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Electric Vehicles: Holy Grail or Fool's Gold

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Abstract

Abstract—Our analysis shows that there is likely to be minor short term risk or reward for electric utilities with respect to electric vehicle adoption, but also that significant long term value or risk exists, depending on how judiciously utilities manage pricing, charging and infrastructure. The margin of difference between profit and loss lies with the extent to which customer adoption is clustered, whether customers demand faster charging times, and how utilities are able to insure optimal charging times are met, relative to existing system utility peak loads. Customer car purchases are likely to cluster geographically within neighborhoods. Customers appear to want fast charging and convenience, albeit within some price tolerance. And once established, a robust PEV market may be difficult to keep up with, in terms of infrastructure additions, if ignored for too long. We share several methodological innovations and results to address these questions including Bass model market forecasting, consumer choice simulations, mapping spatial adoption and forecasting, and profitability assessment over various time and location based criteria.

Keywords: Electric-drive, sales, Load Management, Off-Peak, EV (electric vehicle), Smart grid, Modelling

Nomenclature

PHEV	–Plug-in Hybrid Electric Vehicle
PEV	–Plug-in Electric Vehicle
EV	–Electric Vehicle
LoadSEER	–Load Spatial Electric Expansion and risk

1. Introduction

This paper considers the impact of PEV's on long-run distribution (T&D) infrastructure planning, focusing on Cincinnati Ohio and Charlotte North Carolina within the Duke Energy service territory. Specifically we (a) forecast the adoption rates of various vehicle types across specific customer segments, (b) forecast the future location of these customer segments, including which ones appear to be clustered in certain regions (e.g., small EV usage within university areas), (c) employ long run LoadSEER® spatial forecasts of the likely placement of these future loads, and (d) identify the penetration threshold rates for various regions, above which existing T&D capacity is insufficient. The study considers the impact on time and location uncertainties in creating local or regional constraints on the grid, the requirement of new electric capacity, the timing of that capacity need, and the spatial clustering of the potential mismatch. The results reveal that several factors contribute to the risk, or value, of electric vehicle adoption. Further, LoadSEER® analysis suggests that significant spatial clustering, given customer segment adoption patterns, is likely to pose significant risks to certain areas where clustered adoption exceeds existing T&D infrastructure.

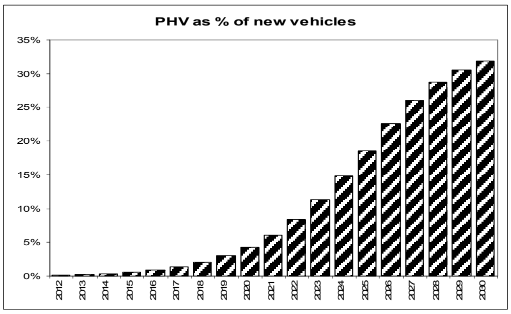
2. Technical Work Preparation

2.1. Initial number of PEVs

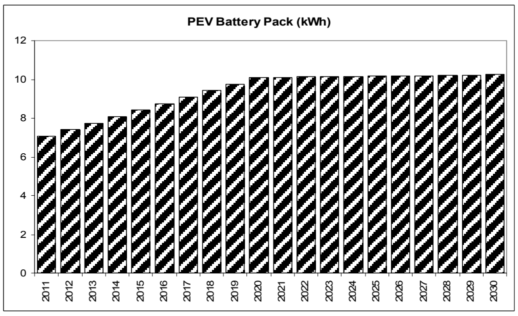
The total number of announced PEVs in production by 2011 from major automobile manufacturers in the United States is about 100,000. Since Duke Energy's residential population is roughly 3.7% of US population, we start with the reasonable assumption that about 3,700 PEVs exist in the study area in that year. Of course, this initial estimate depends on several factors, mostly externally driven (e.g., oil prices, consumer behavior, governmental intervention, car production goals), but 3,700 cars in 2011 is not an unreasonable short run forecast with which to begin to explore the consequences and trends that might emerge over the long run.

2.2. Penetration and usage forecast

We use commonly accepted Bass model[i] forecasting principles such that by changing the innovation and imitation variables that drive the Bass Model, we match the initial number of estimated adopted vehicles to the expected initial estimate of PEVs in the study area. At the same time, we modify the adoption rate so that it resembles adoption of Hybrid vehicles that we have experienced within these areas in the past eight years. The resulting model forecasts



Graph 1 - Market penetration using Bass model



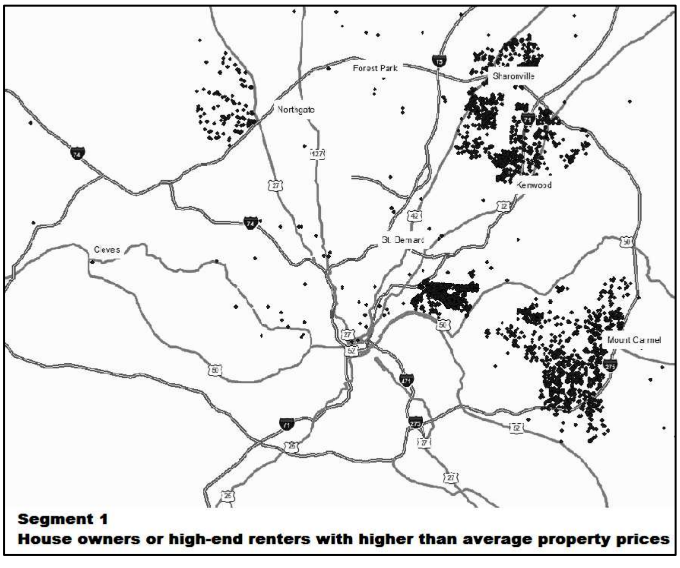
Graph 2 – Assumption for an average battery pack

penetration percentage as total number of new vehicles in the market (Graph 1). Note that government intervention would increase the rate of adoption through the innovation parameter, whereas increased oil prices would likely increase adoption not only through innovation (motivating early adopters), but also through the imitation parameter (as evidenced via word of mouth communication between adopters).

Considering the current state of the US economy as well as the current cost of batteries, we anticipate that most early PEVs will have smaller battery packs, but will gradually increase in size to satisfy the needs of average families for full EV daily driving without the need for charging during the day (Graph 2). According to US Department of Transportation Federal Highway administration data, there are 0.69 vehicles per person[ii] which we use to calculate total number of vehicles in the study area. This is likely a conservative estimate for cities with limited mass transit, like Cincinnati and Charlotte, but nonetheless a reasonable assumption in this case. Combining penetration of PEVs with average expected battery packs for each vehicle, as well as total number of vehicles in the road, yields total annual energy (GWh) used by PEVs. Note that this model forecasts Usage of PEVs in the study area regardless of physical location of these vehicles; spatial segmentation and scoring will help us pinpoint the location of this load.

2.3. Segmentation

A series of consumer research methods was employed to determine the relative appeal of PEVs, hybrids and alternative transportation modes to area consumers, including paired comparison computerized adaptive conjoint analysis, discrete choice methods, and Chi-Square Interaction methods. Differences and key drivers were assessed for both existing purchases (e.g., existing hybrids) as well as futuristic vehicles described as a combination of textual attributes (e.g., all electric, 90 MPG, 80mph top speed, charging available only at night). Demographic and attitudinal information were also collected, with which demographic segments were developed consistent with each group's tendency to prefer certain types of PEV functionality, charging rates,



Graph 3 – Potential Plug-in Electric Vehicles adopters are tightly clustered within our study area convenience, MPG, MPH and other vehicle characteristics. Not surprisingly, several of these preference clusters are clumped together, suggesting that similar vehicle characteristics appeal to similarly situated consumers (see Graph 3). This tendency indicates the locational importance of PEV planning to the extent that fast charging vehicles are adopted more readily in certain neighborhoods over others. Ideally, knowing where PEV adoption is occurring and at what rate will make infrastructure planning more efficient and effective.

2.4. Scoring households

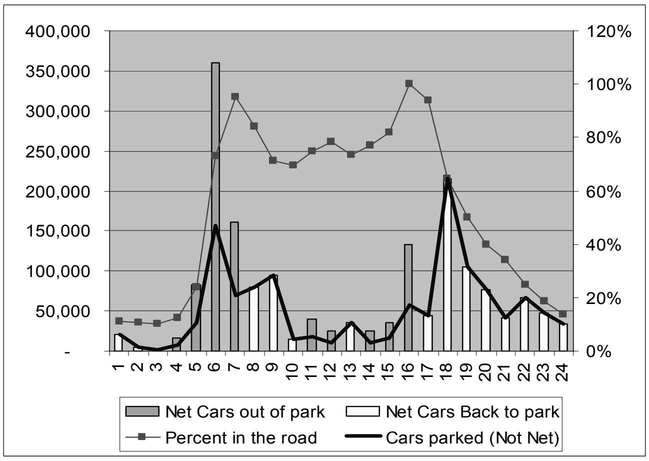
To determine the effect of added load in electric transmission and distribution systems, we identified which households are more likely to adopt plug-in electric vehicles using a scoring system related to their observed choices within the consumer research in Section C. Note that the given score is not a probability per se, but more like the way financial companies score credit holders. It simply ranks residential customers in the study area based on their desire to adopt a PEV. Scoring is done using a non-linear regression model with segments denoted as dependent variables and household demographics and segment identifiers (binary) as independent variables. The numbers in this model pertain to residential households where segments are ranked by likelihood, and we normalize its output between zero and one, termed a PEV score.

2.5. PEV daily load shape

In order to have a better understanding of the effect of PEV at the time of system peak (coincident peak), we need to know the hourly distribution or load shape associated to daily usage of PEVs. The Federal Highway Administration maintains records of both forecast and historical traffic patternsiii. The total number of vehicles used daily to "work away from home" and the travel time to work is shown in the following histogram for most "Metropolitan Statistical Areas" (MSAs)iv. The number of vehicles "back to parked" and "out of parking" is calculated from the percentage change in the number of vehicles on the road for a given hour. In addition, knowing travel time will let us calculate total number of vehicles that are parked at each hour (Table 1 and Graph 4). We used charging characteristics of a Li-ion battery, in this case, since it is the battery choice for most PEVs. Furthermore we assumed 110 volt and a 50 Amp circuit breaker with five hours slow charging, in spite of significant customer's tendency toward fast charging as revealed in the consumer behavior research. Future efforts will focus on more closely aligning desired battery performance with consumer appeal.

Hour	Percent in the road	Percent Change	Net Cars Back to park	Net Cars out of park	Cars parked (Not Net)
1	11%	-3%	20,644	-	20,644
2	10%	-1%	4,697	-	4,697
3	10%	0%	986	-	986
4	13%	2%	-	16,932	7,366
5	24%	11%	-	82,749	35,996
6	73%	49%	-	360,163	156,671
7	95%	22%	-	160,800	69,948
8	84%	-11%	79,907	-	79,907
9	71%	-13%	94,056	-	94,056
10	70%	-2%	14,091	-	14,091
11	75%	5%	-	39,490	17,178
12	78%	3%	-	24,413	10,620
13	73%	-5%	34,793	-	34,793
14	77%	3%	-	25,399	11,048
15	82%	5%	-	35,779	15,564
16	100%	18%	-	132,560	57,664
17	94%	-6%	44,187	-	44,187
18	64%	-29%	215,367	-	215,367
19	50%	-14%	105,306	-	105,306
20	40%	-10%	76,138	-	76,138
21	34%	-6%	41,403	-	41,403
22	25%	-9%	65,816	-	65,816
23	19%	-6%	47,028	-	47,028
24	14%	-5%	33,865	-	33,865

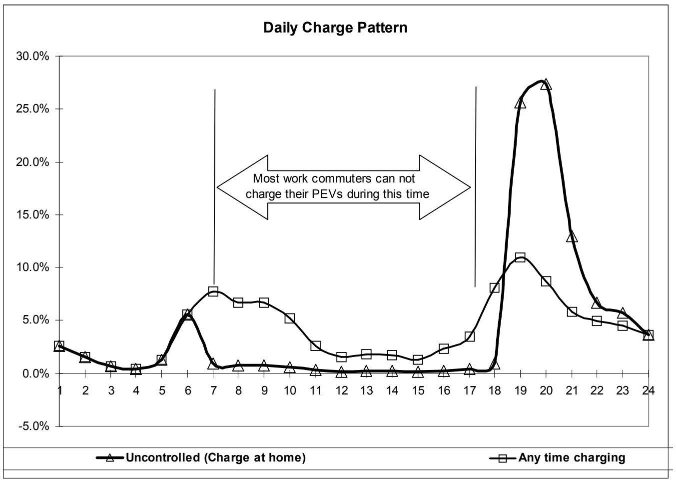
Table 1 – Hourly traffic data



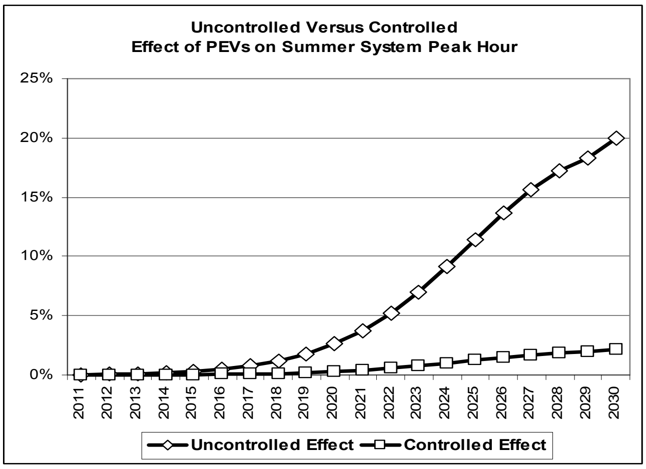
Graph 4 – Percent of vehicles parked and ready to be charged

2.6. Controlled versus Uncontrolled

In an ideal situation we would have charging stations in any parking place so the vehicles could be charged any time they are parked. Such a charging shape is shown in graph 5 as "any time charging" which is a combination of the percent of vehicles parked and the Li-Ion charging shape. Because there are none, or few, charging stations available during the first years of PEV adoption, most work commuters will not have the chance to charge their PEVs before coming back home from work. Federal Highway Administration statistics shows that less than 3% of people work from home, 6% use public transit or walk to their work place, 13% carpool and about 81% use their private vehicle to drive alone to work[v]. Using unemployment data we calculated population share of work commuters who drive to work alone. Then we moved their charging needs to when they likely come home from work to generate the second curve in graph 5 called "Uncontrolled Charge at Home)". Once PEV adoption exceeds some market share threshold, afternoon peaks in such a scenario can quickly increase to be rather significant compared to current system peaks, especially for summer afternoon peaking utilities (see Graph 6).. Such a PEV load shape can be very costly for utilities both because of high cost of peak generation as well as its substantial burden on transmission and distribution systems during peak hours. It is natural for utilities to desire to mitigate and "control" this risk by shifting this load to off-peak use either using time of use pricing or in-home control devices that allow for off peak charging or discharging. In its optimal form utilities would shift most of the evening charging load to early hours of the next day as shown in graph 6 "Controlled (off peak charging)". However, consumers are likely to also demand some minimum charge level capability upon return from work to insure the vehicle is available for emergency service or some other driving need.



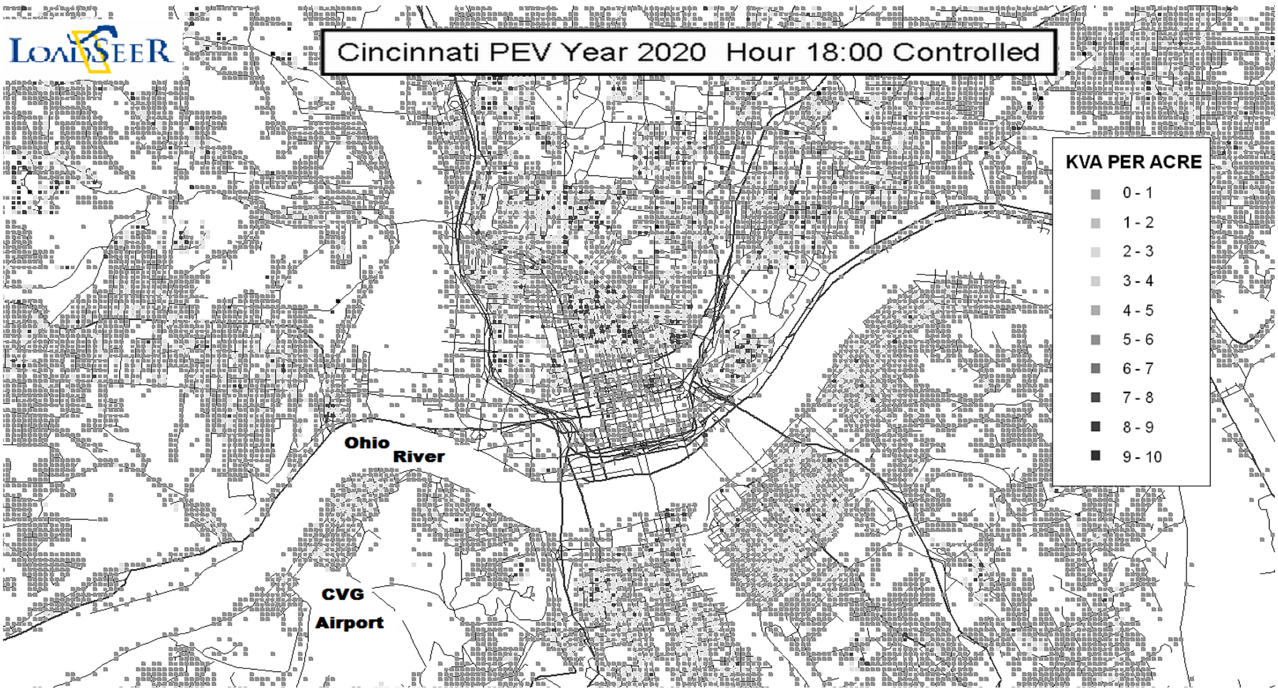
Graph 5- Afternoon peak due to lack of charging station during work hours



Graph 6 –Uncontrolled versus controlled charging as percent of coincident system peak

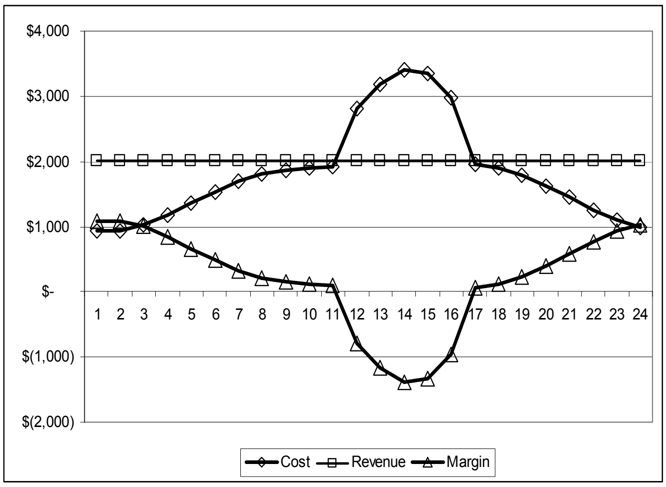
2.7. Spatial PEV load analysis

Interestingly, many consumers appear to have some interest in being able to charge at home vs. going to charging stations, as revealed through consumer research within Duke Energy. By combining expected energy needs (GWh) from the Bass model forecasts with either Controlled or Uncontrolled load shape impacts, we estimate hourly energy needs using residential scores over a forecast time horizon. This hourly energy is distributed between residential customers using LOADSEER® spatial load forecasting software and depicted in Graph 7. PEV hourly load per acre



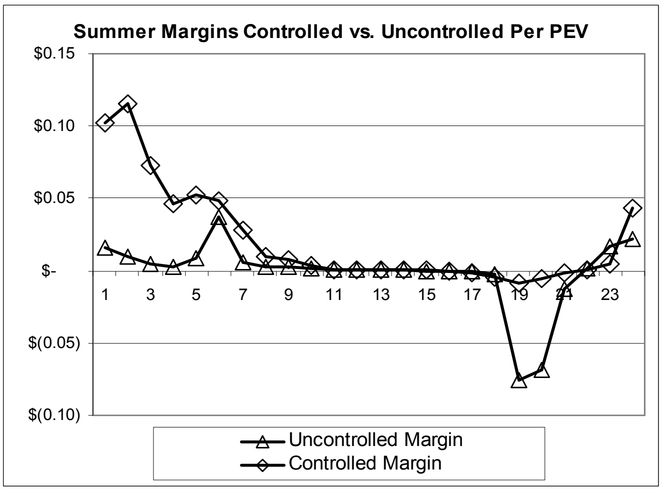
Graph 7 –KVA impact of PEVs per acre during afternoon peak hour fore baseline penetration in year 2020 using LOADSEER®

density increases are calculated for every hour for the next twenty years. Graph 8 represents hourly utility of a 15kW battery pack without



Graph 8 – Utility view of 15kWh battery pack with flat load shape

taking load shapes into account and assuming equal load for each hour of day. It shows good potential earnings if time of day charging can be managed but on peak charging costs are too high which signals need for "Time Of Use" price structure relative to current flat rates. Net Present Value for a seven year car battery is between $500 and $900 if Time of Use pricing and charging / discharging can be managed. Next, we calculated hourly generation costs by escalating ECAR average summer market price using Economy.com's "Producer price index electricity power" index to generate future hourly costs, and



Graph 9 – Controlled versus Uncontrolled margins considering load shapes

then estimate hourly margins using internal Duke Energy's residential tariffs, assuming a car begins its charge in each of 24 five hour charging patterns.

The outcome of forecasting margins can be significantly altered depending on whether utilities adopt a way of mitigating the afternoon peak risk or not as shown in graph 9.

3. Conclusions and future work

Although electric utilities are likely to see both risks and rewards related to the future adoption of electric vehicles, it is clear that the value or risk inherent in this emerging market lies with the utilities' abilities to successfully manage localized distribution issues, Time Of Use (TOU) pricing, charging venues, and infrastructure management. Failure to manage these issues may temper or slow the adoption of electric vehicles. An established and robust PEV market may be difficult to support and maintain, if ignored for too long or if inadequately planned.

Forecasting areas of local clustered adoption, increased understanding of customer preferences for higher voltage fast charging options, pricing hourly usages to shift potential new peak loads and fully integrating the risks and value into long term plans appear to lie at the heart of future prudent planning.

And increased collaboration between utility or charging providers and vehicle manufacturers will further enable the shared development of the infrastructure which is necessary to establish a scalable platform for electric vehicle adoption.

Acknowledgments

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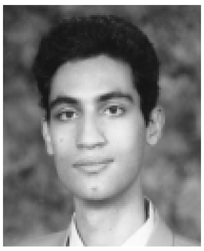
Biographies

Dr. Richard G. Stevie received a Bachelor's degree in Economics from Thomas More College in May 1971, a Master of Arts degree in Economics from the University of Cincinnati in June 1973 and Ph.D. in Economics from the University of Cincinnati n August 1977. His past employers include the Cincinnati Water Works, the United States Environmental Protection Agency's Water Supply, Economic Research Division of the Public Staff of the North Carolina Utilities Commission and Duke Energy's Managing Director of the Customer Market Analytics. In addition, since 1990 he has chaired the Economic Advisory Committee for the Greater Cincinnati Chamber of Commerce. He has been a part-time faculty member of Thomas More College located in Northern Kentucky and the University of Cincinnati teaching undergraduate courses in economics. In addition, he is an outside adviser to the Applied Economics Research Institute in the Department of Economics at the University of Cincinnati as well as a member of an advisory committee to the Economics Department at Northern Kentucky University.



Pedram Mohseni was born in Iran in 1971. He graduated from Allameh Tabatabaie University with BA in Economics. Pedram received William Taft scholarship award in year 1999 from University of Cincinnati where he graduated with an MA in Applied Economics and MS in Information Systems. He joined Duke Energy in year 2001 where he is load forecasting senior analyst.

His special fields of interest included Hourly System Load Forecasting and using Neural Network as well as traditional non-leaner solutions, Load simulation and long term system load forecasting.

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[ii] http://www.fhwa.dot.gov/ctpp/jtw/cha_graph.htm http://www.fhwa.dot.gov/ctpp/jtw/cin_graph.htm

[iii] http://www.fhwa.dot.gov/environment/airtoxic/msatcompare/figure1data.htm

[iv] http://www.fhwa.dot.gov/ctpp/jtw/contents.htm

[v] http://www.fhwa.dot.gov/ctpp/jtw/cha_mtw.htm