have adopted varying financial incentives often related to the properties of the PEVs just discussed. Illinois' 2014 incentives, based on an estimate of incremental price relative to a similar gasoline vehicle, were available to BEVs and to GM EREVs and the i3 REX, but no PHEVs. Illinois promised rebates after vehicle purchase, but did not allocate funds to support its promises. Nevertheless, when qualified PEVs were purchased in Illinois, it was under the anticipation that rebates would be awarded. Logic was that PEVs capable of true all-electric operation without the engine turning on should be the only vehicles to qualify. Pennsylvania awarded $2000 grants to the same set of vehicles, but instead of awarding nothing to PHEVs, allocated $1000 each to them. Massachusetts adopted the same strategy as Pennsylvania, with $2500 and $1500 per PEV respectively. New Jersey followed the letter of the CARB ZEV regulations, only awarding credits to ZEVs. However, since we define the i3 REX as a PHEV in our computations, New Jersey selectively supported only one "PHEV" type. Texas included the Ford Energi systems, but not the Plug-in Prius or the Tesla. In those cases, the manufacturers may not have provided the vehicles. Our records indicate that only 0.9% of PHEVs registered in Texas in 2014 were Plug-in Prius. None were Teslas. This discussion illustrates that the states that adopted new incentives just for PEVs used incentive strategies that varied significantly with respect to which type of PEVs to support.

Another class of incentives was the previously existing alternative fuel vehicle incentive that had no sunset provision and was still in force when new BEV models became available. Incentive programs for Georgia ($5000

for BEVs, $0 for all PHEVs) and Washington State (~ $2000 per BEV) had originally been developed as alternative fuel incentives intended only for "dedicated" alternative fuelled vehicles that could not use gasoline. The original intent may have been to support compressed natural gas vehicles for energy security, with electric vehicles included for "political correctness" with little expectation that many would be sold. This type of incentive had not worked for CNG, but it did work very well for BEVs. Since the incentive worked better than intended the costs to the states were unexpectedly high. Tal and his co-authors wrote two papers suggesting that subsidies for the Plug-in Prius and the Tesla were not as effective as for other PEVs [8, 9]. Tesla buyers were argued to be insensitive to subsidies. Georgia recently eliminated its $5000 BEV-only incentive (highest in the nation). Washington placed a $35000 limit on the retail price of a PEV that would be subsidized, thereby removing luxury/performance vehicles (Tesla and most German PEVs) from the state subsidy program. California capped the income that households could have and qualify for a PEV tax credit. Illinois discontinued its subsidy program. These actions occurred over the last year. They do not influence our 2014 statistical evaluation, but the effects of the subsidy removals on recent overall sales (down) have been important. Tesla sales continued to increase. At the same time, however, list prices of several PEV models have come down, while the technology significantly improved, particularly for Tesla BEVs.

3. Methods

To address market-share-diminishing extreme temperature range issues for BEVs vs. seasonal temperature peaks [11-13] we compare results for warm, moderate and cold temperature regions. Theoretically, moderate temperature states should be most advantageous for BEVs because there would be minimal extreme temperature problems for the vehicles. The three Pacific Coast states, which have been leaders in BEV advocacy, are the only moderate temperature states. We cross match these climate groupings against three kind and degree of incentives groupings. State incentive categories used are (1) none (2) balanced incentives favouring neither BEVs nor PHEVs, (3) "BEV-biased" incentives that are higher for BEVs than PHEVs.

We use R. L. Polk records of new vehicle registrations for model year 2014 and 2015 in the U.S. during calendar year 2014. Using manufacturer's suggested retail price (MSRP), the PEV market for our tables are segmented as follows: (1) luxury/performance (>$60,000), (2) mid- ($40-50,000), and (3) mass-market (<$40,000).

States were assigned to bins "cold", "moderate" or "warm" by extreme temperatures of the largest city in January and July, as reported by Weatherspark.com. Cold regions were those where the sum of *peak* daily percentages of freezing (15°F to 32°F) and frigid (below 15°F) temperatures (always January) exceeded 41%. Moderate locations had (A) < 23% freezing and frigid days in January and (B) < 10% hot (85°F to 100°F) and sweltering (above 100°F) temperature peak days in July. Only California, Oregon and Washington had moderate climates by this definition. All remaining states were in the warm category. Dividing lines between warm and moderate were the existence of relatively mild temperatures in the summer *and* winter. Within these three climate groupings, sales of BEVs as a share of PEVs, are examined. Also, to examine general success of PEV introduction efforts, we present the share of PEVs registered relative to all vehicles registered.

Our cut point for cold vs. warm was Baltimore Maryland. Although this resulted in a significantly larger share of states being identified as "cold", it had a significant advantage with respect to consideration of the California Air Resources Board ZEV regulations applied under Clean Air Act Section 177. These are the Eastern "Section 177" states. By putting all of these states in the cold group, we are able to test whether the adoption of the California ZEV regulations led to more success in these cold states than in other cold states that remained under federal regulation.

Aside from adjusting the financial incentive programs for BEVs and PHEVs as described in the prior section, we used a data base provided to us by ICCT [14]. We examined the relative patterns of *total* incentives (vehicle subsidies, vehicle ownership fees, home and public charging subsidies, high occupancy vehicle lane one driver use privileges, free parking, and emissions test exemptions). The total benefit estimates for BEVs were compared to PHEVs. When the estimates for BEVs exceeded those for PHEVs by $600 or more, we defined the state as having provided "BEV-biased" incentives. 7 states fit into this category based on our modified ICCT incentives benefit totals. Oregon was added to this group because of its exceptionally successful installation of public charging infrastructure along Interstates and scenic highways (https://transportevolved.com/2014/11/26/oregon-

proves-key-electric-car-adoption-isnt-necessarily-purchase-incentives/), which is very important for BEVs, but not PHEVs (Fig. 1).

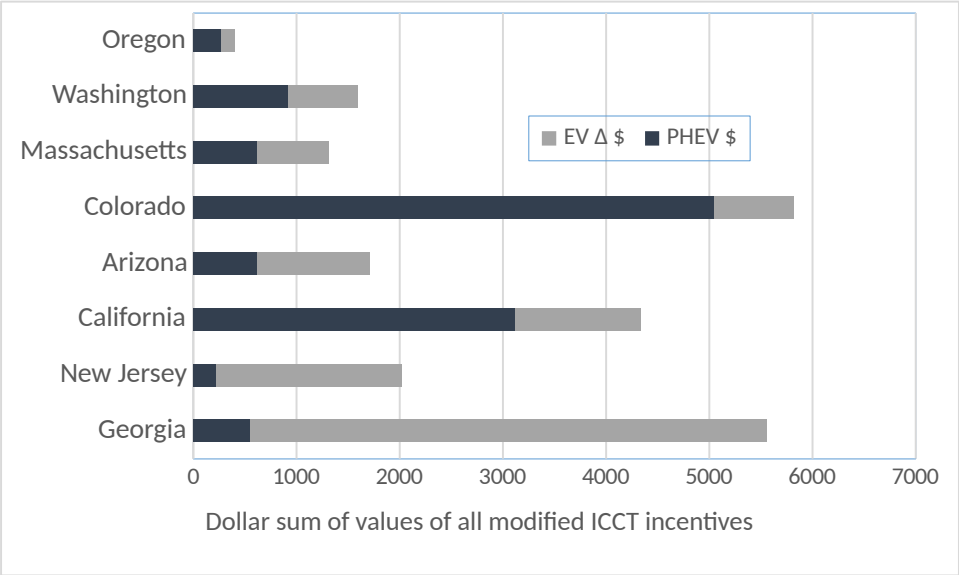

Fig. 1. Estimates of total PHEV incentive and additional BEV increment in "BEV biased" states

Otherwise we put the state into the "balanced" incentives group. 21 states fell in this category. 20 states had no incentives of any kind. Two states – Nebraska (-$400) and Virginia (-$262) had negative incentives. They were not included in the analysis. Their statistics were compared to those for other groups, verifying that negative incentives had a negative effect.

4. Results

4.1. Quantitative comparisons

Our first set of compilations for 48 states and DC were based on an earlier Polk data file that did not yet include registrations for all of 2015 (Table 1). We then used a later Polk data tabulation of registrations to compile the market shares of BEVs for each of our three market segments (Table 2). Comparable results across the two tables, using the different data files, differ slightly but are close enough that interpretations remain the same. Values in parentheses in Table 1 are averages of state percentages. Other values are based on the total number of vehicles in the listed group of states.

As a group, the three Pacific coast states with moderate temperatures and BEV biased incentives have had the greatest overall success in implementing PEVs in 2014. The next most successful were the two warm states with BEV-biased subsidies, Georgia and Arizona. Georgia was an outlier among the warm states, with by far the highest share of PEVs in those states, with the highest share of BEVs in the group as well. At 2.5%, California had more than double the PEV share of the next three leading states, which ranged from 1.0 to 1.1%. Among these four states, the nominal and original leader in promoting zero emissions vehicles (ZEVs), California − had a significantly lower share of BEVs. This is partly due to the fact that 80% of the national registrations of the Prius PHEV were in California, apparently to both meet CARB regulations and take advantage of high occupancy vehicle (HOV) lane access. Perhaps when HOV lane access is available to both BEVs and PHEVs, PHEVs are favoured by those who drive very long distances using these lanes.

Collectively the cold states that adopted CARB regulation had higher PEV shares than the cold states that did not. BEV shares, though variable were similar overall across cold states. The percent of BEVs in the no incentive states was consistently lower than in states that had incentives. Cold temperature consistently reduced the share of BEVs relative to warm states. However, in the moderate temperature states in the only place they appear – "BEV biased" incentive states – the share of BEVs was less than the average of the other five BEV-biased

incentive states. The BEV bias did not lead to a *consistently* higher BEV share relative to states that had incentives but no bias.

On average, for the total market, the BEV share was more than doubled by incentives. Without incentives, BEVs only captured 18% of the market. More dramatically, the PEV share of registrations rose sharply in BEV-biased states.

In the cold states these estimates indicate that incentives did not lead to greater shares of PEVs among registered vehicles. In warm states incentives were very effective in getting more PEVs deployed relative to the no incentives case. For the warm states it can be argued that incentives did successfully promote BEVs and PEVs. For cold states that argument cannot be supported.

In every case, the absence of incentives led to a lower share of BEVs. To the extent that BEVs are succeeding on a national average basis, these statistics imply that 2014 state incentives were critical.

Table 1. BEV, PHEV and overall PEV success vs. incentives and temperature categories, entire nation.

		Value of Incentives Category		
		None	Balanced	BEV biased
Moderate temperature states				
	BEV share (%)	No states	No states	41 (50)
	PEV % of registrations	No states	No states	2.52 (1.66)
	No. of states	0	0	3
Warm states				
	BEV share (%)	31 (31)	47 (45)*	75 (62)
	PEV % of registrations	0.07 (0.06)	0.19 (0.31)*	0.73 (0.69)
	No. of states	3	10	2
East Section 177 states (all cold)				
	BEV share (%)	21 (22)	25 (27)	43 (44)
	PEV % of registrations	0.34 (0.36)	0.41 (0.36)	0.32 (0.33)
	No. of states	2	5	2
Other cold (not section 177)				
	BEV share (%)	18 (23)	39 (37)^	35(35)
	PEV % of registrations	0.25 (0.17)	0.22 (0.22)^	0.44 (0.44)
	No. of states	15	6	1
Total incentive category markets				
	BEV share (%)	18	38	44
	PEV % of registrations	0.23	0.24	1.57
	No. of states	20	21	8
* Virginia had mild balanced negative subsidies, 34% BEVs & 0.34% PEVs				
^ Nebraska had mild balanced negative subsidies, 16% BEVs & 0.18% PEVs				

BEV share temperature effects illustrated in Tables 1 and 2 are significant. These are discussed in detail in [11].

For this paper, the key points in Table 2 are:

Incentives generally helped BEVs gain market share (blue Total Market boxes highlighted).

Additional PEV% of registrations achieved by BEV-biased Incentives (Table 1) were accomplished primarily by increasing the share of mass market BEVs (Table 2, pink mass market rows for BEV share of the total market within the Warm states climate group and the Section 177 East cold groupings).

Though moderate temperature was theoretically important, it appears that summertime range problems of BEVs are not presently a deterrent (green box, in the Pro-BEV Incentives section of Table 2). The moderate climate states did not have a higher share of BEVs within the BEV-biased group. This may be because purchasers of 2014 BEVs are not expecting to use them for long-distance travel, so summer and winter long-distance range limitations are not critical, while winter travel limitations in everyday travel are. Digging into details − *perhaps* the fact that the share of luxury/performance BEVs drops in the warm climate states (79% vs. group average of 89%) is related to problems with summer intercity travel for the long-range BEVs in that group. Only those BEVs can seriously be considered for longer inter-city trips.

Table 2. BEV vs. PHEV success in mass-, mid- and luxury/performance markets, by incentive groups

BEV share of PEVs: States with no Incentives				
	Cold, non-177	Cold, East, 177	Warm, non-177	Total Market
Mass Market	11%	24%	29%	13%
Mid Market	37%	50%	28%	37%
Luxury/Performance	55%	88%	70%	57%
Total Market (temp.)	19%	28%	37%	**20%**
# states	15	2	3	20
Share of BEVs Within Market Segment Categories Within State Group: no Incentives				
	Cold, non-177	Cold, East, 177	Warm, non-177	Total Market
Mass Market	50%	***81%***	***57%***	***53%***
Mid Market	6%	5%	4%	6%
Luxury/Performance	44%	14%	38%	41%
Share of PHEVs Within Market Segments Within State Group: no Incentives				
	Cold, non-177	Cold, East, 177	Warm, non-177	Total Market
Mass Market	90%	98%	84%	90%
Mid Market	2%	2%	7%	2%
Luxury/Performance	8%	1%	10%	8%

BEV share of PEVs: States with Neutral Incentives				
	Cold, non-177	Cold, East, 177	Warm, non-177	Total Market
Mass Market	14%	28%	40%	29%
Mid Market	47%	43%	41%	43%
Luxury/Performance	80%	82%	78%	79%
Total Market (temp.)	26%	42%	51%	**41%**
# states	5	6	10	21
Share of BEVs Within Market Segment Categories Within State Group: Neutral Incentives				
	Cold, non-177	Cold, East, 177	Warm, non-177	Total Market
Mass Market	43%	***47%***	***53%***	***50%***
Mid Market	8%	5%	5%	5%
Luxury/Performance	49%	48%	43%	45%
Share of PHEVs Within Market Segments Within State Group: Neutral Incentives				
	Cold, non-177	Cold, East, 177	Warm, non-177	Total Market
Mass Market	93%	87%	81%	87%
Mid Market	3%	5%	7%	5%
Luxury/Performance	4%	7%	13%	8%

Table 2 (cont.) BEV vs. PHEV success in mass-, mid- and luxury/performance markets, by incentive groups

BEV share of PEVs: States with BEV-biased Incentives					
	Cold, non-177	Cold, East, 177	Warm, non-177	Moderate, West Coast	Total Market
Mass Market	29%	36%	85%	39%	45%
Mid Market	41%	64%	66%	68%	66%
Luxury/Performance	88%	91%	79%	90%	89%
Total Market (temp.)	45%	44%	85%	46%	**51%**
# states	2	1	2	3	8
Share of BEVs Within Market Segment Categories Within State Group: BEV-biased Incentives					
	Cold, non-177	Cold, East, 177	Warm, non-177	Moderate, West Coast	Total Market
Mass Market	41%	***69%***	***92%***	***70%***	***74%***
Mid Market	8%	5%	2%	8%	7%
Luxury/Performance	50%	25%	6%	21%	19%
Share of PHEVs Within Market Segments Within State Group: BEV-biased Incentives					
	Cold, non-177	Cold, East, 177	Warm, non-177	Moderate, West Coast	Total Market
Mass Market	84%	96%	86%	95%	94%
Mid Market	10%	2%	5%	3%	4%
Luxury/Performance	6%	2%	9%	2%	3%

4.2. Case-by case investigation.

Utilities of interest in this study were Austin Energy, the Sacramento Municipal Utility District (SMUD), Detroit Edison (DTE), Southern California Edison (SCE), and Duke Power. For purposes of this paper, to the extent that key factors unrelated to utility actions have been accounted for, a comparison of the PEV success rates where utilities were active, relative to nearby areas where they were not active is one indicator of success. To illustrate

the effect of this approach, note that we rate SMUD as ineffective because it has a low PEV% compared to the California average (1.4% vs. 2.8%), while Austin Energy is judged a success because it achieved 0.64%, in comparison to a state average of 0.17%. Considered on a regional basis, both California and Texas were successful.

North Carolina and Duke Energy. Duke Energy is a very large multi-state investor owned utility. We studied activities in one of the six states that it operates in, North Carolina (0.21% PEVs). In the South, Duke also serves South Carolina (0.11% PEVs) and Florida (0.29%). While neighbouring Georgia (1.00%) had one of the most successful BEV promotion programs in the nation, other surrounding states were relatively unsuccessful (Tennessee, 0.18%; Virginia, 0.26%) On average, North Carolina was unremarkable compared to surrounding states.

A feature of all three of Duke's southern states is the prevalence of many small rural or city scale municipal utilities. Duke service areas are often fragmented and inter-woven among multiple small city public utilities. Many of these public utilities list affiliation with Touchstone Energy Cooperatives. The Touchstone Energy Cooperatives brand represents a nationwide alliance made of more than 750 local, consumer-owned electric cooperatives in 46 states. No information on plug-in electric vehicles is provided on the Touchstone website. In the Charlotte metro area, where Duke serves the center-city, there were several different municipal utilities serving cities and towns in the suburbs, along with several others served by Duke. Duke was active in investigating PEVs and did discuss them on its website. However, the Duke website was hard to navigate.

When we compared results for Charlotte and Raleigh in North Carolina, Charlotte did poorly, Raleigh did well. Duke's exclusive service in Charlotte led to 0.23% PEVs, but in the suburbs the rate dropped to 0.11%. Overall, suburban Charlotte had 0.12% PEVs registered. Since Duke had a program in downtown Charlotte, while there was no metro area wide program, Charlotte proper was a relative success. The Raleigh metro area had 0.48% PEVs, well above the state average, and deserves further study. We did find that Duke was able to fill a position for a PEV programs manager in Raleigh, but not Charlotte.

California, Southern California Edison (SCE), and Sacramento Municipal Utility District (SMUD). In contrast to North Carolina, California had a coordinated PEV Collaborative, with major utilities working together with many other stakeholders. This collaboration involved both investor-owned and municipal utilities. To the best of our knowledge, with the possible exception of Michigan, there was no similarly comprehensive organization of state utilities in any other states. With a well-coordinated strategy among state utilities adding to the strongest and longest lasting incentives package (ZEV regulations) of any state, California led the nation in PEV% (2.83%) by a wide margin. In comparison to other utilities in other states, SMUD did well, at 1.4% for its service territory Sacramento. Compared to its suburbs, which had a 2.2% PEV share, SMUD did poorly. Also, relative to California as a whole it did not do so well. The suburbs of Los Angeles, primarily served by Southern California Edison, had a 2.5% PEV share, predominantly PHEVs (65%) Center-cities Los Angeles and Long Beach had 1.8% PEVs, more than the center-city Sacramento. The Los Angeles / Long Beach PHEV share was high, at 57%. Sacramento had 41% PHEVs. Its suburbs had 54% PHEVs. Sacramento did have a lower income than Los Angeles, San Francisco, or San Diego.

Inside California, and therefore the U.S. as a whole, the most successful metro area by far is San Francisco, at 5.3% PEVs, 48% of which are PHEVs.

In 2013 SMUD prepared a report for the U.S. Department of Energy and General Motors, estimating average incremental infrastructure integration costs of charging at kW rates from 1.4 to 19.2 kW [16]. They illustrated sharply higher costs for those PEVs that would be charged at rates of 6.6 to 19.2 kW (several BEVs), in comparison to 1.4 to 3.3 kW (all PHEVs, some BEVs). Unlike Austin Energy (see below), SMUD did not adopt a 2014 residential infrastructure installation program. Although the California Public Utilities Commission ruled that Investor Owned Utilities in California could not rate base charging infrastructure installation, this ruling did not apply to SMUD, a public utility. Sacramento is an inland metro area that does have hotter summer conditions than the larger coastal metro areas, so warm weather range issues could have been a problem.

Austin Energy. Where Texas had a lower share of PEVs in all vehicle registrations than its "warm states with balanced subsidy" group (0.17% vs. 0.31%), it did very well compared to surrounding states: Oklahoma (0.02%). Louisiana (0.05%), Arkansas (0.06%) and New Mexico, a western section 177 state (also 0.17%). Incentives in

Texas look effective when compared to surrounding states. Austin Energy is largely a municipal utility serving the center city of the Austin metropolitan area. Austin Energy had an aggressive residential EVSE subsidy program that installed Level 2 chargers. Axsen and Kurani's survey of potential PEV buyers indicated that level 2 EVSE increased the chances of purchase of a BEV instead of a PHEV [15]. With the assistance of its EVSE installation incentives, the city of Austin had a 0.64% PEV share, far above the Texas share. In contrast to SMUD, which had a lower PEV% of registrations than its suburbs, Austin had considerably more than its suburbs. Collectively, the suburbs surrounding Austin, some partly served by Austin Energy, had a 0.39% PEV share. Consistent with the predictions of Axsen and Kurani, the EVSE assistance increased the Austin BEV share to 60%, while encouraging BEV sales in the entire metro area. In the suburbs the BEV share was a still high 58%.

Unlike any utility we studied, Austin Energy made a reduced rate available for charging PEVs that did not require the PEV owner to pay more for air conditioning of the house. There was an extreme penalty for the whole house if the PEV was charged on peak. It was made clear that overnight charging was the only acceptable time to charge. Submetering, a relatively inexpensive way to separately measure PEV charging, was used by Austin Energy.

Detroit Edison. The Michigan Public Utilities Commission worked closely with Michigan cities and utilities. There were no state incentives in Michigan. However, Michigan was the most successful state among cold weather states without subsidy, achieving a PEV% share of 0.54%. Detroit proper had a PEV share of 0.66%, while the suburbs had a share of 0.59%, nearly the same as the state average. Rather than promote BEVs or residential charging installations, Detroit Edison emphasized on its website that PHEVs could routinely be charged with existing plugs. Surrounding states were far less successful: Ohio 0.19%, Indiana 0.22%, and Wisconsin 0.23%.

The PHEV share in Michigan was higher than for any other state. Despite the fact that only four Prius PHEVs were registered in the Detroit Metro area, 93% of PEVs were PHEVs. 98% of the Detroit Metro PHEVs were manufactured by either Ford or General Motors.

5. Conclusions/Findings

- Cold climate was a deterrent to PEV success in general, and mass market BEV success in particular.
- Comprehensive incentives led to higher PEV shares of all registrations and higher shares of BEVs within PEVs.
- BEV-biased incentives were very effective in increasing the sales of mass market BEVs. Luxury/performance and mid-market BEVs were less affected.
- Collaboration among utilities within a state may be very important. The state with the best collaboration, California, had the highest PEV share. This collaboration involved both investor-owned and municipal utilities.
- Lack of coordination between a large investor owned utility (Duke Energy) and small municipal utilities is a candidate explanation for low PEV market penetration in North Carolina
- The utility judged most successful in the North, Detroit Edison, succeeded by encouraging PHEVs. A utility judged highly successful in the South, Austin Energy, promoted BEVs.
- Austin Energy's success was associated with subsidy of residential EVSE in conjunction with a rate providing a reduced PEV-charge electricity price, but requiring an extreme whole house price penalty for daytime charging, with no increase in cost of electricity for air conditioning.

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