Expanding the UC Davis GIS Electric Vehicle Planning Toolbox Beyond California: The Delaware Valley Regional Planning Commission Case Study

July 2021

A Research Report from the National Center for Sustainable Transportation

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The planning tool created in his project is publicly available at https://dvrpcgis.maps.arcgis.com/apps/MapSeries/index.html?appid=793fa4e10eac43b387adfc9cd2621a3d

16. Abstract

This project creates a toolkit that run in ArcGIS and allows users to project where EV owners will live, work, and charge. There are three distinct modules: market analysis, workplace charging, and home charging presented in block group level. The tool can be updated by the MPO users to reflect new technologies and policies, and to be used by local planners using the web interface. DVRPC has uploaded the tool's results to an ArcGIS online interface so that interested parties may use the results in their own analyses. The researchers expect these results to be useful for electric distribution companies, businesses, developers, EV charging companies, and all levels of governments in their EV planning efforts.

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EXECUTIVE SUMMARY

Plug-in electric vehicles are quickly moving to the main market. Home charging is the primary location for recharging these cars but public infrastructure including workplace chargers, public chargers, and corridor chargers are becoming more important in growing the market. Too often, planners are left to create charging infrastructure plans with little basis in research, resulting in a patchwork of ideas. There is often no consideration of the effect of pricing and vehicle range. On the other hand, researchers at UC Davis and elsewhere have more and more information on charging behavior, charging needs, future technologies and the ability to forecast future infrastructure needs. In most cases the information collected and processed by the scientists trickled very slowly to the planners' level. As more states develop action plans around zero emission vehicles, the tools required to inform and carry out these policies will be crucial moving forward. The goal of this project is to create a set of infrastructure demand planning tools that are using the state of the art knowledge from academia, the best publicly available data, and the ability to be run, managed, and used by the local planners entrusted with the task. In this project we translated a planning tool calibrated to California in 2014 to a tool that can be used by the Delaware Valley Regional Planning Commission (DVRPC) to create new scenarios and update the results based on local policies and new technologies.

The toolbox is designed to be flexible by creating default values recommended by the research team with the ability to adjust scenarios based on modelers assumptions and an evolving market. By studying its application in another region, the GIS Planning Toolbox can be adapted and generalized for use across the United States. With access to these tools, country-wide university researchers, electric charging providers, utilities, automotive OEMs, metropolitan planning organizations, and transportation departments will be able to base policies for placement of, and funding allocation for, charging infrastructure on robust data analyses.

With our partners at DVRPC we developed a set of sub-models (Figure 1. GIS Toolbox conceptual model) that can be updated as needed. The first step includes preprocessing tools that use publicly available census data, local transportation data, and vehicle availability data that can be updated as needed. The second step is the major analysis of home location of potential EV owners, workplace destinations of those owners, and derived demand for electricity at home and work. We used common ARCGIS tools to develop this step. The last part was disseminating the results by developing a website that includes the results of pre-estimated scenarios, including the number of electric vehicle owners, the number of commuters with electric cars, and the number of chargers needed under different pricing scenarios.

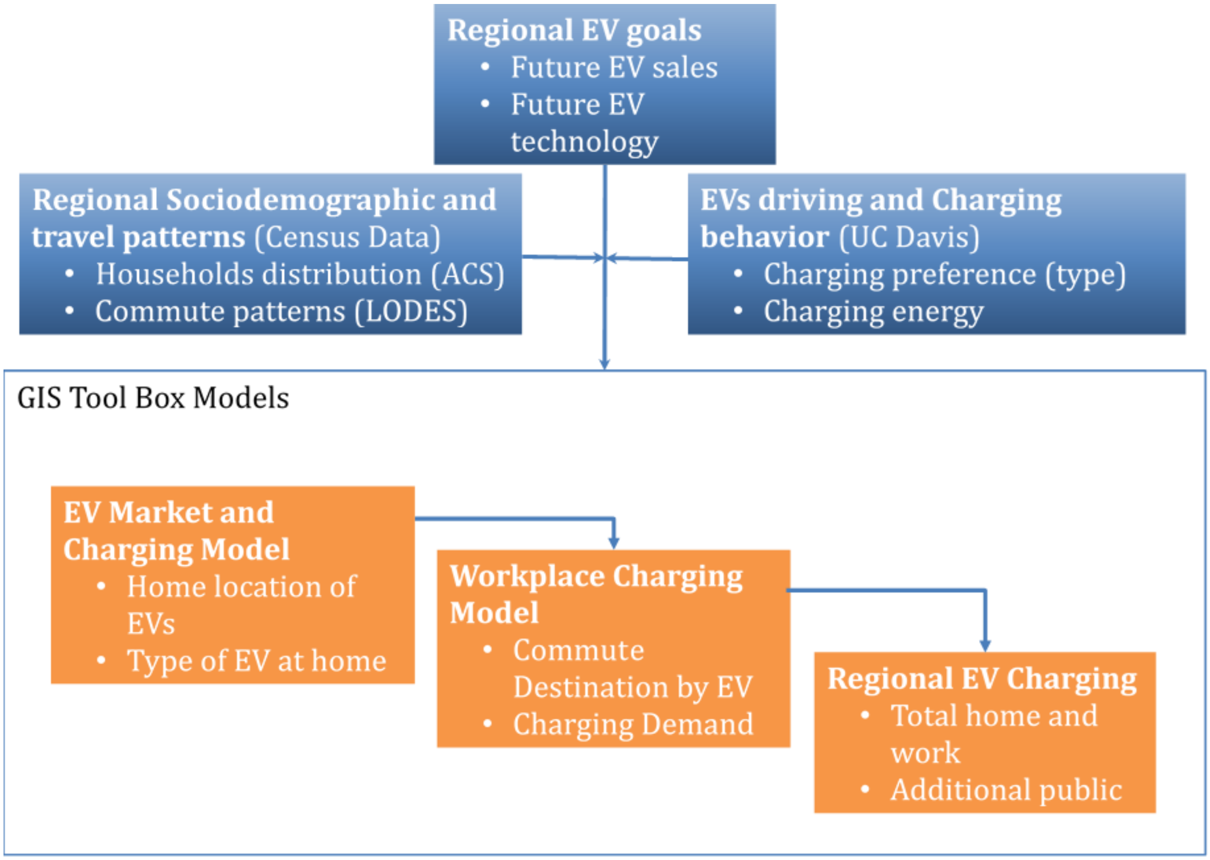


Figure 1. GIS Toolbox conceptual model

We believe that the tools we created in this project are very valuable for planning entities with strong GIS and modeling capabilities such as large MPOs. The results can be used by the local cities and planners without any need for detailed technical knowledge or training using the tool webpage. These organizations can take ownership over the modeling tool and update it as needed for their specific region. For small organizations and regions that are not part of a similar MPO, a website that presents the results of a pre-calibrated model will provide a better solution (Figure 2).

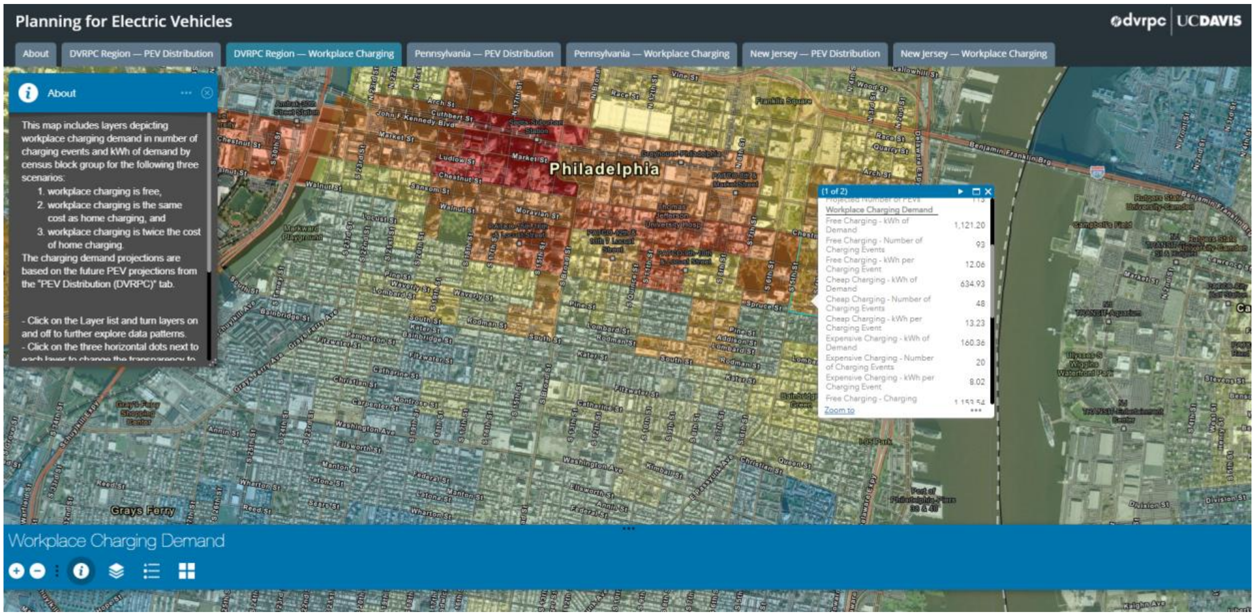


Figure 2. Workplace Charging demand web interface Link[1]

In the future we will explore opportunities to update the tools while building in more capabilities to the websites. We will also explore adding transportation network company vehicles and unique travel patterns, and including semi- and fully autonomous vehicles in future versions.

[1] https://dvrpcgis.maps.arcgis.com/apps/MapSeries/index.html?appid=793fa4e10eac43b387adfc9cd2621a3d

Introduction

Infrastructure is a basic need for plug-in vehicles, however, often planners are tasked with creating charging plans with little basis in research, resulting in a patchwork of ideas. There is often no correlation between the demand for infrastructure and the effect of pricing and vehicle range. As more states develop action plans around zero emission vehicles, the tools required to inform and carry out these policies will be crucial moving forward. This project yielded a practical online tool developed in collaboration with our partners at the Delaware Valley Regional Planning Commission (DVRPC) that can be use by planners and decision makers to estimate the demand for charging infrastructure.

The GIS Toolbox is a set of modeling tools developed by the Plug-in Hybrid & Electric Vehicle Research Center that is composed of a set of scripts in a graphical user interface to plan electric vehicle infrastructure based on extensive research at UC Davis. The tools are user-friendly to a person with rudimentary ArcGIS knowledge and are intended to aid in infrastructure planning as municipalities, companies, and utilities move to accommodate a rapidly growing PEV market. Two main uses of the tools are to create a geographical distribution of the vehicle market and planning the resulting location of charging infrastructure. The tools will work in all states and regions of the United States using publicly available census data. However, because the tools were calibrated from California-specific data (e.g., the California Household Travel Survey/CHTS dataset), in practice the Toolbox has unknown applicability in other states.

Not every state has the same context as California. Demographics, travel patterns, weather, and consumer attitudes towards EVs differ. The toolbox is designed to be flexible by creating value defaults with the ability to adjust scenarios based on modelers' assumptions and an evolving market. However, research is necessary to determine the shortcomings and strengths of the GIS tools when they are used to analyze data from other regions with varying data and market conditions. By studying its application in another region, the GIS Planning Toolbox can be adapted and generalized for use across the United States. With access to these tools, country-wide university researchers, electric charging providers, utilities, automotive OEMs, metropolitan planning organizations, and departments of transportation will be able to base policy for placement of and funding allocation for charging infrastructure on robust data analyses.

We developed a case study through collaboration with the Delaware Valley Regional Planning Commission (DVRPC) that explored how to modify and calibrate the Toolbox for another region. Aiding the DVRPC with certain data analysis activities will pinpoint the changes that need to be made to the tools in order to make them as effective in other locales as they are in California. The goal for this research is to utilize the specific information we glean from the case study and develop a general framework for modifying the GIS tools so they can be used more broadly. DVCRP was chosen as a test region for this project due to their interest in using our toolbox and their expertise and available data necessary to calibrate the tool.

Data

The data used by the tools include variables from the 2016 American Community Survey (ACS) 5-year dataset, and the Longitudinal Employer-Household Dynamics Origin-Destination Employment Statistics (LODES) dataset both available from the US census.

American Community Survey

The variables obtained from the ACS include household *income, household number of vehicles, household unit type,* and *household property value*. However, income is the only variable significantly related to the spatial distribution of PEV sales in the DVRPC area. These variables are composites of the original census variables (see Appendix A for details on variable construction). The census variables were downloaded by using the CENSUS API. All the necessary census variables were downloaded at the block group level consisting of over 7,000 records. A unique ID was generated (GEOID) from the concatenation of the state, tract, and block group census codes. No further processing of the census variables was done because the tools create the necessary variables directly from the raw ACS data.

LODES

The LODES version 7 data contain 2010 block enumerated counts of origin-destination (OD) pairs for work travel. These data were used in order to estimate commute distances which is a key explanatory variable for PEV ownership, particularly the decision to buy a plug-in hybrid (PHEV) or a battery electric (BEV). The data are composed of a combination of confidential census bureau data sources combined with public census data. Noise is added to personal data to protect privacy, and synthetic data methods are used to project total numbers of workers to each block. An important note is that these data *do not* include military or self-employed workers, and so are systematically biased to under-represent total worker travel. Unlike the ACS data, the LODES data had to be processed in order to be used by the tools. Only the *main* data were processed such that out of state workers/residents are not considered in the tools.

Data Processing

The following steps were used to process the LODES data so it could be used by the tools:

- *Aggregation of block level data to block groups*

  Employment totals for each origin and destination pair (OD pair) were summed at the block group level in order to match the spatial enumerations of the ACS data. This was done by loading the raw data into a SQL database and running a set of commands to generate a new dataset.

- *Calculation of OD network distances*

  Once the OD data were aggregated to the block group, commute distances between all OD pairs were calculated based on the shortest time network distance using ESRI's ArcGIS Network Analyst and the StreetMap USA network dataset from 2011. An average Wednesday at 8am was used as the basis for calculating the shortest time commute path. The associated commute distance was calculated from the generated paths such that the final dataset was composed of individual OD pair commute distances. This process was completed by reading the SQL data into ESRI's proprietary database format, running the network calculations, and exporting back to SQL using python and the arcpy module for ArcGIS.

- *Commute Distance variable creation*

  The final distance variables were created by summing up the counts of OD pairs for each block group and classifying them into categories that are generally representative of the various PEV ranges available on the market.

- *Gravity variable*

  The gravity variables were created to take into account the neighborhood effect in PEV adoption behavior. This variable conceptually captures the impact of exposure to the technology as function of the size of phenomena and the distance from it. We use number of PEVs around the neighborhood zones from each block group, but it is scaled based on the distance between each zone and the neighborhood zones.

$$Gravity\ variable = \sum_{N} \frac{PEV_n}{D_n^2}$$

  where PEV_n is total vehicle ownership in neighborhood and D_n is distance.

  In order to decide the distance to define the neighborhood, we examine the spatial dependency of market penetration in DVRPC area. Moran's I statistic, a statistical tool uses to measure spatial autocorrelation, was used and spatial dependency were below than 0.1 after including the zones farther than 20 km based on the weighted median commute distance. Therefore, 20 km was used to capture the neighborhood effect in this tool and the gravity variable was also computed within this distance.

Moran's I is defined as

$$\mathrm{I} = \frac{\mathrm{N}}{\mathrm{W}} \frac{\sum_i \sum_j w_{ij}(x_i - \bar{x})(x_j - \bar{x})}{\sum_i (x_i - \bar{x})^2}$$

where N is the number of census block group indexed by *i* and *j*; *x* is the market penetrations, w_{ij} is the spatial weight matrix based on weighted median commute distance between zones with zeros on the diagonal.

Data Tools

Prepare ACS and LODES data

Purpose

The Prepare ACS and LODES data tool allows the user to specify the geographic extent of the analysis, name the database for the analysis, and generate a few summary tables that are necessary for the remaining PEV tools.

Execution

The first parameter (ACS Table) is for the ACS data which has been precompiled for DVRPC areas, and provided with the tool (acs_data in PennDot_NJ_InputData_1.gdb). The second parameter (LODES Table, LODES_NJ_Penn_art20mile in PennDot_NJ_InputData_1.gdb) is the table file to be used for calculating travel behavior variables. The third and final parameter is a table of current PEV sales data that allows the user to either use an existing spatial distribution of PEV sales for the next step or... If a table is included, the user must specify the fields containing current sales and GEOID. If the user does not have current PEV sales data, the user can enter "Total PEV vehicles you want to assign", then it will be estimated based on the population, employment, and single house ratio. When the current PEV sales data are included, the name of current PEV sales field should be "CurrentPEVsales".

Once successfully complete, this tool will generate a series of feature classes:

- MarketAssignment: Simple table feature class that merged three input tables. It contains population, per capita median income, total housing units, the number of single house owners, single attached houses, single detached houses, apartments, mobile homes, total number of jobs, weighted average commute distance in mile, current PEV sales, and Gravity variables.

Toolbox Submodules

Market Tool: Home Location of Plug-in Vehicle Users

This document describes the current plug-in electric vehicle (PEV) toolbox for ArcGIS, the motivation for the tools, and the empirical evidence to support the validity of the tools. The tools should be used for scenario planning, not for forecasting actual numbers of vehicles in a given region. In this way, the tools are structured around some fundamental explanatory variables with a high amount of parameterization for scenario specific analysis. The current tools in the toolbox include *1. Prepare ACS and LODES data* and *2. Calculate PEV Sales*.

The goal of these tools is to provide some indication of the future geographic extent of PEV households as well as where placement of charging stations may be best utilized. Because the market is young, it is difficult to know whether purchasing and travel behavior of PEV users are static. However, it is time that planners begin to think about infrastructure placement, and car companies think about the spatial distribution of the market. Unlike the conventional and hybrid vehicle markets, understanding spatial distribution of the PEV fleet is important for planning for public and private charging stations.

This tool is intended for anyone interested in analyzing the possible PEV futures by mapping the scenarios in a geographic information system (GIS) environment. Once the scenario is mapped in this environment, the analyst has the full power of a GIS to uncover new phenomena using spatial statistics and geo-visualization techniques.

The motivation for this toolbox is driven by the need to understand the future PEV fleet, with focus on the unique travel behavior of PEV drivers. This behavioral knowledge is expected to help make important planning decisions related to charging infrastructure for a growing PEV market. The tools can easily be adopted, if calibrated to local policies and incentives, for use in any regions in the US by generating similar datasets for other regions.

Calculate PEV Sales

Purpose

The Calculate PEV Sales tool can be used to simulate the geographic dispersion of various PEV buying scenarios. The goal of this tool is to estimate the number of vehicles in a given block group, given the constraints of the scenario defined by the analyst. As stated in the overview, the output from this tool should not be considered a forecast because the analyst directly limits the number of vehicles that will be bought for a given scenario. This tool should be used to explore possible geographic distributions of vehicles given various scenarios of PEV sales.

Conceptual Model

The Calculate PEV Sales tool is structured as a spatial regression model in conjunction with a stochastic process based on Bass diffusion model. The census block group is the? unit of analysis in this toolbox, and the table prepared from the previous step is the primary input dataset. This dataset has to include current sales of PEVs, household characteristics, gravity variables per each census block group. It is also required to enter the total PEVs to assign and a shapefile of census block groups to export results. In addition, a user can modify three set of parameters: Diffusion of Innovation, market limit-charging facility accessibility restriction, socio-demographic variables' impact.

The tool first calculates Market limit per block groups based on housing characteristics; the Market limit-charging facility accessibility restriction parameters are used in this step. Then, the current PEV market penetration rate is computed by the ratio between current PEV sales and market limit. The PEV adoption rate is computed based on the Diffusion of innovation parameter and current PEV market penetration rate. This step helps to take into account of maturity of PEV market per block groups based on Rogers' diffusion of innovation theory. In order to estimate geographic distributions of PEV, the probability to assign PEVs are calculated based on the demographic variable impact parameters and the PEV adoption rate. The total number of PEVs the user wants to assign is divided by the number of iterations, and they are assigned in each iteration. The result from the first iteration will be used as input for the second iteration, and the second iteration results will be used for the third iteration, and so on. This stochastic process is helpful to reflect real world PEV adoption behavior.

Execution

The Calculate PEV Sales tool is organized such that the output from the Prepare ACS and LODES data tool will be used directly. The first parameter (Market Assignment Input Table) must be the table in geodatabase that was either used or generated in the Prepare ACS and LODES data tool. The second parameter (Total PEV vehicles to assign) is the number of PEVs the user wants to assign in addition to the current number of PEVs in the region. The third input (Feature Class of Census BlockGroup) is a shapefile of census block group for the study region.

As mentioned above, there are three sets of parameters: Diffusion of Innovation, Market limit-charging facility accessibility restriction, socio-demographic variables' impact. The default parameter values are provided, but a user can modify these values for his/her own purpose. There are three parameters in Diffusion of Innovation setting: the number of iterations to run, coefficient of innovation, and imitation. These three parameters are related to the PEV adoption rate based on the maturity of PEV market. Therefore, the number of PEVs increased in the block group with high and low level of PEV market penetration can be different because PEV adoption rate will be different because of these parameters. Four parameters can be modified in the Market limit-charging facility accessibility restriction setting. These are used to calculate PEV market limit. The Socio-demographic variables' impact setting has three parameters, they are the coefficient estimated from a regression model; the market penetration rate is a function of median income, weighted average commute distance, and gravity variables. Their default values are 1.473e-6, 1.250e-3, and 3.946e-7, respectively.

Spatio-Temporal Constraints

The current tools are provided with a dataset of Delaware Valley Regional Planning Commission (DVRPC) area only. Without the creation of similar datasets, these tools are only useful in DVRPC regions. Subsets of the DVRPC can easily be generated with little effort on the part of the analyst (discussed in the specific tool sections below). The temporal scale by which the tool is expected to be useful is a range of 0-5 year future horizons. This rough limitation is recommended because of the expected dynamic nature between independent and dependent variables used to develop these tools. Relationships between socio-demographics and PEV ownership/travel behavior are likely to change in the near future as the market for PEVs grows. The classic "early adopter" mentality will likely be replaced by a more mainstream consumer which could represent drastic structural changes to our empirical models.

Empirical Evidence

The tools in this toolbox are designed based on the empirical statistical models of PEV buyers in California and DVRPC areas. The empirical evidence from California PEV owners is reviewed in detail in the following document.[2] In summary, PEV ownership has been found to be a function of income, commute distance, and Gravity variable. The choices involved in buying a PEV are illustrated in the following section *Conceptual Model* where the tool execution processes mirror the empirical binary logistic regression models from. While the data used in the empirical models was specific for PEV owners, the tools described below use the Odds Ratios and normalized coefficients from those models in identifying potential PEV households based on publicly available aggregate data.

[2] Tal, G., & Nicholas, M. A. (2013). Studying the PEV Market in California Comparing the PEV, PHEV and Hybrid Markets. Paper presented at the EVS27 International Battery, Hybrid and Fuel Cell Electric Vehicle Symposium.

Work Charging Demand Analysis Tool

This tool is built based on ArcGIS, and the motivation to develop this tool is to help predict work charging demand. Four forms of data are essential: commute distance, PEV ownership, split ratio of different PEV modes, and vehicle efficiency.

Charging events and electricity consumption are calculated based on travel distance and battery range. This tool also allows two additional charging strategies. If work charging is free, PEV drivers will avoid charging at home to the extent possible. Conversely, if there is a cost to charge at work which is more expensive than home electricity but still cheaper than conventional fuel, PEV drivers will try to avoid charging at work to the extent possible. If prices at home and work are equal, drivers will split charging between home and work to the extent possible.

Figure 3 shows a sample result for people who live in block group A or B and work and block group C.

- Taking PHEV30 from block group A as a sample. The travel distance from A to C is 20 miles which is within its range. But since its range cannot complete a round trip between A and C, it will always charge for 20-miles no matter it's free or not to charge at work, and the electricity consumption at work (assuming the vehicle efficiency is 3 miles/kWh) is

$$20 \text{ miles} \,/\, 3 \text{ mile/kWh} \;=\; 6.7\text{kWh}$$

- For PHEV15 from block group A, since its range is shorter than the travel distance, the electricity consumption at work will be equivalent to its range which is

$$15 \text{ miles} \,/\, 3 \text{ mile/kWh} \;=\; 5\text{kWh}$$

- For BEVs, if its range is shorter than the one-way travel distance, the model will consider this vehicle not eligible to be used for commute purpose.

- For PEVs whose range is longer than the round-trip travel distance, its charging strategy will be determined based on whether charging at work is free or paid. Taking a BEV80 from block group A as an example, the round-trip travel distance between A and C is 40 miles which is shorter than BEV80's range. Therefore, if charging at work is free, the BEV80 will charge at work and the electricity consumption at work will be equivalent to the round-way travel distance which is

$$40 \text{ miles} \,/\, 3 \text{ mile/kWh} \;=\; 13.3 \text{ kWh}$$

  But if commuters have to pay a higher price to charge at work than at home, drivers of a BEV80 won't charge at work unless the round trip distance exceeds useful range (the useful range is the range minus a user defined mileage buffer). If the useful range were 72 miles, if the workplace were more than 72 miles round trip, the driver would charge at work in all cases.

- If the trip to work is very short, then the BEV will not charge every day. If the modeler decides this a maximum period of 3 days before charging at work, then a BEV that has less than 24 miles round trip to work (72 miles/3 days) would charge on every third day if charging were free.

- If the price of charging is the same as home, the BEV will always plug in at home and only plug in at work sometimes similar to a price higher than home. The difference is that the "sometimes" is further controlled by the convenience buffer. The convenience buffer reduces the useful range of the vehicle. If the minimum range buffer is 8 miles on a BEV 80, the battery only has a useful range of 72 miles. A convenience buffer of 12 miles will reduce the range to 60 miles. If the price at home and work is the same, this convenience buffer is the "nice-to-have range" representing the value that overcomes the inconvenience of plugging in.

- The total charging events and electricity consumption will be all commuters who work at a block group. For the sample of Figure 3, total charging at block group C will be the sum of commuters from block group A and B.

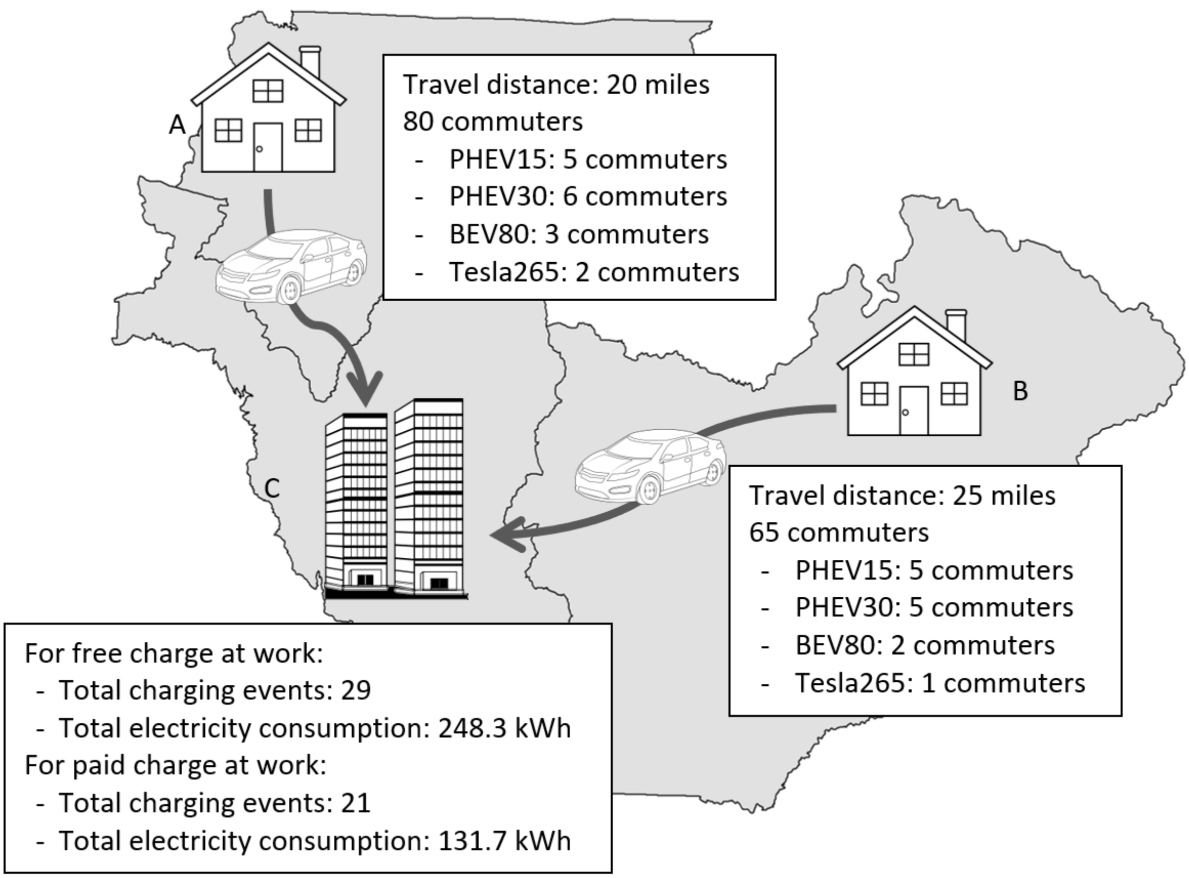


Figure 3. Demonstration of Work Charging Demand Analysis

Data Requirements

The spatial resolution of results depends on user's input data. If the input data is at block group level, the prediction will be at block group level. If the input data is at county level, the prediction will be at county level. Following descriptions are at block group level.

Detailed number of travelers who commute between block groups is calculated based on user-defined information about commute trips (Table 1), PEV ownership (Table 2), and PEV scenarios (Table 3). Assuming there are totally 447 people who live at block group A and work and block group B, C, or E, as Table 1 shows. Among these commuters, 53 of them own PHEV, 28 of them own Tesla, and 19 of them own other BEVs, as Table 2 shows, and the information of each specific PEV modes are given in Table 3. Based on this information, number of each PEV mode that commute between each pair of block groups can be calculated. Detailed calculation process is given later.

Commute Trips

Commute trips is a table that contains commute distance between block group pairs. The column name should be exactly the same as Table 1. Distance is in the unit of miles. The total jobs demonstrate the split ratio of household from block group A to different block groups for work and it will be used to calculate commute trip numbers of corresponding block group pairs.

Table 1. Sample of Commute Trips

Home Block Group	Work Block Group	Distance	Total Jobs
060150002023	060150002024	31.4	128
060150002023	060150002025	53.2	254
060150002023	060150002026	25.6	65

PEV Ownership

PEV ownership is a shapefile containing the total number of PEVs at each block group. This tool is designed as integration with "PEV GIS Toolbox" by Dillon T. Fitch, Gil Tal, and Michael Nicholas. The "PEV GIS Toolbox" will generate the PEV ownership of each blockgroup as a table, and the attribute table contains all required information. Additionally, users can create the PEV ownership shapefile by themselves, and it requires exactly the same column names as Table 2.

For example, assume there are 28 LongPEV households in block group A and they will be assigned proportionally to the three routes based on number of jobs at each destination which is defined in Table 1. Thus, the number of PHEV households who commute from block group A to block group B will be:

$$28 * \frac{128}{128 + 254 + 65} \approx 9.4$$

Table 2. Sample of PEV Ownership

GEOID	New Car Households	PEV Households	LongPEV Households	ShortBEV Households
060150002023	237	48	28	20
060150002024	144	17	10	7

PEV Scenario

PEV scenario is a table that contains the split ratio of different PEV modes. Users can define vehicle populations two ways: generally (assume the split ratio is consistent everywhere in each block group) or specifically where each block group (or tract or county) vehicle population is defined. Table 3 shows a general scenario, and Table 4 shows a specific scenario.

For the general scenario in Table 3, each row represents the split ratio of PEV technologies within a category. There are 2 categories: Long and Short. Within each category there is a split of vehicle technologies that sum to 100% within the category. Within the Long category are BEV150+ and all PHEVs. Within the short category, are all BEVs less than 150 miles range. The column name requires names to be exactly the same as in Table 3. PEV type can only be "PHEV", or "BEV" prepended with long or short. Efficiency is in miles per kWh.

According to the previous calculation, there are 9.4 LongPEV households that commute from A to B. Among those households, the number of PHEV20 households will be:

$$9.4 * 0.4 \approx 3.8$$

Table 3. Sample of General PEV Scenario

PEV Type	Model	Range	Split Ratio	Efficiency
LongPHEV	Prius	11	0.15	2.82
LongPHEV	Ford	20	0.4	2.61
LongPHEV	Volt	38	0.25	2.82
LongBEV	Tesla60	245	0.05	2.82
LongBEV	Tesla85	265	0.15	2.64
ShortBEV	BEV80	80	0.98	3.41
ShortBEV	BEV100	150	0.02	2.82

Users can also define specific PEV scenario for each tract as shown in Table 4.

Table 4. Sample of Specific PEV Scenario

Tract	PEV Type	Model	Range	Split Ratio	Efficiency
6115040100	LongPHEV	Prius	11	0.15	2.82
6115040100	LongPHEV	Ford	20	0.4	2.61
6115040100	LongPHEV	Volt	38	0.25	2.82
6115040100	LongBEV	Tesla60	245	0.05	2.82
6115040100	LongBEV	Tesla85	265	0.15	2.64
6115040100	ShortBEV	BEV80	80	0.98	3.41
6115040100	ShortBEV	BEV100	150	0.02	2.82
6115040200	LongPHEV	Prius	11	0.15	2.82
6115040200	LongPHEV	Ford	20	0.4	2.61
6115040200	LongPHEV	Volt	38	0.25	2.82
6115040200	LongBEV	Tesla60	245	0.05	2.82
6115040200	LongBEV	Tesla85	265	0.15	2.64
6115040200	ShortBEV	BEV80	80	0.98	3.41
6115040200	ShortBEV	BEV100	150	0.02	2.82

Range Buffer (Miles)

This value is the minimum value drivers will arrive home with after a round-trip commute. In a BEV80 with a range buffer of 10 miles, the driver will never use more than 70 miles of the available 80 miles. A BEV80's "useful range" is 80 minus its range buffer.

Convenience Buffer (Miles)

A further range reduction is possible for BEVs with the "convenience range" or the amount of extra travel required to overcome the inconvenience of plugging in. If this is again 10 miles, the "preferred range" of the vehicle would be 60 miles. 60 miles is used as the threshold for determining whether a user will plug in when they don't technically need it, but if it is the same price as home, they will plug in at work anyway. If it is free, it will help determine how many days a user skips plugging in if the commute is short.

Work Charging Price

Price, range, and the inconvenience of plugging in have an interaction that affects charging demand. For the workplace scenarios, we assume a straightforward interaction where users will minimize cost to the extent possible within the range limits of their vehicle. Driving using home electricity is assumed to be cheaper than driving on gasoline. There are three pricing scenarios at work: free, equal to home and more than home but less than gasoline on a cents per mile basis. Inconvenience is reflected in a reduction of battery range of the vehicle.

The range in a PHEV is simply the nameplate range of the car so that a PHEV20 will have 20 miles of useful range. There are 3 ranges for a BEV80. Nameplate = 80 miles, Useful = (Nameplate minus Range Buffer), and Preferred = (Useful minus Convenience Buffer). Here are some of the interactions these ranges have with price.

1. By default, the charging price at work is assumed to be the same as charging at home. In this case, if the vehicle cannot complete a round-trip between home and work on electricity, the PEV will charge at work and the electricity consumption is determined by commute distance and battery size. If the vehicle can complete a round-trip on electricity, PEV drivers will not charge at the workplace. For BEVs when the price of electricity is the same at home and work, and additional factor is considered, a "convenience buffer". If the round trip is longer than the preferred range, but still possible a BEV will plug in at home and work.
2. By choosing free work charging, it is assumed that commuters will charge at work as many times as possible while avoiding charging at home. If the vehicle can complete at least one round-trip on electricity, there are two more parameters that define charging strategy: the PEV won't be charged if it can make more than one round trip within the preferred range, but the PEV will be charged at least every maximum charging interval days.
3. By choosing paid work charging, it is assumed that the charging price at work is higher than at home, so people will only charge at work when it is necessary to stay on electric drive within the useful range of the car.

Below are some scenarios to explain the interactions.

Scenario 1: Interval threshold is once per 2 days. Range buffer set to 10 miles. Convenience range at 11 miles. Preferred range is 59 miles. Useful range is 70 miles. 7 mile one-way commute.

- Free work charging.
    - BEV80 with 7 mile commute will charge 28 mi/day every 2 days
    - PHEV20 with a 7 mile commute will charge 14 mi/day
- Same price as home (neither checked)
    - BEV80 with 7 mile commute will charge 0 miles per day
    - PHEV20 with a 7 mile commute will charge 0 mi/day
- Paid work charging
    - BEV80 with 7 mile commute will charge 0 mi/day
    - PHEV20 with a 7 mile commute will charge 0 mi/day

Scenario 2: Interval threshold is once per 2 days. Range buffer set to 10 miles. Convenience range at 11 miles. Preferred range is 59 miles. Useful range is 70 miles. 15 mile one-way commute.

- Free work charging.
    - BEV80 with 15 mile commute will charge 30 mi/day every day
    - PHEV20 with a 15 mile commute will charge 15 mi/day

- Same price as home (neither checked)
  - BEV80 with 15 mile commute will charge 0 miles per day
  - PHEV20 with a 15 mile commute will charge 15 mi/day
- Paid work charging
  - BEV80 with 15 mile commute will charge 0 mi/day
  - PHEV20 with a 15 mile commute will charge 15 mi/day

Scenario 3: Interval threshold is once per 2 days. Range buffer set to 10 miles. Convenience range at 11 miles. Preferred range is 59 miles. Useful range is 70 miles. 30 mile one-way commute.

- Free work charging.
  - BEV80 with 30 mile commute will charge 60 mi/day every day
  - PHEV20 with a 30 mile commute will charge 20 mi/day
- Same price as home (neither checked)
  - BEV80 with 30 mile commute will charge 30 miles per day
  - PHEV20 with a 30 mile commute will charge 20 mi/day
- Paid work charging
  - BEV80 with 30 mile commute will charge 0 mi/day
  - PHEV20 with a 30 mile commute will charge 20 mi/day

Total Number of Commuters per Home Block Group

Total number of commuters per home block group will help to determine representativeness of each commuter. This is especially important when the model is implemented to specific regions instead of statewide.

Table 5. Sample Table of Total Number of Commuters per Home Block Group

Home Block Group	Total Jobs
60014001001	850
60014002001	336

Maximum Charging Interval (Days)

This is another parameter that defines BEV drivers charging behavior. It defines the maximum charging interval in days so that BEV drivers will not charge every day at the workplace if multiple round trips can be completed within the preferred range. However, if there is very short commute of say 2 miles round trip, even if the BEV can make 35 round trips, a “maximum charging interval” of 2 days would trigger a charging event every other day, regardless of how many round trips are technically possible.

Time of Day Setting

The last set of parameters in this tool is time-of-day setting. Because LODES data are based upon the W-2 records, it does not take into account when people commute. Therefore, the total number of commute trips in LODES dataset tend to be overestimated. In American Community Survey dataset, the number of residents commuting is reported in 16 departure time intervals. These can be found the eighth table in ACS geodatabase, named as "X08_COMMUTING", and the variables are B08302e1-B08302e15. The workplace charging toolbox was developed to estimate charging demand based on arrival time, median commute travel time (30 minutes) is applied in the toolbox. It means if the commute trips between 06:00-06:29 (departed) are used to estimate the workplace charging demand between (06:30-06:59). There are 16 checkboxes in the bottom of tool, and users must select at least one check box to run the workplace tool.

Model Calibration and Validation

The DVRCP planning area is spread over two states and two sets of travel demand modeling tools. That allows us to test the travel demand model included in the GIS toolbox and to calibrate based on the tool origin and destination matrix vs the local travel demand model. We run the workplace charging model using three values for the cost of workplace charging Network Analyst data of commuting distances for each state.

We started by exploring the time of day distribution of commute trips in DVRPC area. Time of day scaling factor was computed based on the ratio between the number of commuters at given time interval and the total number of commuters in each zone. The American Community Survey data was used to calculate this scaling factors, we use "ACS_2015_5YR_BG_34_NEW_JERSEY.gdb", "ACS_2015_5YR_BG_42_PENNSYLVANIA.gdb" files. Within each gdb file, "X08_COMMUTING" table contains the commute travel information from DVRCP and then, it was applied to the LODES data. The total number of commute trips in LODES data were scaled; Two tables were joined based on origin block group IDs: h_blkgrp, and totaljobs was multiplied by the scaling factors).

We started by combining DVRPC travel analysis zones (TAZ) with the block group level data to compare total number of commute trips as presented in Figure 4.

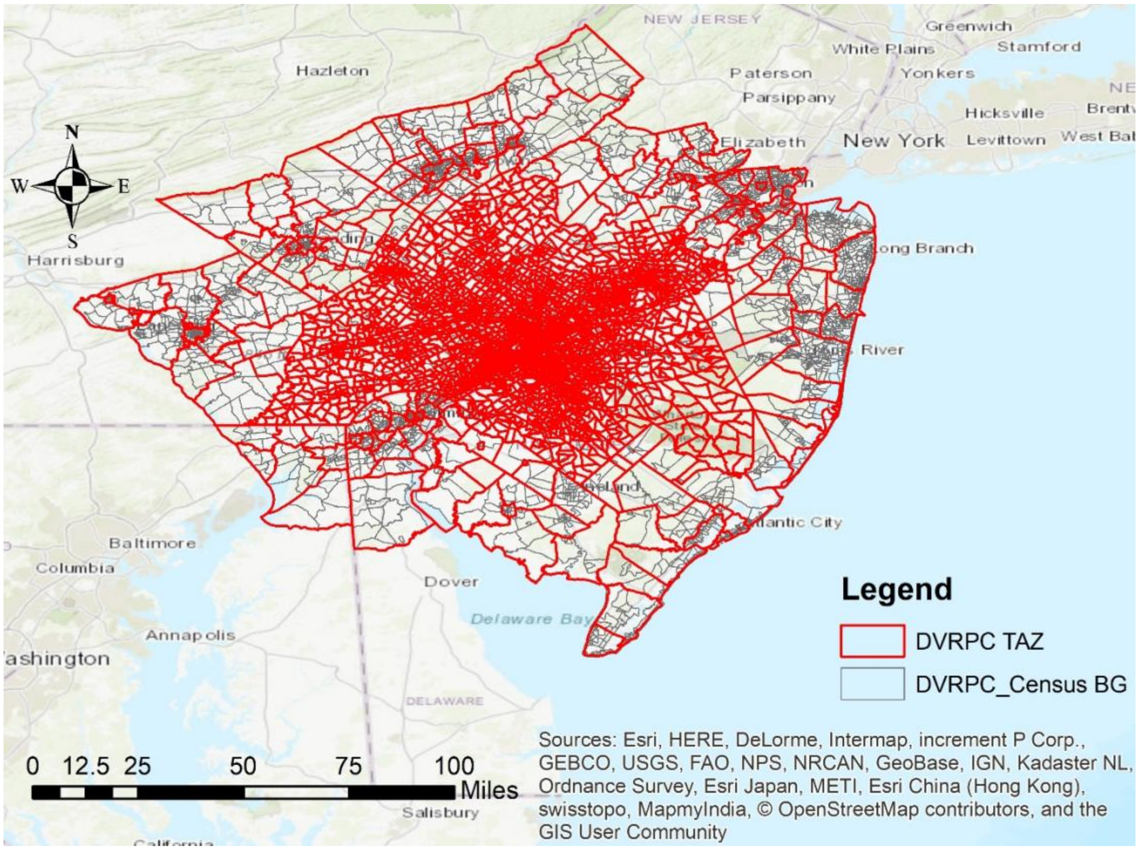


Figure 4. Spatial join and aggregation (Matched in TAZ level)

The initial results show high correlation between the tool OD matrix and the MPO matrix but with much higher total trips estimated (Figure 5) DVRCP shows 2.1 million commute trips per day. The total LODES home-work ODs is 4.3 million which includes telecommuters, part time employees and all modes commuters.

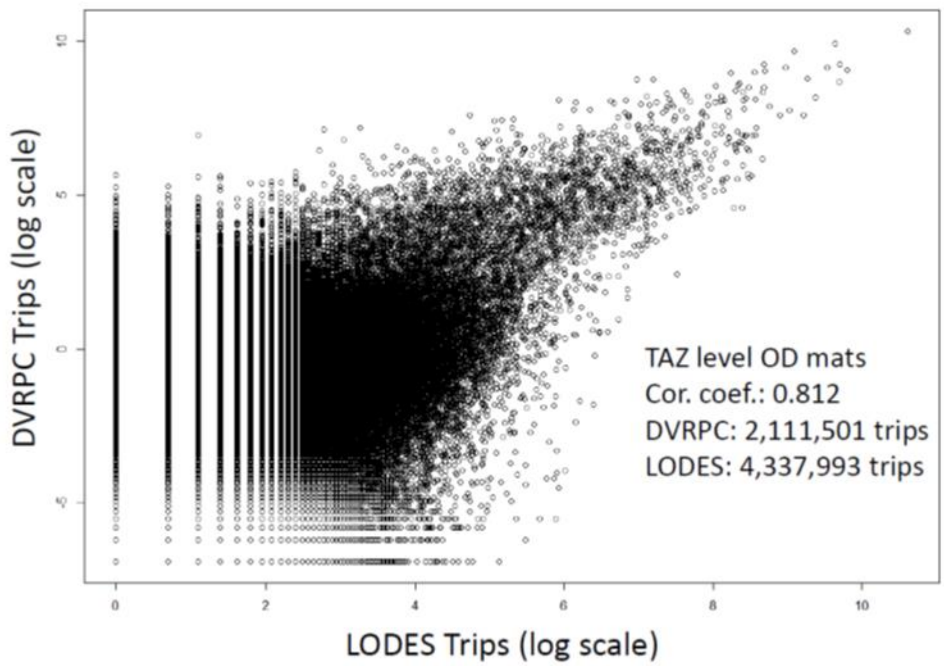


Figure 5. Origin-Destination matrices comparison between DVRPC and LODES trips. LEHD Origin-Destination employment statistics (LODES) from: https://lehd.ces.census.gov/data/#lodes

To account for the difference between the two models we applied four steps analysis including: filtering external zones (MPO data), calculating scaling factors based on ACS data (AM Peak or Vehicle commute trips / All commute trips per zone) and applying scaling factors and comparison for each block group.

Next, we calibrated the total number of PEVs forecasts by the household model with the 2017 DMV records for both states in the VDRPC region and tested the results against the total number of plug-in vehicles and Toyota Prius vehicles in each zone. The Prius is not an electric vehicle, but early research in California suggests high correlation between the early adopters of hybrid and electric vehicles.

Results and Tool Demonstration

The DVRPC team selected two scenarios to run and loaded the results to an online mapping tool. This toolkit produces, at the census block group level, predictions of the spatial distribution of Plug-In Electric Vehicles (PEVs) and the workplace charging demand of those vehicles. The calculations are based on the current distribution of PEVs from PennDOT and NJDOT, demographic data from the ACS 5-year summaries, commuting data from LODES, and commuting distances between block groups from DVRPC's Travel Demand Model. The spatial distribution of PEVs and demand for workplace charging reflect the following scenarios:

- DVRPC Region: 5 percent of passenger vehicles (or about 200,000 vehicles) are PEVs;
- Pennsylvania: 5 percent of passenger vehicles (or about 400,000 vehicles) are PEVs;

- New Jersey: 330,000 passenger vehicles (about 10 percent) are PEVs. (This is in line with the New Jersey state-wide EV adoption goal).

PEV Distribution shows layers for current and future numbers of PEVs at the census block group and municipal levels. The municipal PEV counts were aggregated from the census block group counts, assigning the counts from each block group to the municipality housing that block group's centroid. Workplace Charging Demand shows layers depicting workplace charging demand in number of charging events and kWh of demand by census block group for the following three scenarios: workplace charging is free, workplace charging is the same cost as home charging, and workplace charging is twice the cost of home charging.

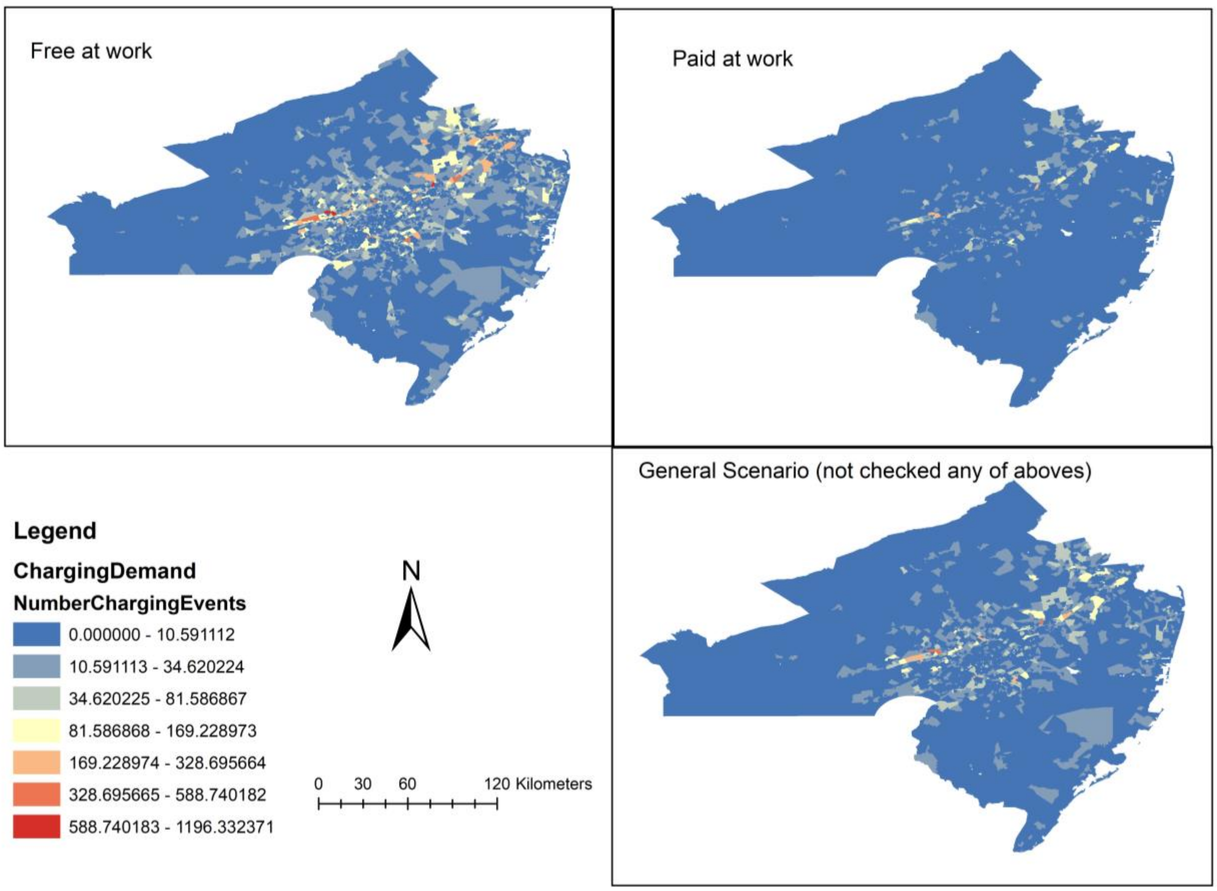


Figure 6. Demand for charging in terms of number of charging events at work under free and paid scenarios

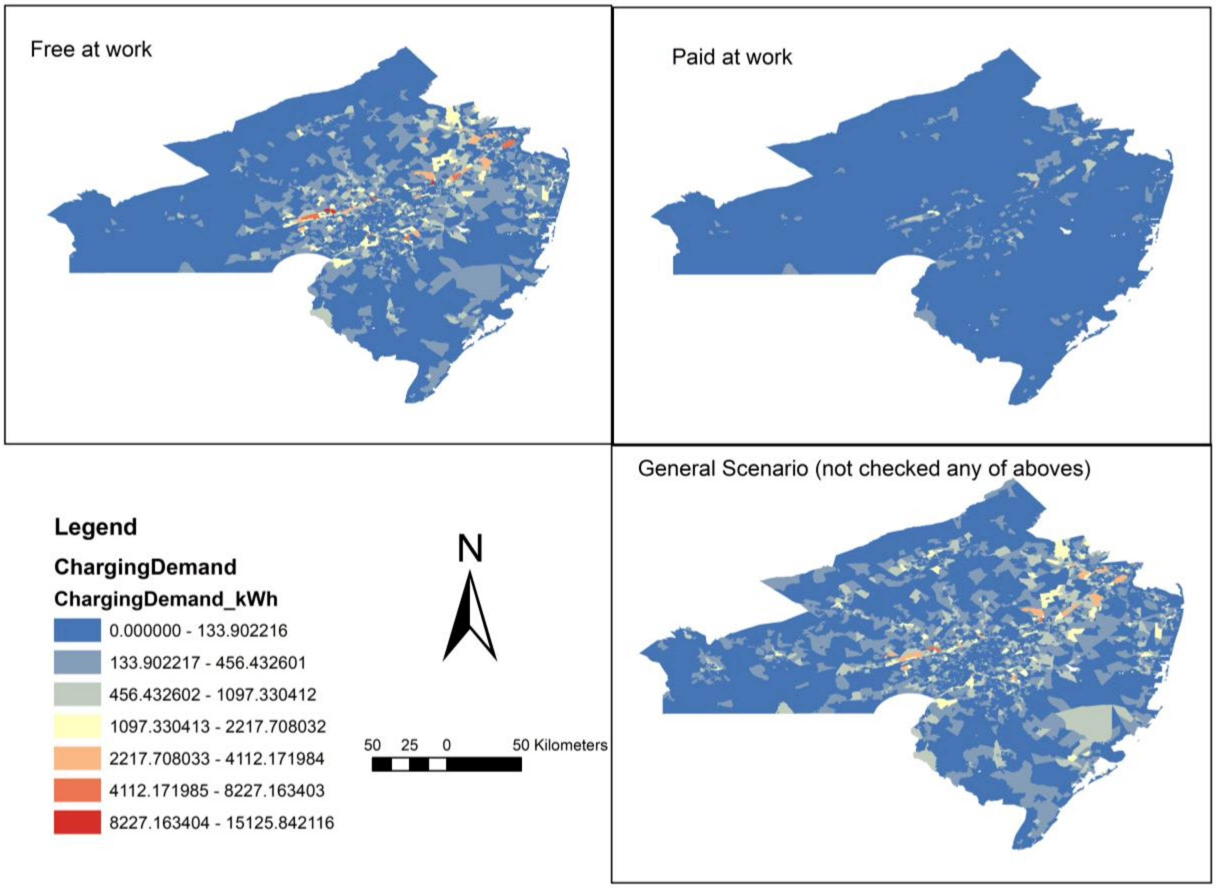


Figure 7. Demand for charging in terms of number of kWh at work under free and paid scenarios. Created from: https://dvrpcgis.maps.arcgis.com/apps/MapSeries/index.html?appid=793fa4e10eac43b387adfc9cd2621a3d

In comparing the results of these two scenarios showing either free or paid workplace charging, it is clear that free charging will create a much higher demand both in terms of number of charging events and total kWh energy demand. This requires the installation of more chargers to meet the demand and would likely require upgrades to the electrical grid systems serving EV drivers at workplaces. This becomes particularly challenging in central business districts and other areas with high workplace density. Paid workplace charging may be important in reducing the upfront investment needed to encourage EV adoption and balance workplace and home charging demands.

Conclusion

The goal of this project is to create a set of infrastructure demand planning tools that are using the state of the art knowledge from academia, the best publicly available data, and the ability to be run managed and used by local planners entrusted with the task. In this project we translated a planning tool calibrated to California in 2014 to a tool used by the Delaware Valley Regional Planning Commission (DVRPC) that can now create new scenarios and update the results based on local policies and new technologies. We updated our charging behavior assumption based on data collected over the years (for example to match PHEV owners charging more than once a day when needed) and the impact of home charging availability.

The final results are still yet to be tested against the growing numbers of electric vehicles in the study region since 2017.

References

1. Governor’s Interagency Working Group on Zero-Emission Vehicles. (October 2016). Office of Governor Edmund G. Brown Jr. “2016 ZEV Action Plan: An updated roadmap toward 1.5 million zero-emission vehicles on California roadways by 2025”.

2. ZEV Program Implementation Task Force (2014). “Multi-State ZEV Action Plan.”

3. Tal, Gil, Dillon T. Fitch, and Michael A. Nicholas (2014). “Modeling the Spatial Distribution of Plug-in Electric Vehicle Owners in California: A GIS Scenario Planning Tool. Institute of Transportation Studies at UC Davis, Working Paper UCD-ITS-WP-14-06

Data Management

Add publicly available data used in this project was directly downloaded from the census website https://www.census.gov/

Products of Research

No data was collected to complete this project.

The project is based on publicly available data including (December 2017) distribution of PEVs from the Pennsylvania Department of Transportation (PennDOT) and the New Jersey Motor Vehicle Commission (NJ MVC) via the New Jersey Department of Environmental Protection (NJ DEP); demographic data from the 2012-2016 American Community Survey (ACS) 5-year summaries; commuting data from Longitudinal Employer-Household Dynamics (LEHD) Origin-Destination Employment Statistics (LODES), version 7;

Data Format and Content

Not applicable.

Data Access and Sharing

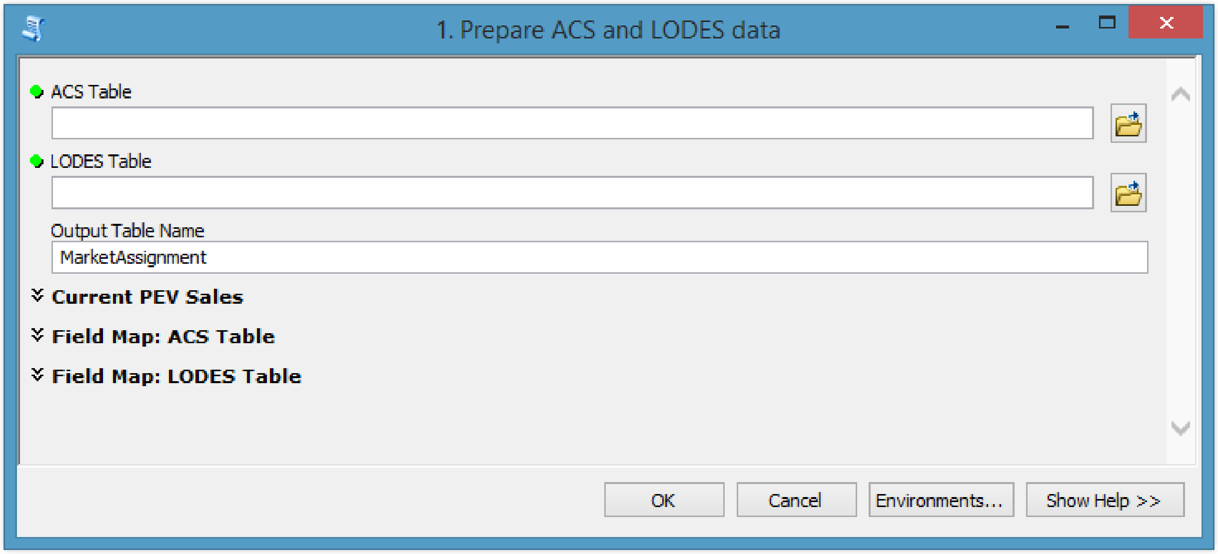
The demographic data from the 2012-2016 American Community Survey (ACS) 5-year summaries and the commuting data from Longitudinal Employer-Household Dynamics (LEHD) Origin-Destination Employment Statistics (LODES), version 7 can be downloaded from https://lehd.ces.census.gov/data/.

Calibrated data can be downloaded from https://dvrpcgis.maps.arcgis.com/apps/MapSeries/index.html?appid=793fa4e10eac43b387adfc9cd2621a3d

Reuse and Redistribution

Additional data can be used based on the Delaware Valley Regional Planning Commission (DVRPC) terms https://www.dvrpc.org/policies.

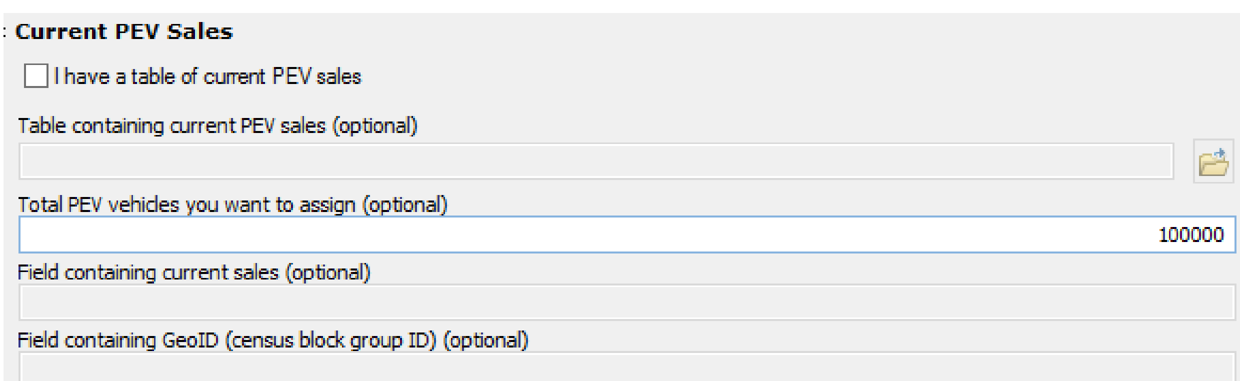
Appendix A: Market Tool Input Setting



Inputs – both input tables need to be file geodatabase tables

1. ACS table
   a. The nationwide ACS table (PennDOT_NJ_InputData_1.gdb\acs_data)

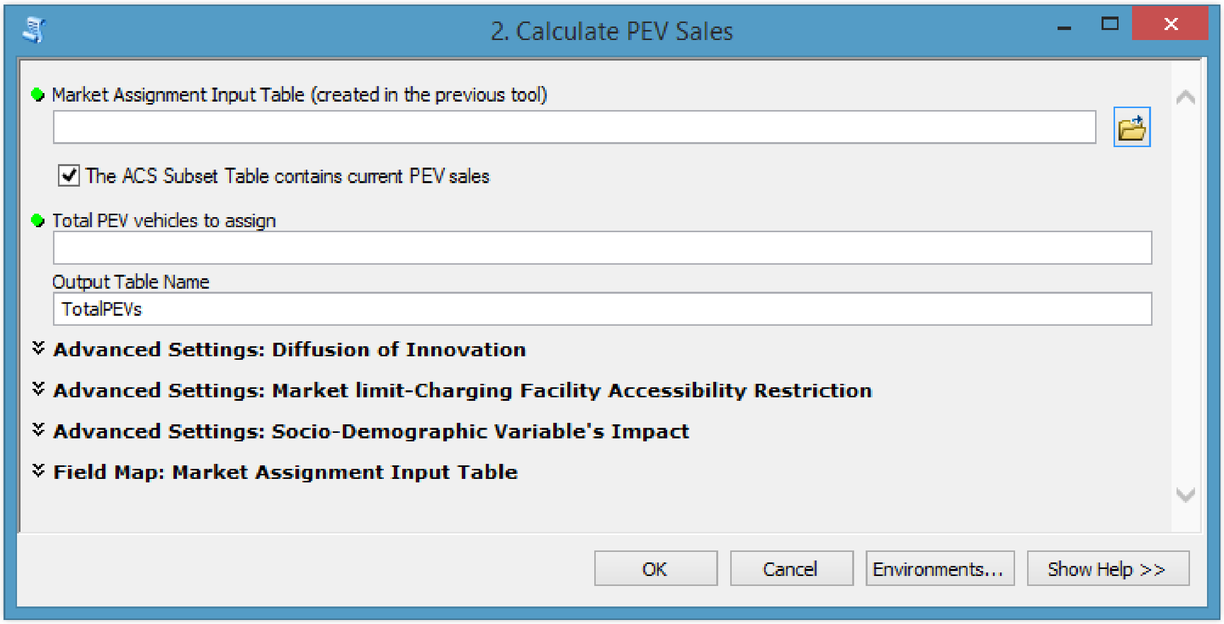
2. LODES Table
   a. The LODES table for your study area
      i. Provided is a LODES table for the entire US (PennDOT_NJ_InputData_1.gdb\LODES_NJ_Penn_art_20mile). You need to select from this table all of the home block groups in your study area. Export this selection to a new table, and input that here.



The tool needs to know if you already have current PEV sales for your study area. If you do, then it will attach these values to the output table. If you do not, it will estimate current sales. Use the first box to indicate whether or not you have a table of current PEV sales.

If you do not, put a number in the second box (shown above) that represents how many sales you will be allocating in the second tool of this toolbox. It will assign 5% of these as "current sales"

If you want to use, add PennDOT_NJ_InputData_1.gdb\CurrentPEV in the second box then select the 2 fields that contain the 2 important values: the one containing current sales and the one containing the census block group numbers.



1. Market Assignment Table
    a. This is the output from the first tool.
2. Check this box if the table added in the box above (the market assignment table) contains current PEV sales. If you used the first tool, then check this box.
3. Total PEV vehicles to assign
    a. Input the total number of PEV vehicles you want to assign
4. Output Table Name
    a. Input a name for the output table from this tool that will contain the current PEV sales

Appendix B: Workplace Charging Demand Tool Input Setting

There are three result files generated, as the figure on the right shows. CommuteTrips contains detailed information about the number of commuters who travel between each block group pairs and the amount of electricity they consume, as Table A1 shows. ChargingDemand_stat contains summary information about electricity consumption for each work block group. This is also the attribute table of the ChargingDemand file.

- WorkplaceCharging_Results.gdb
  - ChargingDemand
  - ChargingDemand_stat
  - CommuteTrips

Table A1. Sample Result of Commute Trips

Table

CommuteTrips

Home_BlkGrp	Work_BlkGrp	total_Jobs	Distance	JobRatio	LongPEVHHs	ShortBEVHHs	Ford	Prius	Volt	Tesla60	Tesla85	BEV80	BEV100	TotalChargingDistance_Mi	TotalChargingDemand_kWh	NumberChargingEvents
60014010001	60590626102	2	411.385386	0.00885	0.008797	0.003105	0.001552	0.003519	0.005278	0.001087	0.000466	0.001552	0.001552	1.002829	0.334276	0.011901
60014010002	60372077101	3	372.24259	0.009231	0.001619	0.00054	0	0.000648	0.000972	0	0	0.00027	0.00027	0.176497	0.058832	0.002159
60014010002	60372079001	2	373.241705	0.006154	0.001079	0.00036	0	0.000432	0.000648	0	0	0.00018	0.00018	0.117665	0.039222	0.001439
60014010002	60373107022	3	362.609273	0.009231	0.001619	0.00054	0	0.000648	0.000972	0	0	0.00027	0.00027	0.176497	0.058832	0.002159
60014010002	60374083011	2	387.560875	0.006154	0.001079	0.00036	0	0.000432	0.000648	0	0	0.00018	0.00018	0.117665	0.039222	0.001439
60014010002	60590626102	3	411.31543	0.009231	0.001619	0.00054	0	0.000648	0.000972	0	0	0.00027	0.00027	0.176497	0.058832	0.002159
60014010002	61110053032	2	387.171595	0.006154	0.001079	0.00036	0	0.000432	0.000648	0	0	0.00018	0.00018	0.117665	0.039222	0.001439
60014013001	60371239013	2	358.090857	0.004938	0.026565	0.008085	0.004331	0.010626	0.015939	0.003032	0.001299	0.004043	0.004043	2.699263	0.899754	0.03465
60014013001	60590626102	4	410.490664	0.009877	0.053131	0.01617	0.008663	0.021252	0.031878	0.006064	0.002599	0.008085	0.008085	5.398526	1.799509	0.069301
60014014001	60372170023	2	372.982094	0.005291	0.007425	0.002475	0.001238	0.00297	0.004455	0.000866	0.000371	0.001238	0.001238	0.809333	0.269778	0.0099
60014014001	60373107022	3	362.099222	0.007937	0.011138	0.003713	0.001856	0.004455	0.006683	0.001299	0.000557	0.001856	0.001856	1.214	0.404667	0.01485
60014014001	60375039022	2	390.618619	0.005291	0.007425	0.002475	0.001238	0.00297	0.004455	0.000866	0.000371	0.001238	0.001238	0.809333	0.269778	0.0099
60014014001	60590218144	2	404.770759	0.005291	0.007425	0.002475	0.001238	0.00297	0.004455	0.000866	0.000371	0.001238	0.001238	0.809333	0.269778	0.0099
60014014001	60590626102	4	410.757226	0.010582	0.01485	0.00495	0.002475	0.00594	0.00891	0.001733	0.000743	0.002475	0.002475	1.618667	0.539556	0.0198
60014014001	60590755151	2	408.90531	0.005291	0.007425	0.002475	0.001238	0.00297	0.004455	0.000866	0.000371	0.001238	0.001238	0.809333	0.269778	0.0099
60014014001	60710033024	2	419.871978	0.005291	0.007425	0.002475	0.001238	0.00297	0.004455	0.000866	0.000371	0.001238	0.001238	0.809333	0.269778	0.0099
60014015001	60372077101	2	372.934751	0.006944	0.008121	0.002842	0.001624	0.003248	0.004873	0.001137	0.000487	0.001421	0.001421	0.919723	0.306574	0.010964
60014015001	60373107022	2	362.513805	0.006944	0.008121	0.002842	0.001624	0.003248	0.004873	0.001137	0.000487	0.001421	0.001421	0.919723	0.306574	0.010964
60014015001	60590320531	2	425.604743	0.006944	0.008121	0.002842	0.001624	0.003248	0.004873	0.001137	0.000487	0.001421	0.001421	0.919723	0.306574	0.010964

1 (0 out of 1084037 Selected)

CommuteTrips

NCST

Appendix C: Limitations

The Longitudinal Employer-Household Dynamics Origin-Destination Employment Statistics (LODES) Data provides detailed information about employment including home and work block group, travel distance, and the total number of jobs. Thus, LODES data can be used as the commute trips. But there are several limitations to LODES data which requires interpretation by users.

For companies that distribute among several block groups, the work location of all employees might be assigned to one singe block group in LODES data which could cause misunderstanding. For example, the campus of University of California, Davis covers several block groups but all employees of UC Davis are assigned to work at the same block group as highlighted in Figure A1 which causes the model result to not reflect the exact location of work charging demand.

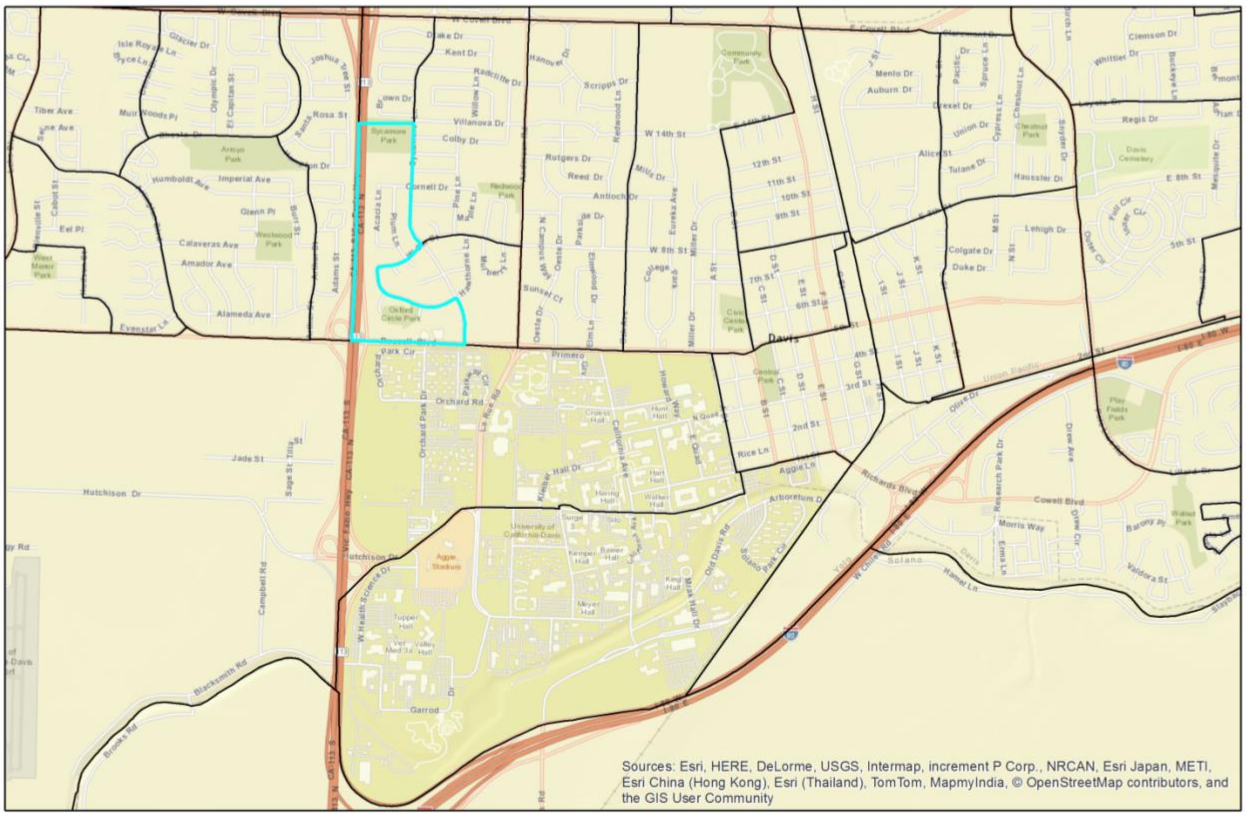


Figure A1. Block group in which all UC Davis employees are assigned to work according to LODES Data

In order to eliminate the bias caused by different block group size, the density of charging demand (calculated as the total charging demand divided by the size of corresponding block group) can be used to evaluate the concentration of workplace charging demand. It should reflect the density of employment, but it could cause misunderstanding for large block groups. For example, Google headquarters at Mountain View has over 10,000 employees and it has dense demand for workplace charging. However, the size of the corresponding block group where Google headquarters is located, as highlighted in Figure A2, is much larger than the average size of block groups. Therefore, that block group has very high total charging demand but a relatively low density of charging demand.

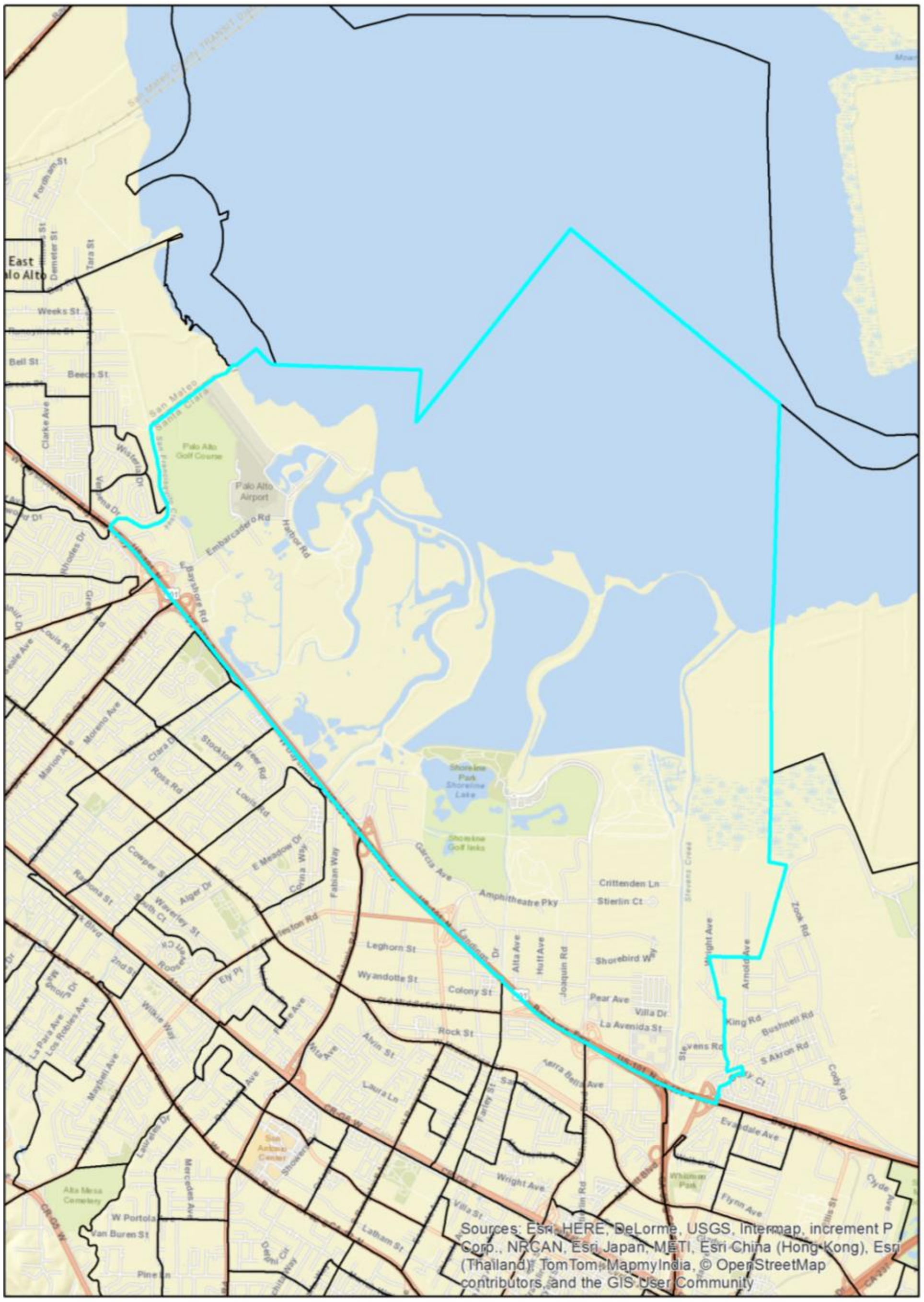
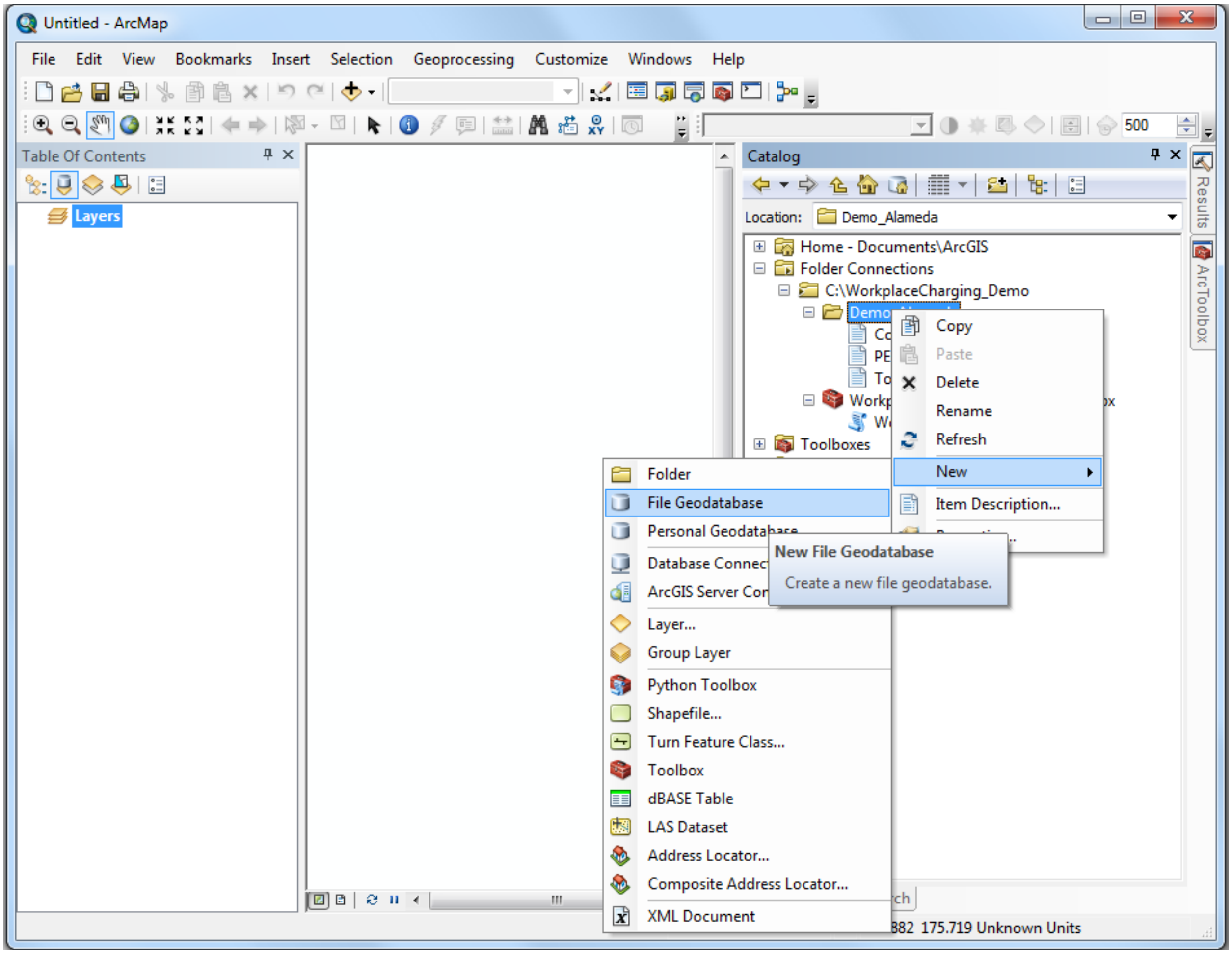


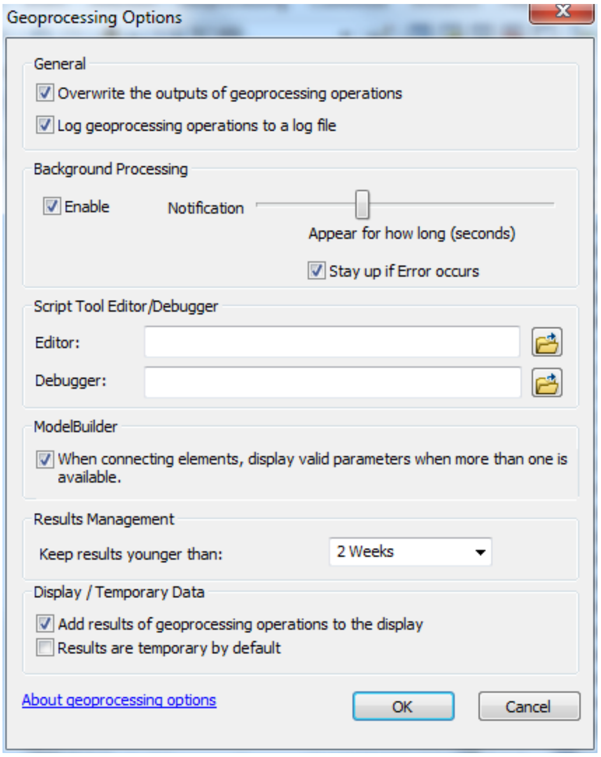
Figure A2. Block group of Google headquarters

Appendix D: Tutorial about “WorkCharging” ToolBox

1. Create a new Geodatabase as the workspace for later analysis.

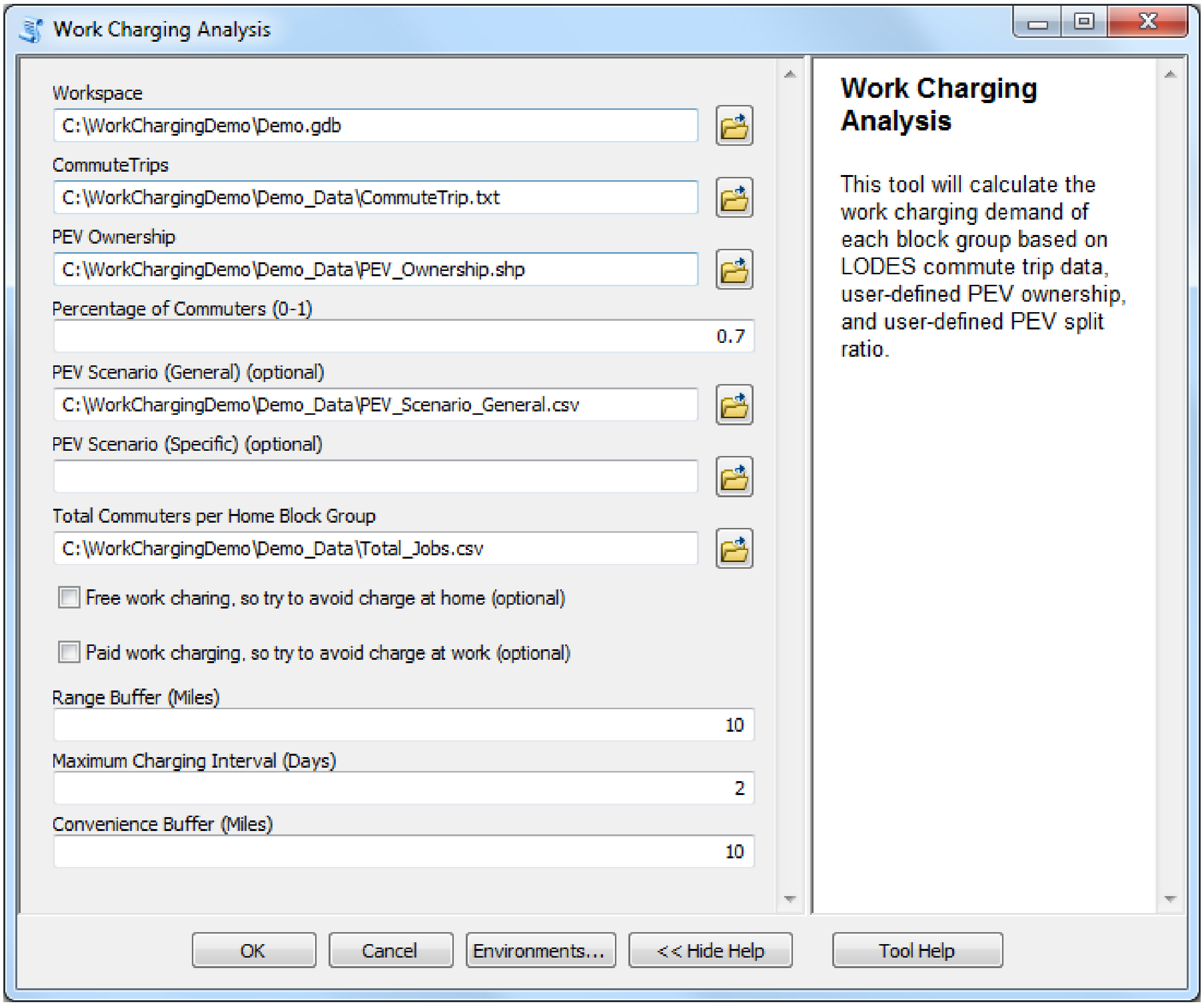


2. In the Geoprocessing Options, make sure the "overwrite the outputs of geoprocessing operation" is checked.



NCST

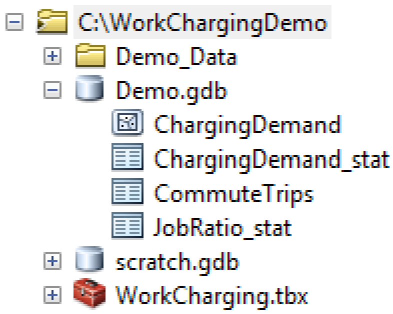
3. Run the “Work Charging Analysis” tool in the “WorkCharging” toolbox. All data required for this analysis are in the “Demo_Data” folder.



4. Select the time of day you are interested in

- [ ] 12:30am - 5:30am (optional)
- [ ] 5:30am - 6am (optional)
- [x] 6am - 6:30am (optional)
- [x] 6:30am -7am (optional)
- [x] 7am - 7:30am (optional)
- [x] 7:30am - 8am (optional)
- [x] 8am - 8:30am (optional)
- [x] 8:30am - 9am (optional)
- [ ] 9:am - 9:30am (optional)
- [ ] 9:30am - 10:30am (optional)
- [ ] 10:30am - 11:30am (optional)
- [ ] 11:30am - 12:30am (optional)
- [ ] 12:30pm - 4:30pm (optional)
- [ ] 4:30pm - 12:30am (optional)

5. After running the tool, there should be some results as following:



- *ChargingDemand*

  This is a shapefile with same polygons as the PEV_Ownership but also the charging demand results in its attribute table.

- *CommuteTrips*

  This table contains detailed information about the number of commuters, total charging distance, total charging demand and number of charging events travel between block groups.

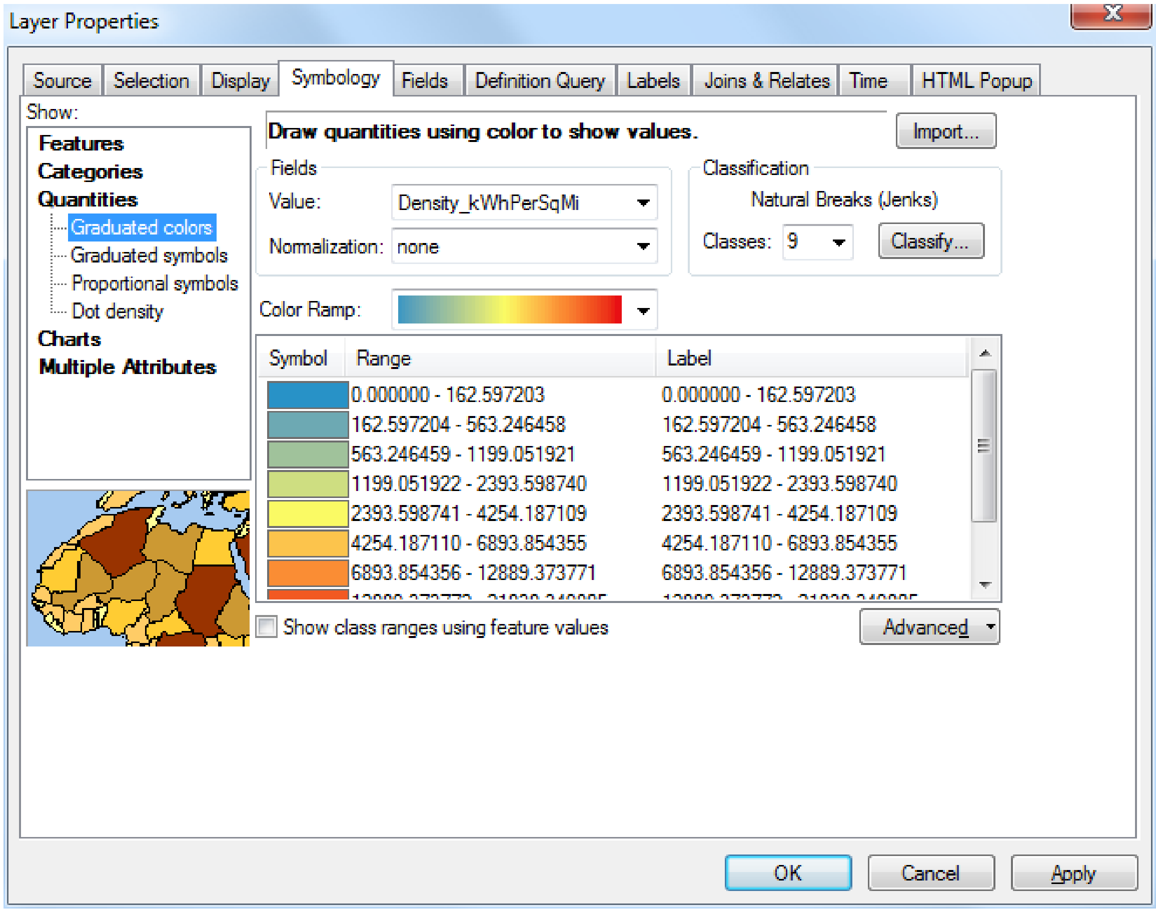
- *ChargingDemand_stat*

  This is a summary table about total work charging demand by block group.

- *JobRatio_stat*

  This is a summary table about total number of jobs from each home block group. This helps to calculate the JobRatio in the "CommuteTrips" table which is the ratio of job number between specific block groups and the total job number from the corresponding home block group.

6. The total charging demand of each block group can be visualized by right clicking the “ChargingDemand” layer and set its symbology to be graduated colors based on the value of “Density_kWhPerSqMi”.



And the result would be: