State of Charge: Technical Appendix
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Appendix A: Calculating Emissions from EV Charging

Average vs. Marginal Emissions

There is more than one way to estimate the emissions from charging an EV on the electricity grid, and from using electricity in general. The approach we have chosen, which involves the average emissions intensity of all electricity production in various regions of the country, treats all the electricity produced and consumed in a region equally. That is, no matter how much electricity you use or whether you were using it yesterday or not, your electricity is assumed to be just as clean (or dirty) as anyone else’s.

The data we used to estimate regional global warming emissions intensities were based on actual reported power plant emissions for the year 2009. In its Emissions & Generation Resource Integrated Database (eGRID), the U.S. Environmental Protection Agency (EPA) assembled global warming and other emissions data from thousands of power plants operating across the country. The EPA then computed emissions for 26 regions across the entire United States, based on the power plants that supplied electricity to households in those regions.

An alternative approach involves “marginal” emissions. The marginal emissions intensity is estimated by examining what power plants, or types of power plants, are likely to be deployed when new electricity demand is added to the electricity grid above and beyond the demand that already exists. For example, the electricity consumed by an additional load, such as a newly purchased EV or even an extra television set, would have a slightly different emissions intensity from electricity used by an existing light fixture in your home.

The concept of marginal electricity rates is important, especially when evaluating how electricity demand from thousands or millions of new EVs added to the grid over the coming decades will be met. If the new generation needed to meet EV charging demand is composed of renewables or other sources of generation that are cleaner than existing power plants, then the net impact of EVs will be to lower the grid’s emissions intensity. If new plants are built that have higher emissions rates than today’s average, the net impact of increased EV demand will be to increase emissions intensity. This fact has inspired a variety of analyses, using marginal emissions approaches, to evaluate the potential impact of increasing amounts of EV charging on future emissions of the electricity grid (ANL 2010; ORNL 2008b; EPRI and NRDC 2007a; NREL 2007).

While a marginal emissions analysis of EV charging is important for forward-looking studies of the policy implications of large-scale EV adoption, our goal in
this analysis is to give consumers an idea of what the typical global warming emissions of the electricity used to charge their EV will be on today’s electricity grid. Therefore we use the average emissions intensity of the electricity, essentially treating all electricity on the grid at a given time as a shared resource, or pool of electrons, available to all electricity consumers. This approach ignores the impact of any changes in electricity production that may be caused by a single individual plugging in an EV—an impact that is virtually imperceptible.¹

**Regional Emissions Estimates: Data Sources and Calculations**

The greenhouse gas (GHG) emissions we attribute to driving an electric vehicle are those that result from the production of electricity needed to charge the vehicle. We factor in emissions created by power plants when generating the electricity, and also emissions that result from obtaining and transporting the fuel used in these plants.

**Power Plant Emissions**

The emissions produced by electricity generation for EV charging come from the aforementioned eGRID database, which is a comprehensive source of emissions data for every power plant in the United States that generates electricity for the grid and that provides its data to the government (EPA 2010c). We used the most up-to-date version of eGRID possible, eGRID 2012 v1.0, which contains plant emissions and generation data from the year 2009 and subregion organization from the year 2012 (EPA 2012b). The GHG emissions rate for electricity generation for each of the 26 regions analyzed in the report comes from the *eGRID2012 Version 1.0 Subregion File (Year 2009 Data)* (EPA 2012a).

The subregions are groups of plants organized by the EPA based on Power Control Areas (PCAs) and North American Reliability (NERC) regions (EPA 2010c). These groupings, which are meant to reflect which power plants serve which households, reasonably approximate the grid mix of electricity used by those households. The level of disaggregation of the eGRID subregions allows for more precise calculation of plant GHG intensities than a national average, as regional variations in grid mix are taken into account. For this reason, eGRID was chosen over other data sources that had the same detailed plant information but fewer subregions. The actual grid mix of a household’s electricity is specific to the individual utilities serving each household, but specific grid-mix data are not readily available for most utilities and therefore were not used in the study.

¹ An individual EV driven 30 miles per day will consume about 300 kWh per month. This is the equivalent of adding less than half a household’s worth of electricity consumption to a regional grid with millions of homes (based on EIA data on average household electricity consumption).
eGRID’s methodology treats the subregions as closed systems, calculating the emissions intensity of generation for each one based on the emissions intensities of the plants it contains. This methodology ignores imports and exports of electricity between subregions, which harms the accuracy of the regional emissions estimates. Further disaggregation of these subregions would increase the precision of the emissions estimates, but would exacerbate the loss of accuracy due to the omission of imports and exports. Therefore, the 26 eGRID subregions are recommended by the eGRID’s designers as the level of disaggregation best suited for GHG emissions estimates of electricity use, as they achieve the best balance between the precision gained by disaggregation and the accuracy lost by omitting imports and exports (EPA 2009).

**Transmission Loss Factors**
The eGRID emissions rates do not account for transmission and distribution losses between the power plant and the household. To account for these losses, so we could calculate emissions per unit of energy used (rather than energy produced), we followed eGRID’s recommendation (EPA 2010c) to increase the emissions rates using grid loss factors found in the file *eGRID2012 Version 1.0 Grid Gross Loss (Year 2009 Data)* (EPA 2012a), shown in Table A.2. There are five grid loss factors that vary by regions called interconnect power grids, and each state is given a grid loss factor based on the interconnect power grid it belongs to in the file *eGRID2010 Version 1.1 State Import-Export File (Year 2007 Data)* (EPA 2010a). Although eGRID subregions are based on utility service territories that do not coincide with state boundaries, we assigned each subregion one of these factors based on those of the states. The purpose of doing this was to avoid having multiple emissions rates for a single subregion that serves two or more states with different grid loss factors. The determination of which state grid loss factors were assigned to a subregion was based on a rough representational map of approximate subregion boundaries superimposed over state boundaries. For subregions that encompass parts of multiple states with different grid loss factors, the most prevalent grid loss factor—based on geographic area of the portions of the states comprising the subregion—was used.

**Upstream Emissions Factors**
The eGRID subregion emissions rates include only those emissions produced at the plant generating the electricity, and they exclude upstream emissions resulting from the mining and transport of the power plant feedstock (EPA 2010c). Therefore we calculated a feedstock emissions rate for each subregion;

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this rate depends on which fuel types the corresponding power plants use. Each fuel type has a unique upstream emissions rate, which we obtained from a life-cycle emissions model, called GREET, developed by Argonne National Laboratory. The percentage of generation from each fuel type in a subregion was then obtained from the eGRID2012 Version 1.0 Subregion File (Year 2009 Data) (EPA 2012a).

For each subregion, the fuel-type emissions rates are multiplied by the share of generation they represent in that subregion; the sum of these products is the subregion’s feedstock emissions rate. Most fuel types in GREET correspond directly to a fuel type in eGRID, but there were a few exceptions. A very small share of generation in eGRID subregions corresponds to a fuel type labeled “generic fossil;” for this fuel type, the emissions rate from GREET for natural gas was chosen as a conservative guess since its value is higher than those of coal and oil (the other two fossil fuels with known feedstock emissions rates in GREET). An even smaller share of generation in eGRID subregions comes from unknown sources; for this category of fuel type, the feedstock emissions rate (which varies for each region) is the generation-weighted average of the upstream emissions rates for the other fuel types.

GREET has already built a uniform grid loss factor into these feedstock emissions rates. But to keep the loss factors consistent with the power plant emissions rates, we back this factor out of the feedstock emissions rates. We then apply the same loss factor from eGRID used for power plant emissions rates to each subregion’s feedstock emissions rate.

Total GHG Emissions Rate of EV Charging
The total GHG emissions rate of EV charging for eGRID subregions was computed by summing the grid-loss-adjusted power plant emissions rates for each subregion with the corresponding grid-loss-adjusted feedstock emissions rate.

Determining Which Subregion Each City Is In
Each city analyzed in the report is mapped to one eGRID subregion and is assigned the GHG emissions rate of charging for that subregion. The cities are assigned to the subregions using the EPA’s Power Profiler Zip Code Tool v3-1. The Power Profiler identifies the electric utilities, each of which belong to a specific subregion, that serve a zip code, then maps subregions to zip codes accordingly. A separate zip code database was used to determine all the zip

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3 GREET v1_2011 was used; Feedstock emissions factors come from Table 9: Fuel-Cycle Energy Use and Emissions of Electric Generation: Btu or Grams per mmBtu of Electricity Available at User Sites (wall outlets) in the Electricity tab.
4 From the TOC tab of Power Profiler Zipcode Tool.
codes served by a city; these zip codes were then input to the Power Profiler so the corresponding eGRID subregions could be displayed.

In the large majority of cases, all zip codes are served by utilities that belong to the same subregion. In these cases it was straightforward to assign the city to that eGRID subregion. In a few cities (Jacksonville, El Paso, and Louisville), all zip codes are served by a primary utility belonging to the same subregion, but some of the minor utilities belong to a different subregion. In these cases only the subregion served by the primary utility was used, so that only one subregion was mapped to that city. In a few other cities (Memphis, District of Columbia, Kansas City, and Mesa), the predominant utility in some zip codes belongs to one subregion, while the predominant utility in other zip codes belongs to a different subregion. In these cases the predominant utility for the entire city was chosen, and whichever subregion it belongs to was mapped to that city.

**GHG Emissions Rate Assumptions and Results by Subregion**

The regional grid mix and estimated emissions intensity for all eGRID subregions, with adjustments for upstream emissions and grid losses, are shown in Tables A.1 and A.2.
Table A.1. Grid Mix By Region

<table>
<thead>
<tr>
<th>Grid Region Acronym</th>
<th>Name</th>
<th>% Coal</th>
<th>% Natural Gas</th>
<th>% Nuclear</th>
<th>% Biomass</th>
<th>% Hydro</th>
<th>% Wind, Solar, Geothermal</th>
<th>% Other Fossil</th>
<th>Emissions Intensity (gCO₂e/kWh)</th>
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<td>0</td>
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Source: EPA 2012a.
### Table A.2. EV Charging Emissions Rates by Region

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<tr>
<th>eGrid Subregion Acronym</th>
<th>Emissions from Power Plants (gCO₂e/kWh)</th>
<th>Transmission Loss Multiplier</th>
<th>Emissions from Power Plants after Transmission Loss (gCO₂e/kWh)</th>
<th>Upstream Emissions after Transmission Loss&lt;sup&gt;a&lt;/sup&gt; (gCO₂e/kWh)</th>
<th>2007 EV Charging Global Warming Emissions Rate (gCO₂e/kWh)</th>
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</table>

<sup>a</sup>Upstream emissions are those associated with the extraction and transportation of feedstocks for electricity generation.
Hourly Emissions Estimates: Dispatch Modeling with ORCED

UCS used a modified version of the Oak Ridge Competitive Electricity Dispatch Model to determine the emissions intensity of regional electricity generation on an hourly basis.

Estimation of Average Hourly Emissions

A modified version of the Oak Ridge Competitive Electricity Dispatch Model (ORCED), developed by Stanton Hadley at Oak Ridge National Laboratory, was used to determine the emissions intensity in 2010 of regional electricity generation in the United States on an hourly basis. Unlike the EPA’s eGRID2012 Version 1.0 database,\(^5\) which only reports how much electricity each power plant generates over the course of the year, our modified version of the ORCED model estimates the mix of power plants generating electricity at any given hour of the year. Like the eGRID database, the ORCED model makes use of subregions, each of which represents a network of power plants dedicated to meeting the electricity demand of a specific group of customers. The ORCED model, which uses a greater level of aggregation than the eGRID database, contains 13 regions that correspond to electricity-market module regions found in versions of the Annual Energy Outlook released before 2011. A different hourly grid mix is determined for each of the 13 subregions.

Below is a description of how the model was utilized and updated for this analysis. For a more in-depth presentation on the ORCED model, see The Oak Ridge Competitive Electricity Dispatch (ORCED) Model, online at apps.ornl.gov/~pts/prod/pubs/ldoc9472_orced_modelfinal.pdf.

ORCED Facilitates the Determination of an Hourly Grid Mix

The hourly estimate of the mix of generating units is made possible by an algorithm in the ORCED model that estimates the likely order in which utilities in each region will dispatch power plants to meet incremental increases in electricity demand. The dispatch order for each region is fixed throughout the year, but the level of demand at any given time, along with how much electricity each plant can produce, will determine how many plants need to be run. When electricity demand is high, more plants are running than when electricity demand is low; therefore the grid mix will be slightly different for different levels of demand. The grid mix at any given hour can therefore be estimated as long as one knows the demand at that hour; plants will be “turned on” sequentially following the dispatch order until the demand is met.

\(^5\) See www.epa.gov/cleanenergy/energy-resources/egrid/index.html.
**ORCED Was Modified to Display the Hourly Grid Mix**

The original ORCED model was not equipped with the capability to output the average emissions rate of the grid at a certain hour; instead, it generates output representative of an entire year. Nonetheless, the yearly results are based on predicted mixes of power plants based on a distribution of hourly demand levels built into the model. The ORCED model does not explicitly display the relationship between hourly demand and the mix of power plants that run. Instead, ORCED displays for each plant the percentage of time during the year that demand is high enough to require that plant be run. These percentages vary for summer, winter, and off-peak seasons,\(^6\) so they are displayed separately for each season. An exception exists for hydro power plants, as discussed below. ORCED also displays the percentage of time during the year that each level of demand is seen in each region for each season.

Using the aforementioned data, we were able to modify the model to link each power plant to the minimum level of demand in each season that would require the plant be run. Given that the demand level and season at every hour of the year in a region is built into the ORCED model, we added additional code in order to link each hour to the plants that would need to be run that hour, based on demand and season. Once complete, the modified version of the ORCED model was able to display the mix of all non-hydro plants running at every hour of the year in each region.

Hydro power plants are modeled by ORCED to generate power as a function of demand. As demand in a region increases, hydro plants in that region generate more power. For each season in each region, ORCED displays the different levels of hydro power possible and the percentage of time during the year that demand is high enough to result in each level of production. Because a procedure for linking these percentages to hours of the year was already established for the other types of plants, we added code to the model so that this same procedure could be applied to hydro power.

Our calculations do not include the impacts of intermittent and random outages on hourly grid mixes, yet such outages are incorporated into the model when it is run in its unmodified state. Stanton Hadley (ORCED’s creator), however, assured us that the accuracy of our results was not significantly affected by our omission.

**Plants Were Linked to Emissions Data in ORCED to Determine CO\(_2\) Intensity**

Once the mix of plants running at each hour of the year was determined, plant emissions data were used to compute the weighted-average CO\(_2\) intensity of

\(^6\) This is because plant capacity factors are different for each season. Fewer plants are needed when capacity factors are higher, and vice versa. Within each season, we assume that plants are run at a constant level.
power generation in each region at each hour. Once the emissions intensities of electricity generation were computed, the emissions rates were aggregated over the year, keeping each hour separate so a yearly-average emissions rate for each hour of the day could be obtained. This procedure was performed for each of the 13 regions analyzed in the ORCED model.

**Updates Made to Data in the Model**

Because exogenous data used in the ORCED model were from 2007, we updated much of these data using more recent sources. Data on regional electricity demand, power plant feedstock prices,\(^7\) and the prices of SO\(_2\) and NO\(_x\) allowances (all of which came from the 2007 version of the *Annual Energy Outlook*) were replaced with calendar year 2010 data from AEO 2010.

The version of the ORCED model available for download contained power plant data used for a year 2020 simulation, which means these data include power plants expected to be built between 2010 and 2020 and omit power plants expected to be retired between those same years. Because our analysis was for the year 2010, we needed to remove any power plants built after 2010 from the plant inventory, and we also needed to add power plants scheduled for retirement between 2010 and 2020. Deleting plants built after 2010 was straightforward, but power plant data from a 2010 National Energy Modeling System input file were needed to identify and replace those plants scheduled for retirement between 2010 and 2020 that had been removed from the original ORCED model.

Aside from the changes noted in the paragraph above, the power plant data were not updated from the year 2007. We estimated that the impact of updating the remaining plants with 2010 data would have been minimal.

**Hourly Emissions Results**

Table A.3 shows the estimated average hourly emissions intensity for each ORCED region. The emissions intensities are displayed in grams of CO\(_2\) per kilowatt-hour of electricity generated, and are color-coded on a scale that shifts from dark green to dark red as the CO\(_2\) intensity of electricity generation increases. In general, most regions have slightly higher average emissions intensities during non-peak hours. The reasons for this vary by region. In areas such as California, which have a high percentage of hydro sources, evening emissions intensities can be higher because dams are controlled to generate more power during peak demand (i.e., daytime) and less at night. In many areas where coal-fired power plants provide a significant fraction of electricity needs,

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\(^7\) The price for biomass actually came from the 2009 version of the National Energy Modeling System, as this price was not included in the 2009 or 2010 versions of the *Annual Energy Outlook*.
the grid's emissions intensity decreases when cleaner natural gas plants are ramped up to meet peak demand during the day.

| Table A.3. Hourly Average Global Warming Emissions Intensity for 13 ORCED Regions |

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Each numbered region above corresponds to the same-numbered ORCED region on the following page:
Figure A.1. Map of ORCED Regions

Source: ORNL 2008b.
Appendix B: Calculating the Cost of EV Charging

Collecting Electricity Rate Data
The cost of electricity for home EV charging in each of the cities in our analysis was estimated from electricity rate data gathered from utilities.

How Utilities Were Chosen
The cost analysis for this report focuses on 50 cities, chosen because they were the largest in the United States as measured by city-proper population. In cities with regulated electricity markets, the analysis includes every utility available to the inhabitants of those cities. In cities with deregulated electricity markets, the main delivery providers are included and are assumed to provide electricity only from their default supplier(s). Therefore, some electricity suppliers serving deregulated markets are not included in the analysis. In addition, when information on a delivery provider’s default supplier could not be found, the delivery provider was omitted from the analysis.

How Data Were Collected
Utility rate data were collected by the consulting firm TIAX LLC, with almost all the information coming from publicly available rate sheets posted on utility websites. When the data available online proved to be insufficient, additional information was gathered through phone and email correspondence with utilities. These data were compiled over the period from March 2011 to January 2012. Some of the rate plans included in this report have been updated by utilities since the data were initially gathered, and many of these changes were incorporated into the analysis between September 2011 and January 2012. There is still the possibility, however, that the rate data from some utilities have undergone changes that are not included in this analysis.

Treatment of Zones within Utility Service Territories
The territories of Con Edison, LADWP, and SDG&E, which encompass New York City, Los Angeles, and San Diego, respectively, are divided into zones. One component of Con Edison’s electricity rates varies by zone, while LADWP’s and SDG&E’s baseline quantities—the amounts of electricity consumption available at the cheapest tier—vary by zone as well. For each city, the rate information from the utility’s zone that corresponded most directly to the city proper was chosen. This was Con Edison Zone J for New York City, LADWP Zone 1 for Los Angeles, and SDG&E Inland Zone for San Diego.

PG&E’s service territory (which includes the cities of San Jose, San Francisco, Fresno, and Oakland) is also divided into zones as well. As is the case with SDG&E and LADWP, baseline quantities vary by PG&E’s zones, so we used the
zone-appropriate baseline quantities for each city. San Jose is located in Zone X, San Francisco and Oakland are located in Zone T, and Fresno is located in Zone R.

**Types of Information Gathered**

**Utility Rate Data**

For the utilities included in the analysis, information was gathered about every residential rate plan under which a household can charge an electric vehicle. If language in a plan’s rate sheet suggested that EV charging would not be allowed, that rate plan was omitted from consideration. Separate rates or baseline quantities for customers with electric heating, which are offered by some utilities, were not included in the analysis. Customers with electric heat should check with their utilities for rates if they charge their EVs on the same plan as their household, given that the rates and tier structures for such customers are often different.

All data necessary to assess the cost to a household of charging an EV were collected. These data were of two types: (1) costs that depend on how much energy is used in a month (consumption), and (2) costs that depend on the peak amount of energy used in a given instant (demand).

For the first component, all costs imposed per kilowatt-hour of electricity used—which include items such as energy charges, fuel adjustment factors, and transmission charges—were summed to develop one single marginal rate in cents per kilowatt-hour. The marginal rate indicates how much money the consumer pays for each additional kilowatt-hour used to charge an EV; the total consumption cost of EV charging over a period of time can therefore be found by multiplying this rate by the number of kilowatt-hours used for EV charging during that time. Fixed costs, such as a five-dollar monthly service fee, are omitted because the household would be paying them regardless of whether or not they charge an EV.

The second component, which was found only in three rates included in the analysis, consists of a monthly charge imposed per kilowatt of peak electricity demand. The more electricity a customer uses at once, the higher this cost will be. Therefore the contribution of EV charging to demand costs is found by multiplying the demand cost by the power drawn to charge an EV. This procedure is straightforward for rate plans in which an EV is metered by itself, as the vehicle is the only load drawing power. For rates in which a household and EV are billed together on a single meter, however, this approach assumes that the household’s peak demand is the sum of EV charging demand and peak demand from the rest of the household. This assumption is only true if at some
time during a given month, EV charging coincides with the peak demand from the household’s other appliances. Therefore the assumption represents the worst-case scenario, providing the maximum demand charge possible due to EV charging. In practice, the demand charge may be less if EV charging never coincides with a household’s peak demand for other appliances over the course of a month, and in extreme cases the demand charge may be zero if EVs are charged exclusively during off-peak times and never contribute to a household’s peak demand.

**Tax and Franchise Fees**
For each utility, we gathered information on any taxes or franchise fees (monies paid to municipalities for the right to operate locally) not already factored into the utility’s electricity rates. This information came from sample utility bills, government websites, and phone conversations with utility customer-service representatives. These taxes (which can occur at the state, local, or county level) or franchise fees (which increase the marginal cost of electricity for the utility’s customers) were factored into our rate calculations to determine the actual cost one would pay for electricity.

**Amount of Electricity Used for EV Charging**

**Consumption**
For the sake of simplicity, we assume every EV owner drives his or her EV the same number of miles each day. In this analysis we use 30 miles of daily driving for each EV, based on the average daily mileage per vehicle\(^8\) determined by the 2009 National Household Transportation Survey. We also assume each mile driven in an EV requires 0.34 kWh of electricity from the outlet, based on the 0.34 kWh/mile plug-to-wheel efficiency of the first-generation Nissan LEAF, which is the most prevalent plug-in EV on the road today. Other such EVs have slightly different electric-drive efficiencies and therefore may require more or less electricity to operate, but the efficiencies of the Tesla Roadster and Chevy Volt, two other well-known EVs, are very similar to that of the LEAF. Thus our analysis assumes that 10.2 kWh (30 miles x 0.34 kWh/mile) of electricity are used to charge every EV each day of the year. We assume all EV charging is done at home, where the majority of EV charging is likely to occur. Any charging done at the workplace or other locations would lower household energy consumption.

**Capacity**
In this analysis, we assume all EV charging is done at 3.3 kW, which is the power level for a Level 2 charge using the onboard chargers of both the LEAF and Volt.

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\(^8\) The actual number is 31.1 miles per vehicle.
EV owners also have the option of using a Level 1 charge, which only draws 1.4 kW but takes more than twice as long. When charging on one of the few utility rates that include demand costs, Level 1 charging might be cheaper because of its lower power level.

**Handling of Electricity Rate Data**

**Tiered Rates**

For many utility rates, the consumption component of the costs has a tiered structure—costs vary according to how much electricity is used. A certain number of kilowatt-hours are allocated to each tier, and once those kilowatt-hours are used the consumer moves into the next tier. When an EV is metered separately from the rest of the household, calculating EV charging consumption costs on a tiered rate plan is straightforward; the cost per kilowatt-hour is the average of the tiered rates, weighted by the amount of electricity consumed in each tier. When a household and EV are billed together on a single meter, however, a slightly different methodology must be used. Each month’s EV charging consumption is treated as the “last” electricity used by the household that month, regardless of when the charging actually took place. The result is that EV charging will incur the highest-tiered electricity rates paid by the household each month. An estimate of monthly home (non-EV) electricity consumption is used to determine the specific tier(s) in which EV charging occurs.

For most cities, this estimate comes from state-based data on average monthly residential electricity consumption, available from the U.S. Energy Information Administration.\(^9\) By using average electricity consumption, we assume all households in a given state use the same amount of energy. Customers who use less electricity than average will therefore usually pay a lower rate to charge their EVs on tiered single-meter rates than our analysis shows, and customers who use more electricity than average will probably pay a higher rate. But in some cities, where electricity rates become lower with higher monthly consumption, this trend is actually reversed.

Using monthly average electricity consumption also assumes household energy consumption is the same for each month. But because of seasonal variations in energy consumption, these estimates of household consumption may be too high for some months and too low for others. Such variations may not cancel out—sometimes only one season is tiered, and sometimes the seasons have

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\(^9\) See Table 5: Residential Average Monthly Bill by Census Division and State, online at [www.eia.gov/cneaf/electricity/esr/table5.html](http://www.eia.gov/cneaf/electricity/esr/table5.html).
different baselines that don’t directly reflect the differences in seasonal consumption.

The seasonal variation in monthly residential energy consumption is largely due to the fact that household electricity consumption is strongly related to climate. Therefore estimating a city’s electricity consumption on the basis of state data assumes a relatively homogenous climate exists across all of the state’s populous areas. This assumption is reasonable for many states throughout the country. However, it does not hold up well for California given the wide array of diverse climate zones found among the state’s major cities (Figure B.1).

Figure B.1. Climate Differences among and within the United States

Source: GeoNova 2011.

Therefore different methodologies were used for cities in California. For those served by PG&E, SDG&E, and SCE, the average energy consumption of households was estimated on the basis of a California Public Utilities Commission (CPUC) requirement that these utilities set their baseline quantities to between 50 and 60 percent of the average household consumption of their
customers.\(^{10}\) PG&E claims on its website that it sets its baseline levels using the highest end of this range, so we computed our estimate of the average household energy consumption for each city served by PG&E (San Jose, San Francisco, Fresno, and Oakland) as 167 percent (the inverse of 60 percent) of the PG&E baseline quantities for that city.

We did not come across similar claims from SDG&E and SCE, so the median of the CPUC’s range was used to estimate the average household consumption in cities served by these utilities. The estimated average household consumption for Long Beach was computed as 182 percent (the inverse of 55 percent) of SCE’s baseline quantities, and the estimated average household consumption for San Diego is computed as 182 percent of SDG&E’s baseline quantities. We were unable to ascertain a relationship between the baseline values and electricity consumption for California cities served by SMUD and LADWP, so we contacted these utilities to learn the average yearly electricity consumption of their customers. The yearly average was then divided by 12 to compute a monthly estimate of the average household energy consumption in those locales.

**Rate Variation**

Our analysis estimates the cost of EV charging on a given rate plan over the course of an entire year; to do so we calculate one single electricity rate representative of that whole year of charging. In reality, utility rates often vary by season, month, day, and even hour. By assuming the same amount of EV charging each day, we are able to address most temporal variations on rate; we take averages of the varied rates weighted by the amount of time to which each rate applies.

**Seasonal and Daily Variations**

Seasonal rates are weighted and averaged based on the fraction of the year each season comprises. For example, if summer and winter each spanned six months they would contribute equally to the yearly rate. Monthly and daily rate variations are addressed in the same way. For example, weekend days often differ from weekdays because their peak hours are different or nonexistent. In these cases, the weekly average rate is found by weighting the weekday rate by five-sevenths and the weekend rate by two-sevenths.

\(^{10}\) An unintended advantage of using this methodology for these PG&E cities is that the known relationship between baseline values and electricity consumption allows the estimates of household electricity usage to track seasonal variations in the baseline values. Many of the cities in our analysis have separate baseline values for summer and winter, but only the cities to which this methodology is applied have distinct estimates of household consumption for these seasons as well.
**Time-of-Use Variations**

When charging an EV under a time-of-use plan, in which electricity rates vary by hour, we assume more charging will occur at some hours than at others. Therefore the rates at the most common hours for charging will factor more into the calculation of charging costs than the rates during hours when less charging occurs.

We assume EV drivers on time-of-use plans will try to maximize the amount of charging they are able to do during off-peak times. Because off-peak hours vary among different utilities, we did not attempt to assign a share of charging time to any particular hours of the day. Instead, we assume 70 percent of charging is always done at off-peak rates over the course of a year, whatever those hours may be—reflecting the idea that 70 percent of charging demand can be flexible enough to be done at optimal times. We then assume the other 30 percent of charging occurs at random times, based on need, and therefore the rate at each hour of the day contributes an equal share to this 30 percent of charging costs. This scheme allows our charging profile to reflect a preference for off-peak charging, while making sure that all components of the time-of-use rate are factored into the charging-cost calculation.

Off-peak times under TOU plans comprise anywhere from 5 to 19 hours of the day, depending on the utility, so when combined with the 70 percent of charging we assume always occurs at off-peak times, 76 to 94 percent of the charging under a given utility’s TOU plan will incur off-peak rates. These figures are consistent with what a charging profile developed by the Electric Power Research Institute and the Natural Resources Defense Council (EPRI and NRDC 2007a) would indicate for the share of off-peak charging, if one was to redistribute the public/workplace charging (which is not pertinent to residential charging) proportionally among the other hours. The figures are also supported by preliminary data from an SDG&E rate study, which found that for 360 customers with EVs on separately metered TOU rates, 84 percent of their charging was done at the lowest off-peak rates (Haddow 2012). Although an individual’s EV charging will likely vary from day to day, we assume this charging will fit our distribution over the course of a year.

To determine the cost of charging an EV on a TOU rate, we compute a single average electricity rate by multiplying the off-peak TOU rate by 70 percent, multiplying the rate at each hour of the day both by one-twenty-fourth (that hour’s fraction of the day) and 30 percent, then summing the resulting 25 products. It is important to remember that our charging profile is just an estimate; EV owners can save more than what we calculate by always charging at off-peak times, (or save less if they frequently have to charge during the day).
**Fuel-Price Variations**

Another type of monthly rate variation that occurs in some utility rate plans is marginal cost, based on the changing price of the fuel that power plants use to produce electricity. These marginal rates are calculated for each month’s electricity bill, as they are not predictable. To reduce the uncertainty associated with these costs, utilities publish historic monthly rates, which help give the customer an idea of what the rate might be for upcoming months. For our analysis, we take the average monthly marginal cost over the most recent year and treat it as a single (constant) rate that will apply to the upcoming year.

**Residential Rates Omitted from the Analysis**

Many residential rates offered by utilities in our analysis were excluded, even though one could charge an EV on them:

- TOU rates were sometimes excluded (PG&E’s, for example) when the same utility offered a similar EV rate that was clearly cheaper at all times of the day.
- TOU rates with capacity charges were always excluded when the same utility offered a TOU rate without demand charges. This was done because capacity charges incurred from EV charging are difficult to estimate, and also because TOU rates with capacity charges are generally unfavorable for fueling an EV, given the high power draw of Level 2 charging.
- TOU rates with “surprise” peak times set at the discretion of the utility were also excluded. The peak times for such rates are not posted in advance; instead, the utility warns customers shortly before the peak goes into effect, often with lead times as short as 30 minutes. Because it is impossible to predict how much EV charging will cost without knowing when the peak hours are, we did not feel it was useful to include these rates.
### Results of Charging-Cost Calculations

#### Table B.1. Standard Residential Rate Plan

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<th>Utility</th>
<th>Charging Cost (cents/kWh)</th>
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*Average rate is calculated using the charge profile described in the methodology.*
Table B.3. Time-of-Use Rate—EV Metered Separately (TOU-EV)

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<th>City</th>
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</thead>
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*Average rate is calculated using the charge profile described in the methodology.*
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<th>City</th>
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<th>Annual Charging Costs ($/year)</th>
<th>Annual Savings Compared with 27 mpg Gasoline Vehicle ($/year)</th>
<th>Annual Charging Costs, Off-Peak Only ($/year)</th>
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Table B.4. Charging Costs for the 50 Largest Cities in the Lower 48 States
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Notes:
(1) Gasoline vehicle efficiency of 27 miles per gallon
(2) 11,000 miles per year of driving
(3) $3.50-per-gallon gasoline
See the main report for references.