Macro-scale Siting of Plug-in Electric Vehicle Infrastructure for the North Coast of California

Schatz Energy Research Center
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Introduction

Plug-in electric vehicles (PEVs) present a compelling opportunity for our nation to drastically reduce emissions of both greenhouse gases and criteria air pollutants in the transportation sector. Optimal deployment of electric vehicle supply equipment (EVSE) – or PEV charging infrastructure – is a critical component to accelerating the adoption of PEVs. It will provide the greatest benefit at the least cost, ensuring efficient use of private and public funds.

The Schatz Energy Research Center (SERC) is currently a project partner and technical lead on two California Energy Commission/Public Interest Energy Research (CEC PIER) planning grants (PON-10-602) with the objective to develop regional plans to support PEV readiness[1]. One of the principal questions that SERC has addressed is how to deploy EVSE in a cost-effective manner. This is a complex question to answer with a data-driven, quantitative analysis. Where do PEV drivers live? Where do they drive? How long do they spend at their destinations? How do drivers adapt when they need a charge but no station is available? These and other issues require that planners use the best available region-specific data and account for the interactive effects of multiple PEV drivers simultaneously vying for limited chargers in public venues.

The research team at SERC has developed a unique and powerful approach to evaluate the deployment of EVSE. We built an agent-based micro-simulation model called PEVI, the PEV Infrastructure Model. Individual PEV drivers ("agents") are simulated as they conduct their travel and interact with virtual EVSE. Drivers begin a day with a vehicle, an itinerary of trips, and a set of rules for how to behave. The simulation is started and evolves according to individual driver behaviors and interactions with the EVSE network. The results can be analyzed from a perspective of total omniscience over the day's events.

The model can be used by planners and policy makers as a test bed for a variety of purposes: EVSE can be optimized to maximize service to PEV drivers under a fixed budget; tradeoffs between competing policy goals can be examined, such as subsidizing larger batteries vs. installing more EVSE; and vehicle-to-grid technologies can be evaluated before deployment.

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This document is a summary of the planning analysis that SERC conducted for the North Coast Region, including a description of the agent-based micro-simulation model and how it was used to site PEV charging infrastructure for the region.

Planning PEV Infrastructure on the North Coast Region

The objective of SERC's modeling analysis was to develop an infrastructure deployment plan for the North Coast Region (the counties of Humboldt, Del Norte, and Trinity). The plan includes macro-level (i.e. city or neighborhood level) guidelines for the number and type of electric vehicle chargers needed throughout the region to support a given penetration of electric vehicle sales. An estimate of infrastructure costs and a plan for a phased rollout over time is provided.

The North Coast Region

The North Coast Region is located in the far northwest region of California (Figure 1). The region is rural, yet Humboldt County boasts a relatively large penetration of hybrid electric vehicles (HEVs). In 2012, seven percent of new vehicles registered by Eureka residents were hybrids, the sixth highest rate of adoption in the nation[2]. Based on this pattern, it is expected that the adoption of PEVs in Humboldt will also be among the fastest in the nation.

Figure 1: The North Coast Region is composed of three counties: Humboldt, Trinity, and Del Norte.

[2] http://blog.polk.com/blog/blog-posts-by-tom-libby/large-variation-in-hybrid-and-electric-vehicle-mixes-across-different-metropolitan-areas

The Research Challenge

Our task was to develop a robust and comprehensive set of recommendations for the deployment of EVSE throughout the region for varying levels of PEV adoption. The project team accomplished this by answering the following key questions. How many chargers are needed for a giving penetration of PEVs? Where should the chargers be located within the region? Should Level 2 chargers or Level 3 chargers[3] be installed? How can the deployment be achieved in a cost-effective manner given limited resources for new infrastructure?

Answering these questions required that the following considerations all be taken into account:

- How many PEVs do we expect in our region?
- Where within the region will the PEV drivers live?
- When do PEV drivers make their daily trips? Where and how far do they go?
- How long do drivers spend at each stop in their tour?
- If drivers have a choice of EVSE to use, which will they choose?
- How do drivers impact each others' access to EVSE?
- How will drivers who must charge (in order to complete their tour) be impacted by other drivers who elect to charge despite having no immediate need for the energy?
- How do drivers adapt to their circumstances (e.g. by seeking EVSE elsewhere)?
- How will a given deployment of EVSE improve the experience of drivers? Can we quantify the improvement (e.g. in terms of the number of hours of delay experienced by drivers)? If so, by how much does the EVSE improve their experience?

Our team managed the complexity of this problem by building a detailed simulation model called PEVI, the PEV Infrastructure model. PEVI is capable of *simultaneously* balancing all of the above considerations. The approach is called "agent-based modeling", and it provides a flexible and powerful framework for evaluating the impact of infrastructure on PEV drivers' experiences. The following section describes PEVI in further detail.

PEVI – The Agent-Based PEV Infrastructure Model

Building any agent-based model consists of the following key steps:

1. Create a virtual environment.

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[3] EVSE are categorized by their voltage level and, therefore, the rate at which they can deliver charge to a PEV. Level 1 chargers are 120V and can charge a Nissan Leaf from empty to full in ~16 hours. Level 2 chargers are 240V and charge a Leaf in 6-8 hours, while Level 3 chargers are over 400V (and are direct current) and can deliver a full charge in less than an hour

2. Create virtual agents with a set of rules describing how to interact with the environment and with each other.
3. Place the agents in the environment and let the system evolve according to the rules.
4. Observe what happens.

In the case of PEVI, the environment is the Humboldt County road network[4], including any configuration of EVSE infrastructure we'd like to evaluate. The agents are the PEV drivers. Drivers interact with the environment according to the following rules:

- Every driver is given a vehicle with configurable properties such as type (battery electric vehicle or BEV vs. PHEV), battery capacity, and fuel economy.
- Each driver follows a unique daily itinerary, or a table of times and destinations defining when and where he or she will attempt to travel.
- If drivers need energy to complete their next trip (or, in some cases, to complete the remaining trips in their itinerary) then they attempt to charge. PHEV drivers are assumed to never *need* a charge because they have a gasoline backup with established refueling infrastructure.
- Both BEV and PHEV drivers also attempt to charge even if they don't need the energy. This occurs according to a random process.
- Drivers choose which EVSE to use based on minimizing their cost. This decision places a value on the driver's time of $12.50/hour[5], which is included in the accounting if the driver must make an unplanned stop or is delayed.
- Both BEV and PHEV drivers have a charger at home and elect to charge at the end of the day according to a random process.

The model simulates one day of driving, and any delays or changes to driver itineraries are tracked. At the end of a model run, the experiences of individual drivers can be examined, or the entire run can be summarized by a variety of metrics (e.g. the total number of drivers who experience delay in their itinerary).

PEVI is a stochastic model, meaning that a variety of processes and decisions within the model are based on random chance. The primary purpose of including stochastic processes in PEVI is to avoid reaching conclusions that are overly customized to suit one particular scenario. Instead, the model is run many times with the same set of initial conditions and the *average benefit* of a given EVSE infrastructure is calculated.

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[4] The research team was unable to include Del Norte and Trinity Counties in the PEVI model due to a lack of data and limited project scope and budget. The EVSE guidelines for these counties were instead developed based upon the results of Humboldt analysis.

[5] The value of $12.50/person-hour is based on the Caltrans Economic Analysis Branch and is used by the state of California to account for the economic value of delaying travellers. http://www.dot.ca.gov/hq/tpp/offices/eab/benefit_cost/LCBCA-economic_parameters.html

The North Coast Plug-in Electric Vehicle (NCPEV) team took great care to use the best available regional data sets to ensure that PEVI simulations were as realistic as possible. These data are described in the following section.

Data Driven Planning

The quality of the results of the PEVI model is inextricably tied to the quality of the inputs used to initialize the model. For example, the driver itineraries must be carefully developed to represent a realistic set of trips that follow known driving patterns specific to Humboldt County. This section identifies several of the most important data sets and describes how they were used in this research.

Transportation Demand

The most critical component to building a set of realistic driver itineraries for PEVI is determining where drivers go when they travel. Fortunately, regional travel demand data are available for Humboldt County in the form of the Greater Eureka Area Travel Model (GEATM). The GEATM has been developed and refined for the Humboldt County Association of Governments (HCAOG) for use in a variety of transportation planning activities at HCAOG and Caltrans. The model uses current and projected land-use data, demographic data, and local traffic counts to forecast traffic trends to the year 2020.

National Household Travel Survey

While regional travel demand data are necessary to build realistic driver itineraries, there are some critical missing components to the GEATM data set. It provides no information about exactly when trips are made, how long drivers spend at their destinations, where the drivers live, or what trips drivers chain together into a daily tour. The National Household Travel Survey (NHTS) fills in many of these missing components, albeit at an aggregated national level.

The NHTS is a survey conducted by the U.S. Department of Transportation. The last survey year was 2009, when over 150,000 households participated. Every respondent provides a log of all travel in a day, including non-automotive modes. Each log details the time of departure, time of arrival, time spent at the destination (dwell time), distance traveled, and trip type (home to work, work to other, etc.).

The PEVI itineraries were generated by strategically blending the NHTS and GEATM data sets. Respondents were drawn randomly from the NHTS pool and their tour was fit into the Humboldt Road network in a manner consistent with the demand for trips as specified by the GEATM.

PEV Adoption Projection

The historical adoption of HEVs is the best available indicator for the rate of adoption of PEVs over the next decade. We acquired vehicle registration data for Humboldt County over the decade from 2003-2012 and assumed that PEV penetration in 2012 corresponds to HEV penetration in 2003. Other PEV readiness projects in California have projected adoption using similar assumptions (Williams et al., 2012) and a study by Pike Research predicted penetration levels consistent with our forecast (Hurst & Gartner, 2012).

Figure 2 depicts our projection of PEV adoption in Humboldt. The baseline projection follows the historical trend of HEV adoption. Two accelerated growth scenarios are also presented, representing increased rates of adoption: 10% and 25% faster than the baseline scenario. Three time intervals are emphasized in the figure. They are the intervals over which the various growth scenarios intersect key penetration levels (0.5%, 1%, and 2%). In other words, we expect that PEV penetration will reach 0.5% by 2015, but it could occur as soon as 2014 if adoption rates are accelerated. Likewise we expect PEV penetration to reach 1% between 2017 and 2019 and 2% between 2023 and 2026.

The three adoption levels from
Figure 2 – 0.5%, 1%, and 2% – form the basis for all of the model analyses conducted for this study. In order to effectively support PEV drivers and encourage adoption, planners should target the deployment of EVSE infrastructure to be completed before adoption actually reaches these levels. Hence, the earlier end of each time interval should be interpreted as a target year for EVSE deployment. This would be 2014 for 0.5%, 2017 for 1% and 2023 for 2%.

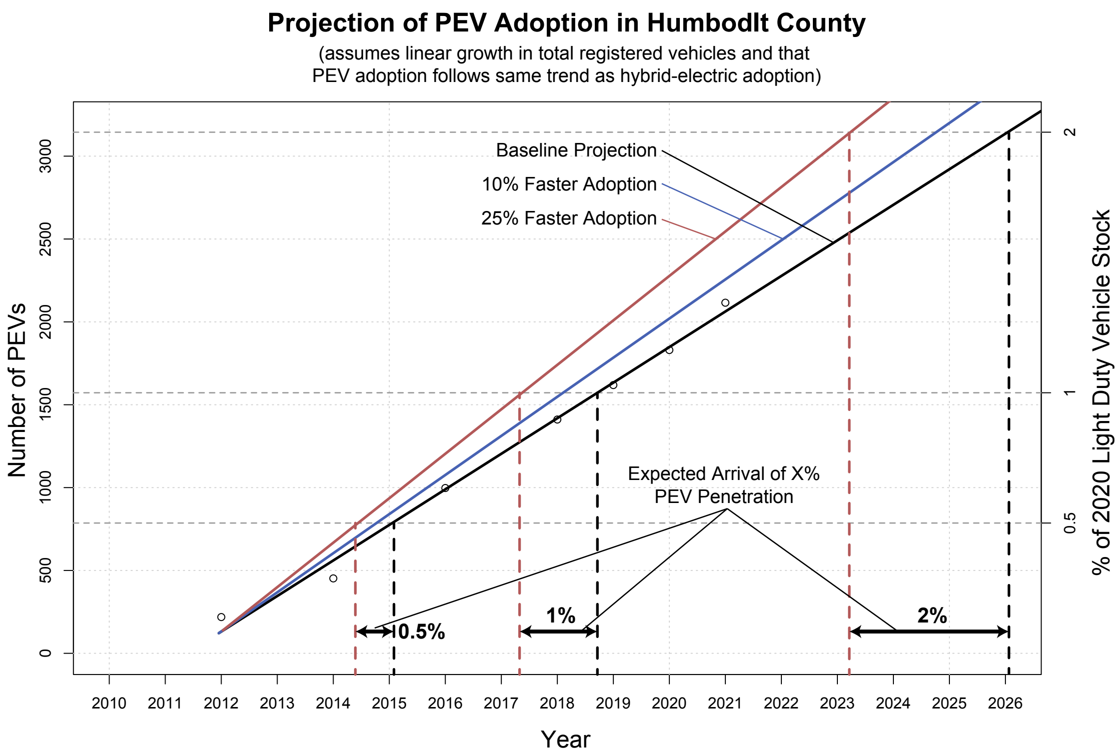


Figure 2: Using vehicle registration data for Humboldt County, PEV adoption is projected as far out as 2026.

Adoption of BEVs vs. PHEVs

From the perspective of deploying EVSE infrastructure, the rate of adoption of battery electric vehicles (BEVs) compared to plug-in hybrid electric vehicles (PHEVs) is vitally important. BEVs require public EVSE in order to complete certain types of travel, whereas public chargers are entirely optional for PHEV drivers. At the same time, the presence of PHEV drivers who may elect to charge in a public venue will have an impact on the availability of infrastructure for use by BEV drivers.

The market for PEVs is still in its infant stage, but current trends are the best available indicator of future growth. Currently, the most popular PEV on the market is the Chevy Volt, a PHEV, having sold 23,461 units nationally in 2012. By comparison, the Nissan Leaf, a BEV, only sold 9,800 units during 2012 (Valdes-Dapena, 2013). As a wider variety of BEVs and PHEVs enters the market, these market trends could continue or change dramatically. So the NCPEV team has modeled a 50% / 50% split between BEVs and PHEVs in the PEVI model for the base scenario. This represents a conservative assumption, as we can be certain that EVSE infrastructure built to support a higher fraction of BEV owners will be adequate to support a lower fraction.

Cost of Installing and Using EVSE

The cost of public chargers is highly site-specific. Many factors contribute to the expense, such as equipment costs, permitting fees, and construction costs. For the PEVI model it was necessary to assume an average installed cost for each level of charging. Table 1 presents our cost assumption alongside cost estimates from several recent studies.

Table 1: Cited Price Estimates of Public Charging Stations, by Source

Study Source	Level I	Level II	Level III
Chang et al. 2012	$878	$1,852	$40,000
Schroeder and Traber 2012	N/A	$6,600	$118,800
Peterson and Michalek 2013	$3,000	$5,000	$20,000
Gogoana 2010	N/A	N/A	$50,000
PEVI Cost Assumptions	**$2,000**	**$6,000**	**$50,000**

The PEVI model also requires the retail price of energy for charging at each type of EVSE. We conducted an economic analysis of operating a public charging station and chose pricing for the PEVI model that corresponds to the break-even price for a charger that is used 10% of the time, or 2.4 hours per day (Table 2).

Table 2: Energy pricing assumed in the PEVI model.

Level	Price ($/kWh)
1	0.20
2	0.34
3	0.55

Model Validation

We conducted two separate comparisons of the model predictions to real-world data to demonstrate the validity of the model. The first validation was a test of the itinerary generation algorithm. The objective of the algorithm is to produce driver itineraries that capture the relevant statistical properties of both the spatially explicit travel demand data and the temporally explicit travel survey data.

In Figure 3 and Figure 4, we plot summaries of the itineraries produced by the model and the original data from the GEATM (travel demand model) and NHTS (transportation survey). We expect these distributions to closely match since the original data were used to produce the itineraries. But it was not a foregone conclusion that the algorithm would produce itineraries that simultaneously agree with both data sets. The differences between the modeled and actual distributions are primarily due to the stochastic nature of the trip generation algorithm. For example, while the GEATM data may specify 100 trips to depart from TAZ 1, we use a random number generator to introduce variability into the number of simulated trips, using 100 as the mean value.

Other differences show that the modeling itineraries do exhibit some selection bias. Specifically, short dwell time (less than 15 minutes) are underrepresented by the modeled itineraries and, correspondingly, the longer duration dwell times are somewhat overrepresented. This difference is an artifact of the itinerary generation process, where trips from the NHTS data set are discarded if they cannot be used in a manner consistent with the GEATM demand for trips. In general, trips from the NHTS data set that had longer dwell times were more consistent with the GEATM data, and therefore are somewhat overrepresented.

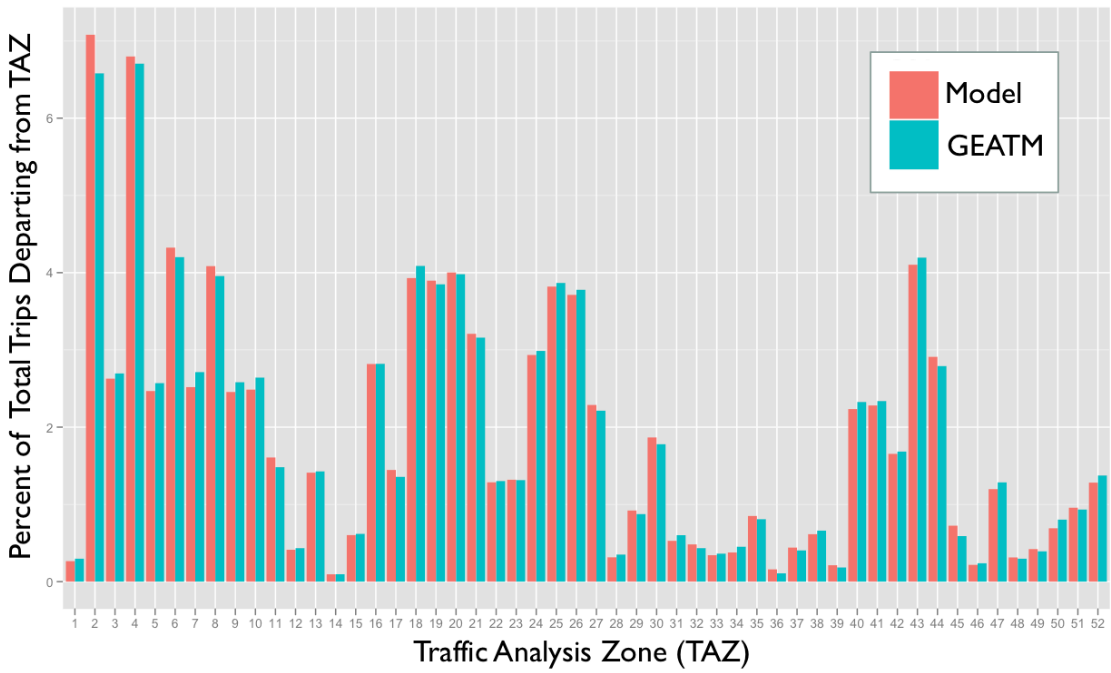


Figure 3: We compare the spatial distribution of the percent of trips departing from each TAZ in the PEVI model based on a single run of the itinerary generation algorithm. The disagreement between the values is primarily due to the stochastic nature of the algorithm.

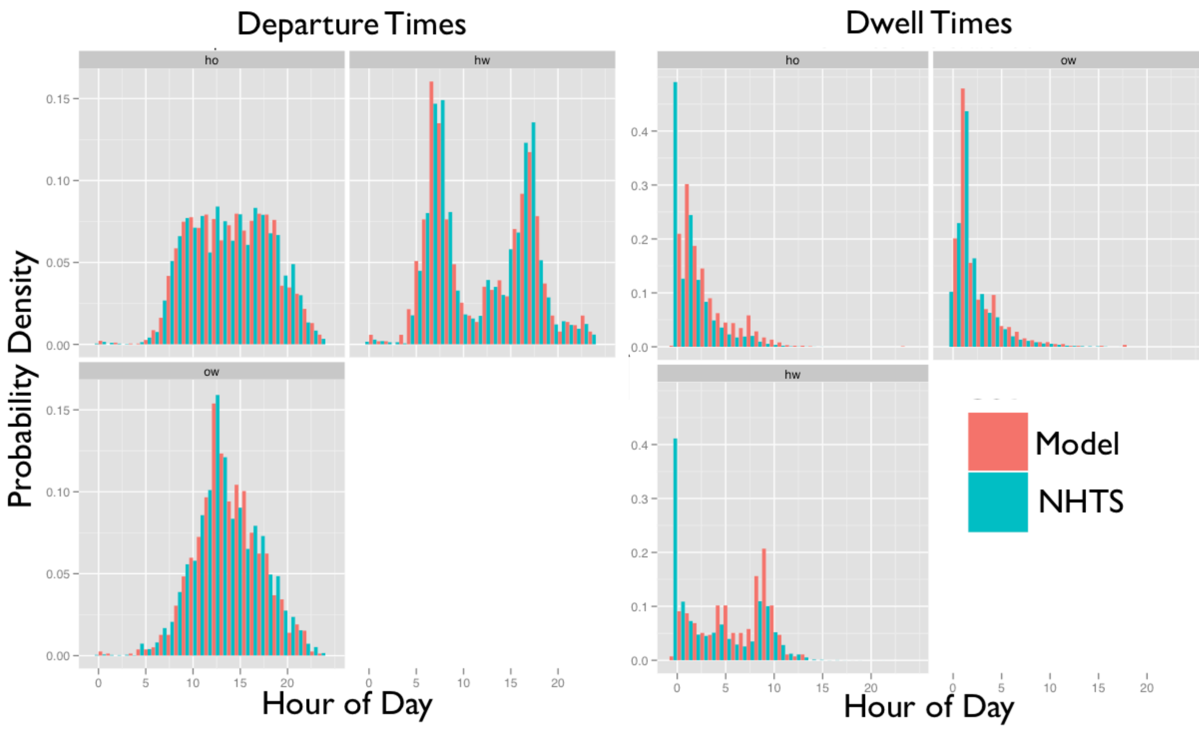


Figure 4:The temporal distribution of departure times and dwell times (time spent at each destination) are plotted for both the PEVI model (red) and the survey data (NHTS). The sub-plots show the distributions by trip type where "ho" is "home-based other", "hw" is "home-based work", and "ow" is "other-based work".

We also compare the outcomes of the PEVI model to the observed behaviors of PEV drivers as documented by The EV Project (Ecotality 2013). The EV Project is a PEV monitoring campaign funded by the U.S. Department of Energy and implemented by Ecotality, an EVSE manufacturer. Over 8000 Nissan Leaf and Chevrolet Volt owners are currently participating in the program along with over 5000 publicly available charging stations. The project reports a variety of statistics associated with the observed charging patterns of PEV owners.

To validate the PEVI model, we focus on results from The EV Project for the metropolitan area of San Francisco, as this is the most proximate region to Humboldt County geographically and culturally. We use the PEVI model to simulate conditions similar to the real-world conditions under which The EV Project data are being collected. A low penetration of PEVs is assumed (0.5%) with a limited number of public EVSE installed throughout the county (25 Level II chargers and 3 Level III chargers distributed according to traffic density). The results of the model are then summarized as plots that permit direct comparison between the charging patterns of the simulated PEV drivers and the real-world PEV drivers.

While we treat similarities between the model results and The EV Project data as a positive result, it is important to note that the PEVI model was not implemented in the same geographic region as The EV Project data. Humboldt County is a largely rural county, with very different travel patterns than a major metropolitan area. So we do not expect exact agreement between these results, but rather we use the comparison as a broad-brush validation of the model predictions.

In Figure 5, we show the distribution of battery state of charge at the beginning of each charging session observed by The EV Project and by the PEVI model. We see that the general shape of the distributions are similar, but there are some differences, most notably that the average state of charge of Leaf batteries from The EV Project data is ~50% while the model results have a higher mean value. In addition, while both the model and The EV Project results for the Volt show that a predominant fraction of vehicles begin charging at 0% state of charge, the residential distribution from the model has a smaller fraction than the EV Project results and the rest of the distribution is centered around a higher state of charge, 60-80% versus 40-60% for The EV Project.

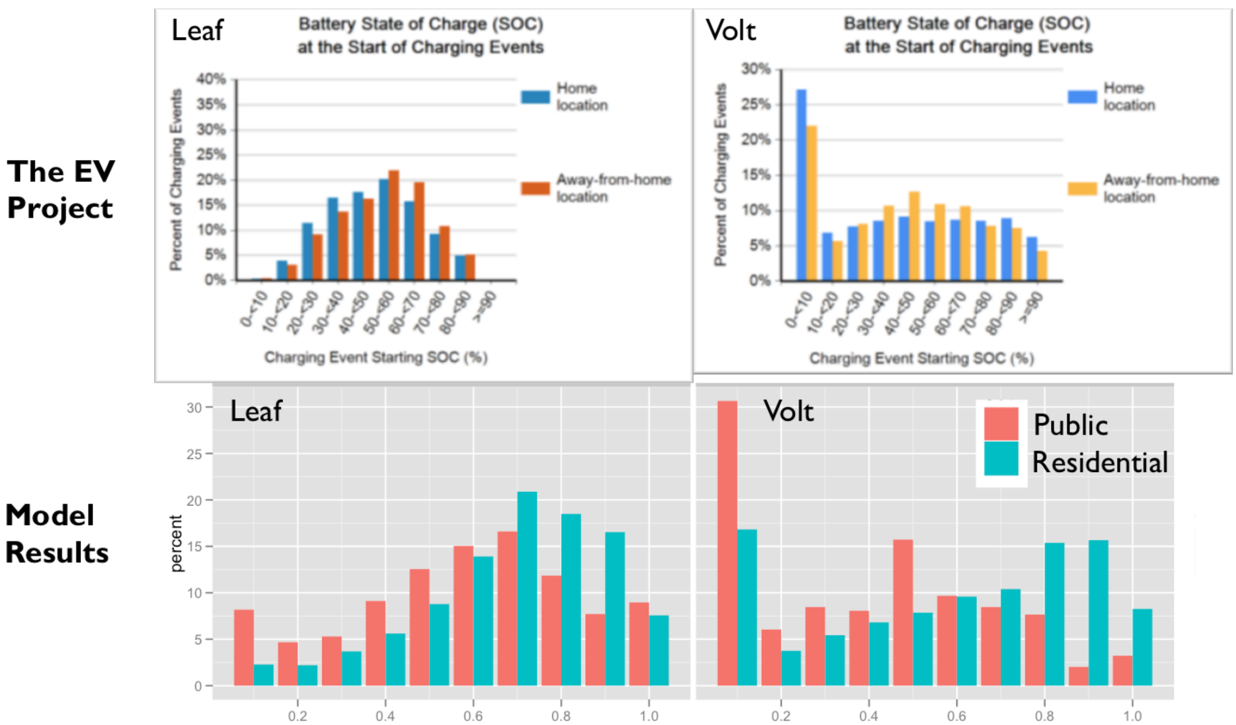


Figure 5: We compare the observed and modeled distributions of the state of charge of the battery at the beginning of a charging session from The EV Project (Ecotality, 2013, San Francisco subset) and the PEVI model. The results are disaggregated by vehicle type (Leaf vs. Volt) and location of the charging station (at home vs. publicly accessible).

Finally, the demand for electricity vs. hour of the day is compared between the results of the model and The EV Project (Figure 6). There is broad similarity between the trends, which peak around the same time of day (8pm) and both spend approximately 4 hours at or near the peak demand. There is considerably more variation in the maximum and minimum demands for The EV Project compared to the model output. This difference is likely due to the fact that The EV Project results are smaller in scale than the model results, so the minute-to-minute variation from small groups of cars has a bigger impact on the aggregated results.

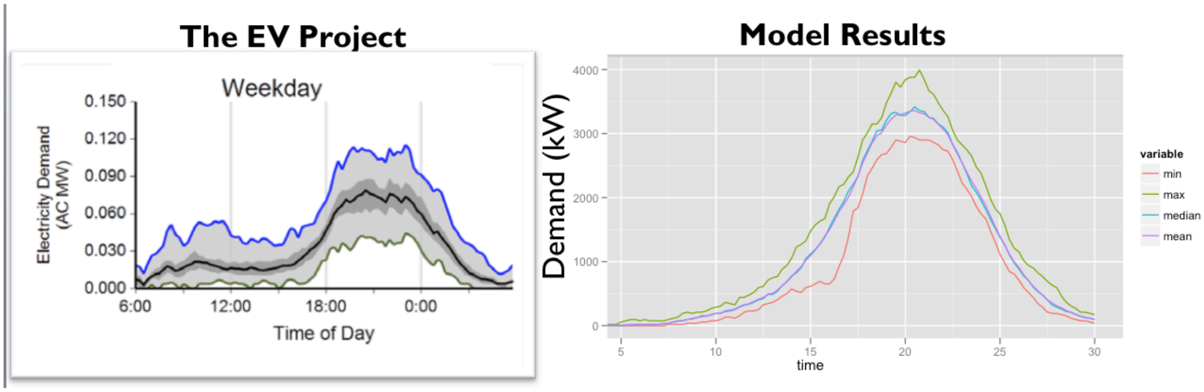


Figure 6: The instantaneous power demand vs. time of day is compared for the observed (Ecotality, 2013, Seattle subset) and modeled PEV charging events at home. The curves on The EV Project plot represent the minimum (green line), median (black line), and maximum (blue line) demand with the interquartile range indicated by the darkly shaded region.

Using PEVI to Site EVSE

The PEVI model provides a quantitative basis for evaluating the efficacy of a given deployment of EVSE throughout the county. We use an optimization algorithm to determine the set of chargers that provides the biggest benefit to PEV drivers at the least cost. The resulting EVSE infrastructure is presented in the next section. This section provides an overview of the optimization algorithm and lists key assumptions used in the analysis.

There are multiple metrics by which we can evaluate the benefit that a given EVSE deployment would provide to PEV drivers. We chose as our primary metric the degree to which a given EVSE deployment decreases the number of drivers who become stranded. Our definition of "stranded" is a driver who experiences a delay of more than three hours.

This metric of benefit to drivers is a relative one. A given EVSE deployment is compared to a base scenario and the average reduction in stranded drivers is calculated. To optimize EVSE deployment for a given penetration of PEV drivers, we take the following steps:

1. Initialize the PEVI model with a PEV penetration of 0.5% and the present-day charging infrastructure in Humboldt County (two chargers in Eureka and one in Arcata). Call this the base scenario and run the model[6], storing the results.

[6] The model is actually run repeatedly (up to 80 times) in this step and in step 2 and the average results are stored.

2. For each of the 52 travel analysis zones (TAZs) in the county, one at a time, place a new Level 2 and Level 3 charger (the chargers are also placed one at a time)[7]. Run the model again and calculate the reduction from the base scenario in drivers who are stranded.

3. Select the TAZ and charger type that provides the maximum reduction in stranded drivers per dollar spent. Add this charger to the EVSE infrastructure and call this the new base scenario.

4. Repeat steps 2 and 3 until adding a new charger stops providing any measurable benefit.

5. Increase the penetration of PEV drivers from 0.5% to 1% (or from 1% to 2%) and repeat steps 2-4.

This process results in a set of charger locations and charger levels that provides the highest benefit to drivers at the least cost. In addition, the order in which chargers are added is tracked, which provides useful insight into which locations should be prioritized for EVSE deployment in the near term[8]. Because PEVI is stochastic, the entire process is repeated a number of times (at least 10) and the various distributions of chargers are averaged together to form a final set of deployment guidelines.

North Coast Region Guidelines for PEV Infrastructure Deployment

In Figures 3 through 5, we present the results of using the PEVI model to site EVSE infrastructure for the three penetrations of 0.5%, 1%, and 2%. Each figure contains three maps: a full map of Humboldt County, a detail of the Cities of Arcata and McKinleyville, and a detail of the City of Eureka. On the maps are icons labeled with the TAZ name and the number of Level 2 and Level 3 chargers assigned to that TAZ. The coloring of each TAZ denotes the intensity of PEV travel demand into and out of that zone over an entire day.

Some icons in the maps occlude neighboring TAZs, so the entire set of results is also presented in tabular form (Tables 3 through 5). In these tables, the number of chargers

[7] We assume all Level 2 chargers also have Level 1 charging capabilities, a common design feature in modern charging stations.

[8] Technical Note: this particular algorithm is essentially a gradient descent optimization. We also implemented a global optimization algorithm called differential evolution, which is a more traditional optimization scheme with an objective of minimizing stranded drivers constrained by cost. We found that both techniques produced virtually identical EVSE deployment results. We therefore conducted our final analyses using the gradient descent method because it generates an entire optimality curve in one run, taking about an order of magnitude less time to complete than a set of global optimization runs.

sited at each TAZ has a decimal value. This is a consequence of the stochastic nature of PEVI. As described above, we conducted the optimization multiple times and calculated the average number of chargers sited at each location.

Qualitative Conclusions about EVSE Deployment

Based on the results of the PEVI modeling analysis, we can draw some useful conclusions about the siting of EVSE in Humboldt County, and by extension, other rural regions.

- Overall, relatively few chargers are needed to support a large number of PEV drivers. Approximately 45 chargers were sufficient to support about 3000 drivers in the 2% penetration scenario.

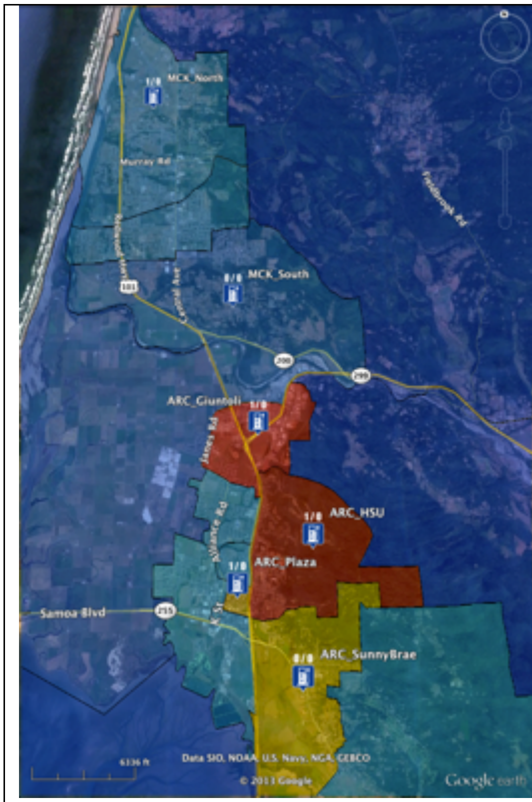
- Level 2 chargers provide a more cost-effective means of supporting PEV drivers than Level 3 chargers. In only one TAZ (Willow Creek) was a Level 3 charger sited. This TAZ happens to also be ideally situated to promote inter-regional connectivity between Humboldt and Trinity Counties.

- EVSE tends to be sited in and around population centers and major regional corridors.

- Several groups of TAZs show some degree of "substitutability". In other words, EVSE could be sited in one TAZ or a neighboring TAZ and the overall impact on PEV drivers will be approximately equivalent as long as the total need for EVSE in that region is satisfied[9]. These groups are:
    - EKA_Henderson_Center, EKA_S_Broadway, EKA_NW101, and EKA_W_Central
    - MCK_South, MCK_Central, MCK_North, and Fieldbrook
    - FOR_South, FOR_Central, FOR_East, and Hydesville
    - Garberville and Redway

[9] Technical note: these groupings were identified by inspecting the covariance matrix formed by running the optimization multiple times and evaluating the degree to which negative correlations exist between the number of PEV chargers sited at a TAZ vs. its neighbors.

EVSE Deployment Guidelines – 0.5% Penetration of PEVs (Target Year: 2014)



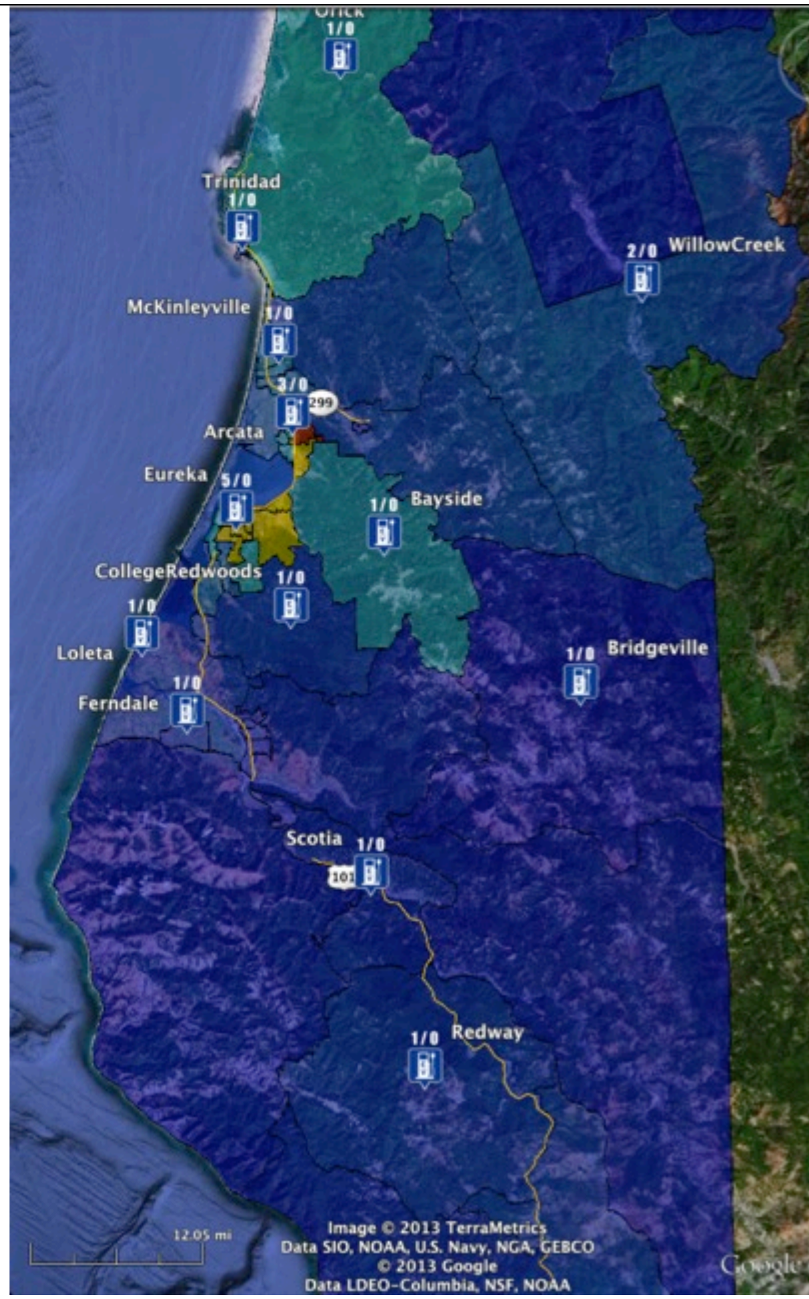
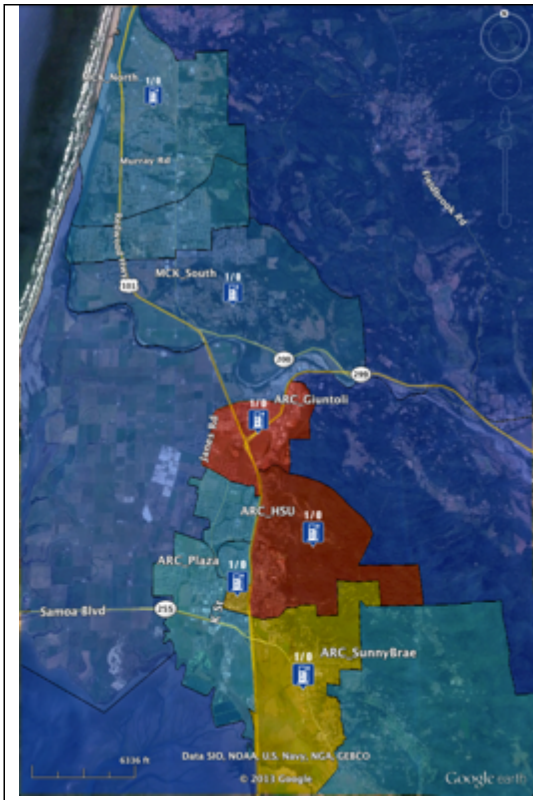


Figure 7 – EVSE deployment guidelines for 0.5% penetration of PEVs (~750 vehicles) in Humboldt County (top right). Each zone is labeled by name and an icon with two numbers: # of Level 2 / # of Level 3 chargers. The detail maps are for McKinleyville and Arcata (top left) and Eureka (bottom left). Some results are occluded in these images. See Table 3 for a full listing of the results by zone. These maps are available for download as navigable Google Earth documents at http://www.redwoodenergy.org/programs/electric-vehicles.

EVSE Deployment Guidelines – 1% Penetration of PEVs (Target Year: 2017)



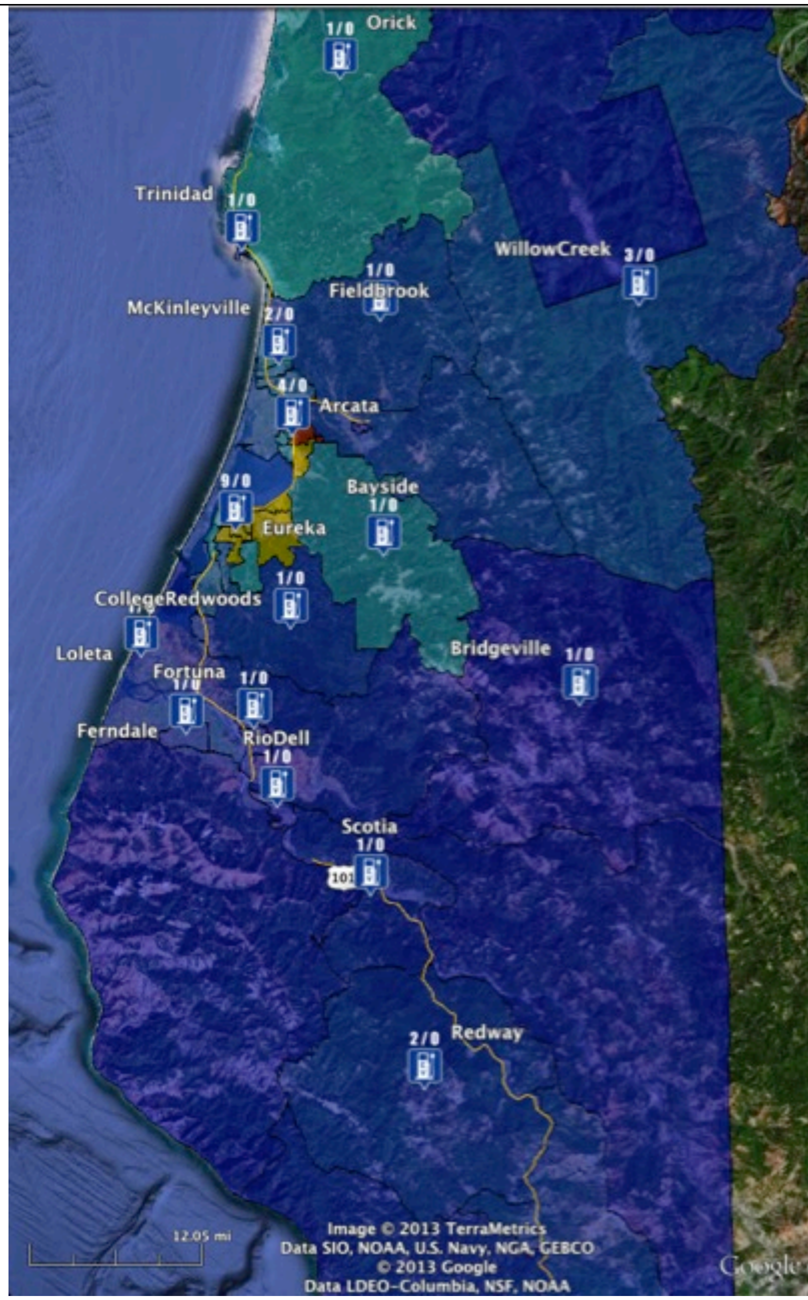
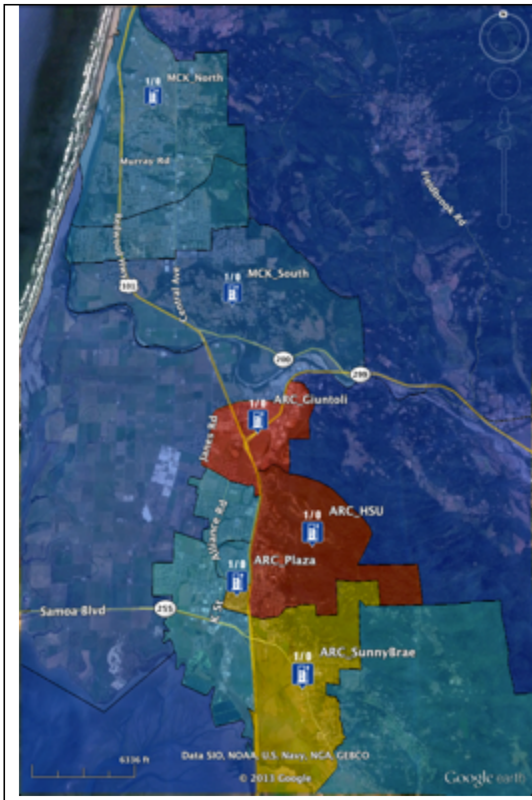


Figure 8 – EVSE deployment guidelines for 1% penetration of PEVs (~1500 vehicles) in Humboldt County (top right). Each zone is labeled by name and an icon with two numbers: # of Level 2 / # of Level 3 chargers. The detail maps are for McKinleyville and Arcata (top left) and Eureka (bottom left). Some results are occluded in these images. See Table 4 for a full listing of the results by zone. These maps are available for download as navigable Google Earth documents at http://www.redwoodenergy.org/programs/electric-vehicles.

EVSE Deployment Guidelines – 2% Penetration of PEVs (Target Year: 2023)



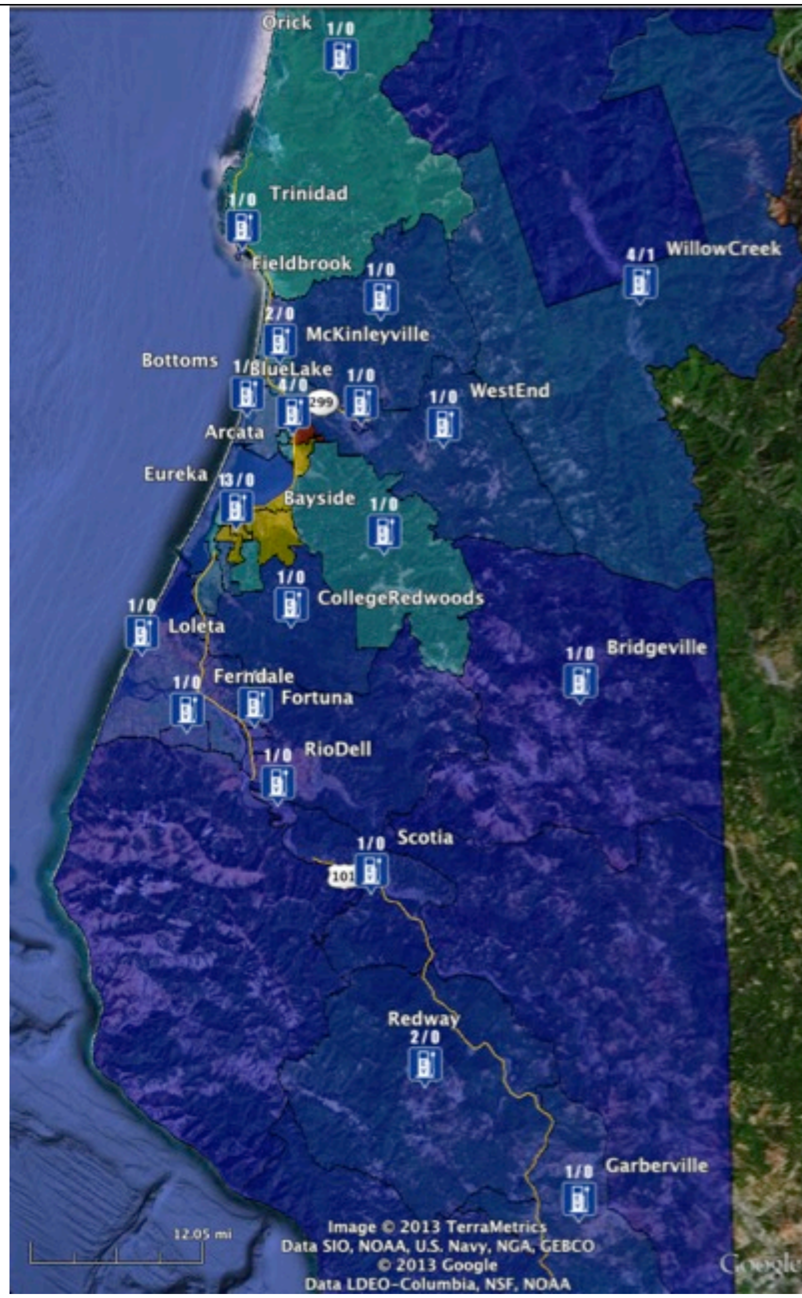


Figure 9 – EVSE deployment guidelines for 2% penetration of PEVs (~3000 vehicles) in Humboldt County (top right). Each zone is labeled by name and an icon with two numbers: # of Level 2 / # of Level 3 chargers. The detail maps are for McKinleyville and Arcata (top left) and Eureka (bottom left). Some results are occluded in these images. See Table 5 for a full listing of the results by zone. These maps are available for download as navigable Google Earth documents at http://www.redwoodenergy.org/programs/electric-vehicles.

EVSE Deployment Guidelines – 0.5% Penetration (Target Year: 2014)

Table 3: The average number of Level 2 and Level 3 chargers placed in each TAZ as well as the priority group (order of placement) for 0.5% penetration.

TAZ	L2	L3	Priority	TAZ	L2	L3	Priority
EKA_Waterfront	1.1	0.0	4	**MCK_South**	0.5	0.1	2
EKA_NW101	1.0	0.1	4	**Samoa**	0.2	0.0	4
EKA_NE101	0.1	0.0	4	**MCK_Central**	0.2	0.1	4
EKA_W_Central	0.2	0.1	3	**MCK_North**	0.6	0.1	1
EKA_E_Central	0.1	0.0	4	**Fieldbrook**	0.4	0.0	2
EKA_N_Broadway	0.2	0.0	3	**Trinidad**	0.6	0.1	1
EKA_S_Broadway	0.2	0.0	3	**Orick**	1.1	0.1	1
EKA_HendersonCenter	0.5	0.1	2	**FOR_North**	0.2	0.0	4
EKA_Harris	0.6	0.0	2	**FOR_Central**	0.4	0.0	2
EKA_Slough	0.2	0.1	3	**FOR_East**	0.5	0.0	2
EKA_Harrison	0.5	0.2	1	**FOR_South**	0.2	0.1	3
Cutten	0.3	0.1	3	**Hydesville**	0.3	0.0	3
Bayview	0.5	0.1	2	**RioDell**	0.3	0.1	2
FieldsLanding	0.5	0.0	2	**Loleta**	0.6	0.0	1
Myrtletown	0.7	0.0	1	**Ferndale**	0.5	0.1	2
CollegeRedwoods	0.8	0.1	1	**WestEnd**	0.5	0.1	2
Bayside	0.8	0.0	1	**BlueLake**	0.3	0.0	3
ARC_SunnyBrae	0.2	0.1	3	**WillowCreek**	2.6	0.1	1
ARC_South	0.2	0.1	3	**HoopaKlamath**	0.1	0.2	3
ARC_Plaza	1.0	0.0	4	**Garberville**	0.4	0.0	2
ARC_Greenview	0.1	0.0	4	**Redway**	1.4	0.0	1
ARC_North	0.1	0.0	4	**Scotia**	0.9	0.1	1
ARC_HSU	0.5	0.0	2	**ShelterCove**	0.1	0.1	4
ARC_Giuntoli	1.0	0.1	1	**Alderpoint**	0.3	0.0	3
ARC_Westwood	0.2	0.0	3	**LostCoast**	0.0	0.0	4
Bottoms	0.1	0.0	4	**Bridgeville**	0.8	0.0	1

EVSE Deployment Guidelines – 1% Penetration (Target Year: 2017)

Table 4: The average number of Level 2 and Level 3 chargers placed in each TAZ as well as the priority group (order of placement) for 1% penetration.

TAZ	L2	L3	Priority	TAZ	L2	L3	Priority
EKA_Waterfront	1.1	0.1	4	**MCK_South**	0.6	0.1	2
EKA_NW101	1.1	0.1	4	**Samoa**	0.2	0.0	4
EKA_NE101	0.1	0.0	4	**MCK_Central**	0.2	0.1	3
EKA_W_Central	0.4	0.2	3	**MCK_North**	0.8	0.1	1
EKA_E_Central	0.4	0.0	4	**Fieldbrook**	0.6	0.0	3
EKA_N_Broadway	0.3	0.0	3	**Trinidad**	0.8	0.1	1
EKA_S_Broadway	0.4	0.1	3	**Orick**	1.1	0.2	1
EKA_HendersonCenter	0.5	0.1	2	**FOR_North**	0.2	0.0	4
EKA_Harris	0.8	0.0	2	**FOR_Central**	0.5	0.1	2
EKA_Slough	0.7	0.1	2	**FOR_East**	0.5	0.1	2
EKA_Harrison	0.9	0.2	1	**FOR_South**	0.3	0.1	3
Cutten	0.5	0.1	2	**Hydesville**	0.4	0.0	3
Bayview	0.7	0.1	2	**RioDell**	0.5	0.1	2
FieldsLanding	0.8	0.0	2	**Loleta**	0.7	0.0	1
Myrtletown	0.7	0.1	1	**Ferndale**	0.7	0.1	2
CollegeRedwoods	1.0	0.1	1	**WestEnd**	0.6	0.1	2
Bayside	1.1	0.0	1	**BlueLake**	0.5	0.0	3
ARC_SunnyBrae	0.5	0.1	3	**WillowCreek**	3.4	0.1	1
ARC_South	0.2	0.1	3	**HoopaKlamath**	0.2	0.2	4
ARC_Plaza	1.0	0.0	4	**Garberville**	0.5	0.0	3
ARC_Greenview	0.3	0.1	4	**Redway**	1.7	0.1	1
ARC_North	0.1	0.1	4	**Scotia**	1.1	0.1	1
ARC_HSU	0.7	0.1	2	**ShelterCove**	0.2	0.1	4
ARC_Giuntoli	1.0	0.1	1	**Alderpoint**	0.4	0.2	3
ARC_Westwood	0.2	0.0	3	**LostCoast**	0.1	0.0	4
Bottoms	0.2	0.1	4	**Bridgeville**	0.9	0.0	1

EVSE Deployment Guidelines – 2% Penetration (Target Year: 2023)

Table 5: The average number of Level 2 and Level 3 chargers placed in each TAZ as well as the priority group (order of placement) for 2% penetration.

TAZ	L2	L3	Priority	TAZ	L2	L3	Priority
EKA_Waterfront	1.1	0.1	4	**MCK_South**	0.8	0.1	2
EKA_NW101	1.1	0.1	4	**Samoa**	0.4	0.0	4
EKA_NE101	0.1	0.0	4	**MCK_Central**	0.4	0.1	3
EKA_W_Central	0.5	0.3	3	**MCK_North**	0.9	0.1	1
EKA_E_Central	0.5	0.0	3	**Fieldbrook**	0.8	0.1	3
EKA_N_Broadway	0.4	0.1	3	**Trinidad**	0.9	0.1	1
EKA_S_Broadway	0.5	0.1	3	**Orick**	1.3	0.3	1
EKA_HendersonCenter	0.8	0.1	2	**FOR_North**	0.3	0.0	4
EKA_Harris	0.9	0.0	2	**FOR_Central**	0.6	0.1	2
EKA_Slough	0.9	0.1	2	**FOR_East**	0.5	0.1	2
EKA_Harrison	1.1	0.2	1	**FOR_South**	0.3	0.1	3
Cutten	0.8	0.2	2	**Hydesville**	0.5	0.1	3
Bayview	0.8	0.1	2	**RioDell**	0.5	0.1	3
FieldsLanding	0.9	0.0	2	**Loleta**	0.8	0.0	1
Myrtletown	0.8	0.1	1	**Ferndale**	0.8	0.1	2
CollegeRedwoods	1.1	0.1	1	**WestEnd**	0.8	0.1	2
Bayside	1.1	0.0	1	**BlueLake**	0.6	0.1	3
ARC_SunnyBrae	0.5	0.2	3	**WillowCreek**	4.5	0.6	1
ARC_South	0.3	0.1	4	**HoopaKlamath**	0.3	0.3	3
ARC_Plaza	1.1	0.1	4	**Garberville**	0.8	0.1	2
ARC_Greenview	0.4	0.1	4	**Redway**	2.2	0.2	1
ARC_North	0.3	0.1	4	**Scotia**	1.2	0.1	1
ARC_HSU	0.9	0.1	2	**ShelterCove**	0.2	0.2	4
ARC_Giuntoli	1.1	0.1	1	**Alderpoint**	0.4	0.2	3
ARC_Westwood	0.4	0.0	4	**LostCoast**	0.1	0.0	4
Bottoms	0.5	0.1	4	**Bridgeville**	1.1	0.1	1

Impact of EVSE Deployment on PEV Drivers

The PEVI model allows us to quantitatively evaluate the impact of EVSE deployment on driver experience. Figure 10 shows the relationship between added infrastructure and the percent of stranded drivers. As chargers are added, the total infrastructure cost increases and the percent of stranded drivers decreases. The breaks in the curves represent the point at which the analysis for a given penetration level is completed and the optimization is then conducted for a new penetration level (step 5 in algorithm described above in the section "Using PEVI to Site EVSE").

It is clear from Figure 10 that the first set of chargers provides the most benefit to drivers and that there are decreasing returns on investment as the infrastructure is built out. It is also worth noting that the total cost of the infrastructure needed to support PEV adoption at a 2% penetration is only about $400,000. This level of capital investment is relatively small compared to the investment required to build a single gasoline/diesel or hydrogen fueling station.

It should be noted that the final set of EVSE infrastructure doesn't completely eliminate stranded drivers. While it is possible to deploy enough chargers to drive stranded events to zero, it takes a very large investment to accomplish this (hundreds of chargers and millions of dollars). The reason for this is because the PEVI model includes itineraries for PEV drivers based on the travel patterns of conventional gasoline-powered drivers (both the GEATM and NHTS data sets are derived from conventional automobiles). The result is that some tours attempted by BEV drivers are quite ambitious, with long distances travelled combined with short dwell times.

Arguably, BEV drivers would rarely attempt such unrealistic tours. The PEVI model mitigates this issue somewhat by assigning the most ambitious tours to a PHEV driver instead of a BEV driver. But some tours still remain (less than 0.25% of all itineraries) that simply can't be supported by a modest EVSE deployment. The NCPEV team concluded that spending millions of dollars on additional infrastructure to support a small number of very aggressive BEV tours would be an inappropriate use of limited funds.

Finally, it is also important to note that as adoption increases, the business case for EVSE owners and operators will become economically viable. In Figure 11, we graph the average charger duty factor (the percent of the time the charger is in use) vs. the cost of EVSE infrastructure. Duty factors on average do not fall below ~10% and could be as high as ~25% as adoption reaches 2%. Even a 10% duty factor is high enough to warrant a price for electricity that is still competitive with the price of gasoline and diesel fuel for conventional vehicles (See Appendix C).

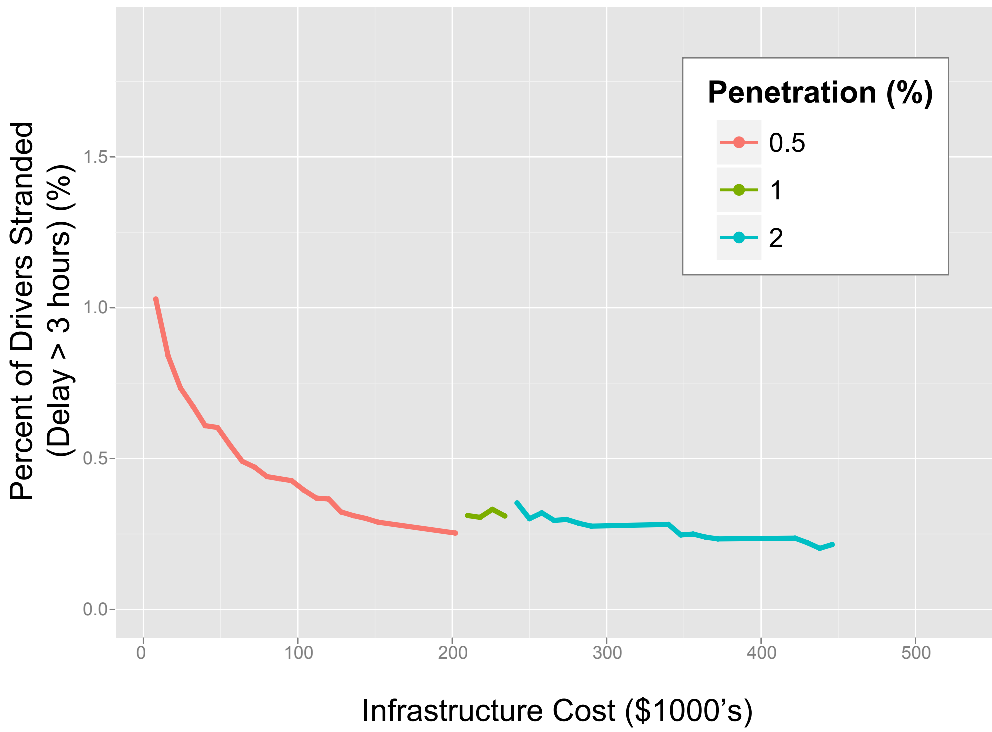


Figure 10: Percent of drivers stranded vs. the cost of deploying PEV chargers one at a time. The horizontal axis represents the cumulative cost of infrastructure.

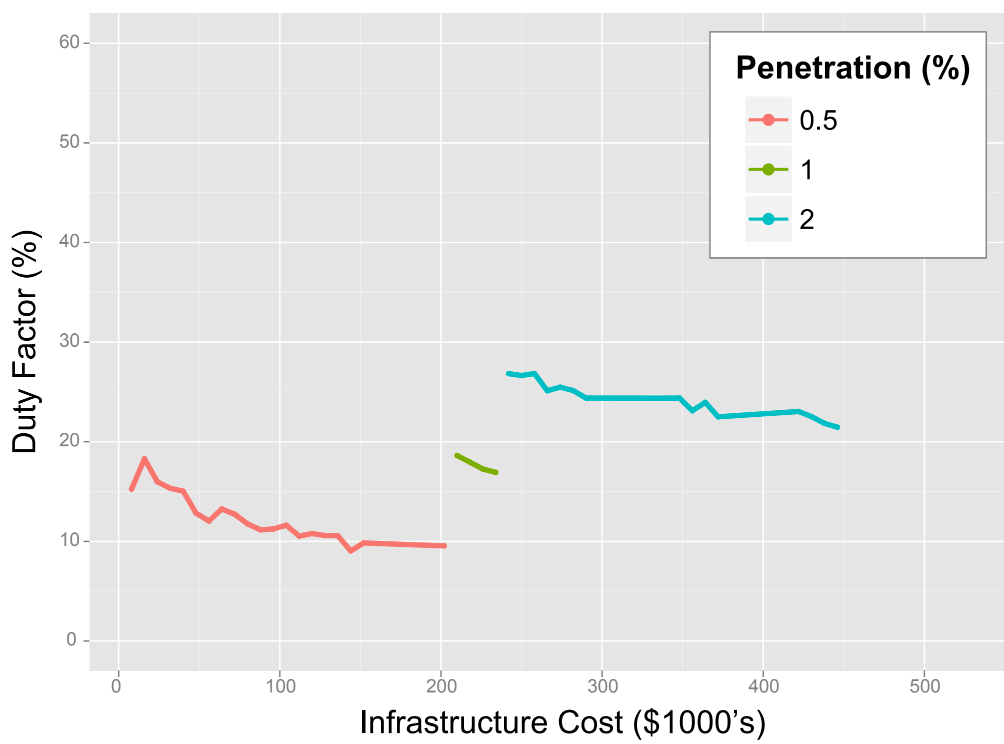


Figure 11: Average duty factor of EVSE vs. the cost of deploying PEV chargers one at a time.

Guidelines for Del Norte and Trinity Counties

Based on the analysis conducted for Humboldt County, some general recommendations can be made for the other counties in the North Coast Region. Table 6 shows extrapolations of the total number of EVSE chargers from the Humboldt County 2% penetration scenario to Del Norte and Trinity Counties based both on the relative populations of the counties and the relative adoption to-date of PEVs.

The PEV chargers in Del Norte and Trinity should be sited according to the general criteria noted above in the section "Qualitative Conclusions about EVSE Deployment." Namely, they should be deployed near the population centers as well as along the major highway corridors (Routes 101, 199, 299, and 36), particularly where these routes pass through population centers.

Finally, in the event that funding is available to install Level 3 chargers throughout the region, there is value in siting Level 3 EVSE along the major corridors to facilitate connectivity between the North Coast counties. This is consistent with findings in the Humboldt County optimization analysis that sited the only Level 3 charger in Willow Creek, about 40 miles east of Arcata along the Highway 299 corridor.

Table 6: An extrapolation of the total number of PEV chargers found for Humboldt County to the counties of Del Norte and Trinity, assuming 2% PEV penetration. Estimates based both on population and recent PEV sales are included.

	2013 Population	Number of chargers (proportional to Humboldt population)	PEV sales	Number of chargers (proportional to Humboldt PEV sales)
Humboldt	134,761	**45**	23	**45**
Del Norte	28,659	**10**	4	**8**
Trinity	13,723	**5**	2	**4**

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Appendix - Table of Abbreviations and Definitions

Abbrev.	Full Name	Definition
BEV	Battery Electric Vehicle	A vehicle that only runs on electricity. The Nissan Leaf and Tesla Model S are popular examples. Often referred to as an "electric vehicle" or EV.
DC	Direct Current	Electric current that flows in one direction.
EVSE	Electric Vehicle Supply Equipment	A charging station where PEVs can recharge their batteries.
GEATM	Greater Eureka Area Travel Model	Travel demand model developed by Caltrans, HCAOG, and others to forecast Humboldt County traffic patterns for transportation planning purposes.
HCAOG	Humboldt County Association of Governments	The regional transportation planning authority in Humboldt County.
HEV	Hybrid Electric Vehicle	A vehicle that uses a battery / electric motor and a conventional internal combustion engine to achieve high fuel economy. The Toyota Prius is the most popular example.
NCPEV	North Coast Plug-in Electric Vehicle	Refers to the PEV study being conducted for the North Coast Region (Humboldt, Del Norte, and Trinity Counties)
NHTS	National Household Transportation Survey	Transportation survey conducted by the U.S. Department of Transportation.
PEV	Plug-in Electric Vehicle	Any vehicle that can be charged from an external source. Includes both BEVs and PHEVs.
PEVI	Plug-in Electric Vehicle Infrastructure Model	The agent-based simulation model developed by the NCPEV research team to evaluate potential EVSE deployment alternatives.
PHEV	Plug-in Hybrid Electric Vehicle	A vehicle with a hybrid gasoline/electric motor that can also be charged from an external source. These vehicles enable some amount of electric-only driving with a gasoline backup. The Chevy Volt is a popular example.
TAZ	Traffic Analysis Zone	A geographic area representing a single source or destination in a transportation model.