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BMW MINI E Smart Charging Analysis for FirstEnergy

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Abstract

Without any utility controls, plug-in electric vehicles (PEVs) will be plugging in during typical coincident peak periods, and therefore, large-scale PEV deployment may create issues for the utility distribution system grid. The objectives of this Electric Power Research Institute (EPRI) study were to learn about electric vehicle (EV) charging patterns in residential and workplace settings and to assess possible grid impacts based on charging data and a forecast of PEV penetration. In the study, four BMW MINI E vehicles were provided to Jersey Central Power & Light employees. The vehicles were used for everyday workplace driving needs, and charging data was collected over a 2-year period from four charging stations—three workplace and one residential. Significantly different load patterns were observed based on charging station application. In addition, a software tool was used to estimate future PEV penetration and resulting aggregate charging load. The results suggest that in managing PEVs as a future load, some form of control would be desirable, to mitigate impacts on grid operation.

Keywords
Plug-in electric vehicle (PEV)
Electric vehicle (EV)
Charging station
Load profiles
Smart charging

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Section 1: Introduction

In mid-2009, BMW deployed a limited number of an all-electric version of the MINI Cooper, the MINI E. Four-hundred and fifty vehicles were leased in California, New York, and New Jersey as a field test of current generation electric vehicles (EV). FirstEnergy leased four of the MINI Es for Jersey Central Power and Light (JCP&L) as part of the New York Metropolitan electric vehicle impacts demonstration. This included installation of four charging stations, three in a workplace setting and one in a residential setting.

Figure 1-1
MINI E at Jersey Central Power & Light

The charging stations were metered and the collected data was analyzed by EPRI to determine typical consumption and operation of the charge stations. The results of the analysis give some insight into how charging stations may be used in residential and commercial settings. In addition, a forecast of plug-in electric vehicle (PEV) penetration was developed to get an idea of expected PEV adoption in the JCP&L service territory over the next twenty years. The forecast includes an estimate of the aggregate charging load profile given various charge control strategies. The results of the analysis and PEV forecast can be used to assess the possible impact of PEV charging on the grid and suggest that some form of charge control may be desirable to manage the impacts.

Background

The MINI E is a BMW MINI Cooper sedan that has been retrofitted by AC Propulsion to be a full-electric vehicle. To accomplish this, the original drivetrain, gasoline motor, and exhaust system were removed and replaced with a high-power electric-drive system and 35 kWh lithium-ion battery pack. The vehicles were expected to have a range of around 100 miles depending on driving conditions, with an estimated consumption of about 220 Wh per mile. With a 240 V charger, the vehicles can recharge in 3 to 4.5 hours, with 32 A and 48 A service respectively. If the vehicles are charged using a standard 110 V household outlet the charge time could be as long as 26.5 hours.

The charging behavior of the four vehicles was studied to get an idea of how PEVs will use different types of charging stations based on varying power levels and locations. The four charging systems installed for the MINI Es are broken down as follows:

- One charging station was installed in a residential setting providing 240 V charging at home,
- Three chargers were installed at parking garages near JCP&L buildings and provided 240 V workplace charging for the vehicles.

All of the chargers used 240 V service, and one of the workplace charges was a fast charger which operated with a higher current draw.

Although the sample size was small, these early findings indicate that widespread adoption of PEV technology could result in changes to how the grid is managed. Developing “smart charging” technologies, which could manage when and how PEVs are charged, will be instrumental in successful adoption of PEVs as a major transportation choice nationwide. As a result of this pilot project, FirstEnergy has begun working with EPRI to develop viable smart charging systems to fuel PEVs while maintaining system reliability. JCP&L also has provided input to the New Jersey Energy Master Plan, and is represented in a group that is addressing statewide adoption and planning of PEV charging station technology in New Jersey.

UC Davis MINI E Consumer Study

Of the 450 MINI Es placed in the U.S., 235 were leased to private households. BMW did a series of surveys with most of these households with help from the Institute of Transportation Studies (ITS) at UC Davis. A more detailed consumer research study[1] was performed by UC Davis with a subset of 54 of the

[1] T. S. Turrentine, D. Garas, A. Lentz, and J. Woodjack, “The UC Davis MINI E Consumer Study,” Institute of Transportation Studies, University of California, Davis, Research Report UCD-ITS-RR-11-05, 2011.

private households that leased the MINI Es. Surveys, interviews, and driving diaries were used over the period of June 2009 to June 2010 to assess customers' driving behavior, satisfaction with the vehicles, and attitudes towards electric vehicles among other things. The study found that the range was sufficient for most driving needs, and that charging at home met most charging needs. The participants found little need for public charging infrastructure. The end-of-lease survey showed that 95% of respondents drove the vehicle 80 miles or fewer each day. The BMW survey respondents reported that they found the MINI E to be suitable for daily driving needs. The downfall of the vehicles was the lack of passenger and trunk space, which in some cases limited how the vehicle could be used. Overall the participants found the vehicle to be fun to drive and even enjoyed the regenerative braking function after they got used to it.

The findings from the first phase field deployment of the MINI E including the UC Davis study will inform the development of the BMW ActiveE which will use a BMW developed powertrain instead of a post-production retrofit.

Sections 2 and 3 provide summary results from the residential and workplace charging data analysis respectively. Section 4 presents information on actual vehicle electricity consumption and the resulting load profiles which highlight differences in expected load with varying location and size of charging stations. The results from the PEV market adoption tool are presented in Section 5.

Feedback from JCP&L Drivers

Feedback from JCP&L drivers was similar to the feedback found in the studies conducted by BMW and UC Davis. To accommodate the limited driving range of the MINI E the drivers adjusted their driving habits by not using the vehicle when they expected to be driving greater distances. The regenerative braking function stood out in the feedback and took some time for the drivers to get used to. Several drivers commented on the fact that this feature lapses during cold weather so that they needed to readjust braking habits. Interestingly, participants in the BMW and UC Davis studies noted that the regenerative braking was inconsistent in hot weather and when the battery had a full charge. At the end of the MINI E program, BMW conducted an end-of-lease survey. UC Davis presented the results of these surveys in a report, indicating that 65% of respondents had issues when driving the MINI E in cold weather, with 75% of these respondents located in the northeastern part of the U.S. Consistent with the UC Davis study, several JCP&L drivers felt that the heating system was inadequate for the cold climate, and also found that the driving range was reduced in colder weather.

In general, feedback from the drivers suggests that the MINI Es performed well in mild weather and were enjoyable to drive. The majority of drivers felt that they would buy an electric vehicle in the future if the purchase price was lower and the vehicle provided a longer all-electric range. Overall, JCP&L's drivers reported positive experiences with the MINI E, which did not seem to negatively impact their preferences to purchase a PEV in the future.

Section 2: Residential Charging Results

Interval metering data for November 23, 2009 through May 31, 2011 was provided to analyze the usage patterns of the residential charging station. The measured interval data for this study included 15 minute electricity consumption for the house, the charging station, and the total household load (house + charging station). A summary of the analyzed data is shown in Table 2-1.

Table 2-1
Residential Dataset Summary

Start date	November 23, 2009
End date	May 31, 2011
Number of days in analysis	555
Number of days with vehicle charging	174
Number of vehicle charge sessions[2]	168

Figure 2-1 shows the number of days that the charger was used each month. Note that July of 2010 was lower because the vehicle was only used during part of the month while vehicle registrations were being updated.

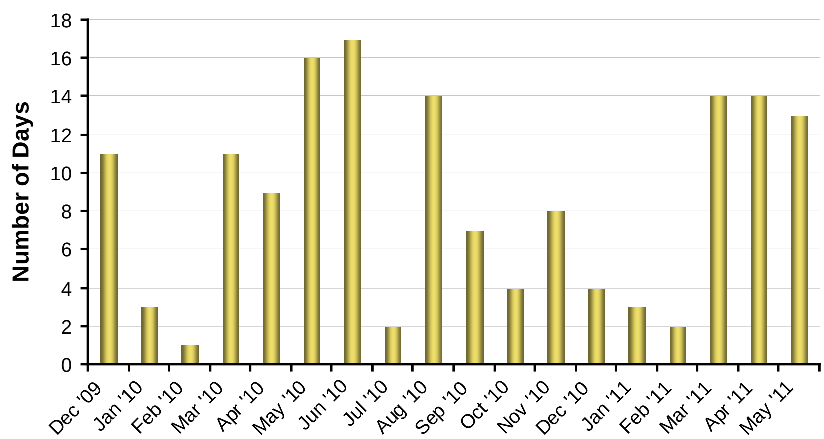

Figure 2-1
Number of Days of Residential Charging by Month

[2] The number of charge sessions is less than the number of days with vehicle charging because some charge sessions span two days.

Based on driver feedback the vehicles were used less often during January and February in 2010 and 2011 due to holidays and weather factors. The lower range experienced by the vehicles due to cold weather also impacted vehicle use.

An Excel macro was used to calculate the 15 minute and hourly demand throughout the day to produce hourly and daily summaries. The daily summary data includes the following information:

- Energy consumed (kWh) by the house and charging station,
- Peak hourly demand (kW) for the house, the charging station, and total household, and the hour it occurs,
- Peak 15 minute demand (kW) for the house, the charging station, and total household, and the time it occurs, and
- Vehicle charge session data for up to three sessions each day including the plug-in time, amount of charge (kWh), and charge duration (minutes).

This data was then tabulated to determine general charging station usage and charge characteristics as shown in Table 2-2. The vehicle was primarily charged at home and on average added 4 kWh a day onto average household consumption. Taking into account the fact that the vehicle charged only about 31% of the days, the average consumption per charge session was higher, around 13 kWh. On days when the vehicle was charging, this load added on average about 57% more energy consumption for the household.

Table 2-2
Residential Charging Summary Characteristics

Average charge session consumption[3]	13 kWh
Average charge duration	3 hours 47 minutes
Average daily household consumption	23 kWh
Average daily TOTAL consumption[4]	27 kWh
Average PHEV % of TOTAL[5]	22%
Average plug-in time	4:38 PM

Figure 2-2 shows the distribution of plug-in times for the vehicle over all home charging sessions. Average vehicle plug-in time is 4:38 PM, with 11% of charge sessions starting during the 4 o'clock hour. Since JCP&L's 2010 peak hour was between 4 and 5 PM, there was substantial coincidence between this residential charging scenario and the system peak. Over 75% of charge sessions were initiated in the evening around system peak, suggesting that some form of smart

[3] This consumption is averaged over the 168 charge sessions.

[4] Household plus vehicle consumption, this number may be interpreted as such: Average household consumption not including vehicle charging is 23 kWh, therefore vehicle charging on intermittent days adds an average of 4 kWh a day to total household energy consumption.

[5] This is an average of the ratio of vehicle charge consumption to total consumption only for days when the vehicle is charging.

charging, where charging is scheduled or delayed based on system conditions will be desirable for residential charging.

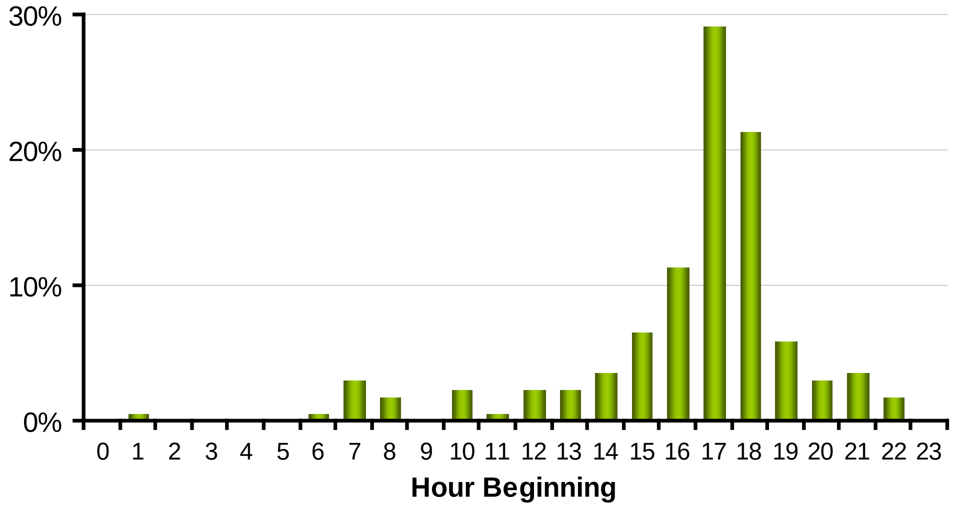

Figure 2-2
Distribution for Hour of Plug-in at the Residential Charging Station

Figure 2-3 shows the distribution for the amount of electricity consumed during each charge session. The majority (48 %) of charge sessions consumed less than 10 kWh of energy. With a total battery capacity of 35 kWh where 30 kWh is available for consumption during driving, this indicates that either the vehicle was being plugged in for shorter periods for a partial recharge, or that the vehicle user was not typically depleting the battery between charges.

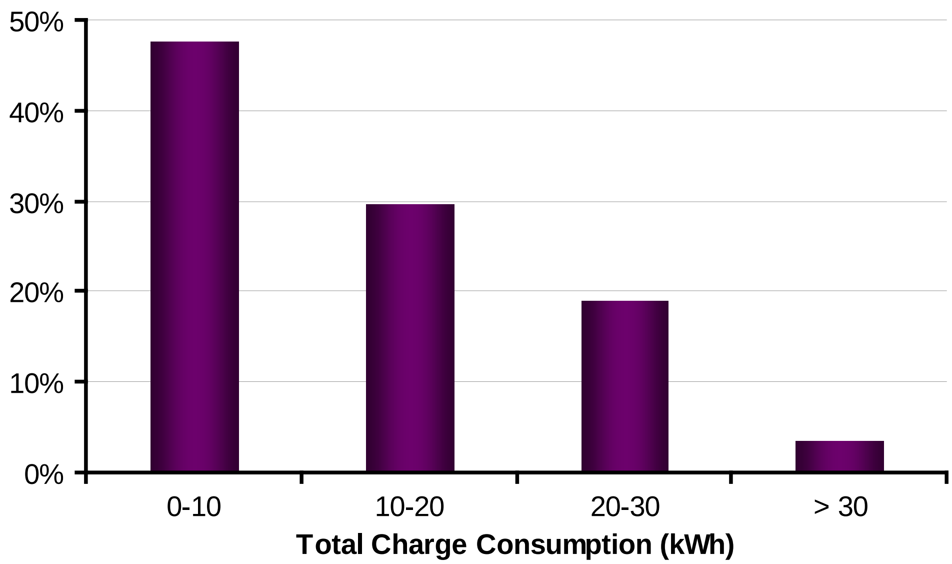

Figure 2-3
Distribution of Consumption During Residential Charge Sessions

Section 3: Workplace Charging Results

Workplace interval metering data for April 9, 2010 through May 31, 2011 was provided to perform analysis for the three workplace charging stations. The interval data represents 15 minute electricity consumption for a vehicle charging at the station. A summary of the analyzed dataset is shown in Table 3-1.

Table 3-1
Workplace Charging Dataset Summary

Start date	April 9, 2010
End date	May 31, 2011
Number of days in analysis[6]	407
Number of charging stations	3

Figure 3-1 shows the number of days that each of the charging stations was used each month. Note that July of 2010 was lower because the vehicles were only used during part of the month while vehicle registrations were being updated.

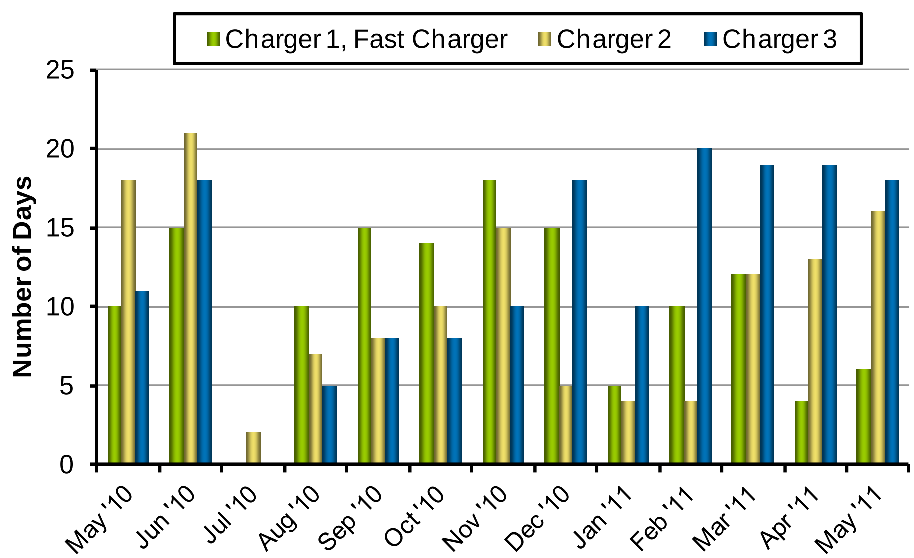

Figure 3-1
Number of Days of Charging for Each Workplace Charter by Month

[6] Missing data for August 3, 2010 through August 12, 2010.

Based on driver feedback the vehicles were used less often during January and February in 2010 and 2011 due to holidays and weather factors. The vehicles were driven by multiple drivers over the study period so the charger usage varies according to their driving habits over the year. The lower range experienced by the vehicles due to cold weather also impacted vehicle use.

An Excel macro was used to calculate the 15 minute and hourly demand throughout the day to produce hourly and daily summaries. The daily summary data includes the following information:

- Energy consumed (kWh) by each charging station,
- Peak hourly demand (kW) for the charging station, and the hour it occurs,
- Peak 15 minute demand (kW) for the charging station and the time it occurs, and
- Charge session data for up to three sessions each day including the plug-in time, amount of charge (kWh), and charge duration (minutes).

This data was tabulated to determine charger usage and charge characteristics for all three workplace chargers as shown in Table 3-2. Compared to the residential charger, the amount of energy consumed in each charge session is on the same order (13 kWh for residential), however the average plug-in time reflects when the vehicles begin charging at work in the morning instead of when the driver returns home.

Table 3-2
Workplace Charging Summary Characteristics

Total number of charge sessions[7]	583
Average charge session consumption[8]	12 kWh
Average charge duration	2 hours 35 minutes
Average plug-in time	9:45 AM

Figure 3-2 shows the distribution of plug-in times for all three vehicles over all charging sessions. On average, the vehicles were plugged in at 9:45 AM, with approximately 60 % of charge sessions were initiated between 7 AM and 9 AM. Compared to residential charging which is more likely to occur in the evening, the three workplace vehicles charged primarily in the early part of each day, greatly reducing the probability of load coincidence with JCP&L's system peak during the summer. However, in the winter, there may be a need for charge control since utilities typically have a period of higher demand in the morning when space and water heating loads are coming online. In addition, distribution circuit limits may necessitate charge control year round depending on the penetration of local chargers.

[7] Total charge sessions for all three charging stations.

[8] This consumption is averaged over the 583 charge sessions.

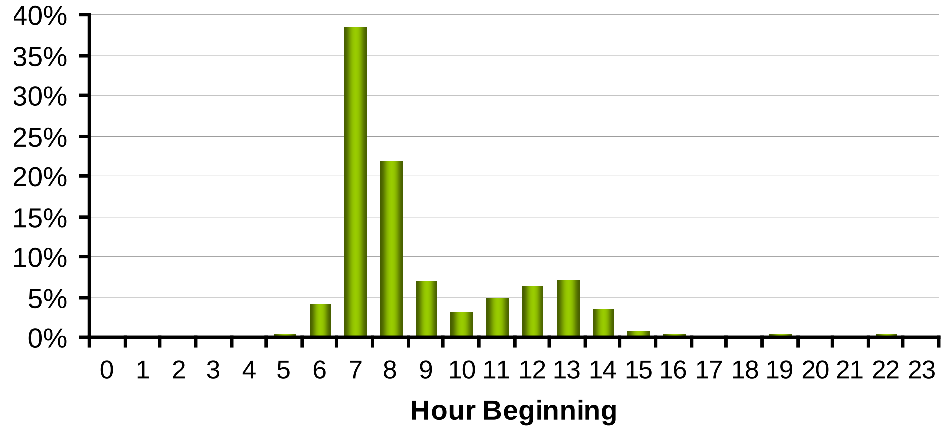

Figure 3-2
Distribution for Hour of Plug-in for Three Workplace Charging Stations

Figure 3-3 shows the distribution for the amount of electricity consumed during each charge session for all three vehicles. Compared to the vehicle charged in a residential setting where 23 % of charge sessions consumed 20 kWh or more, only 12 % of workplace charge sessions consumed more than 20 kWh. This could suggest that the non-residential vehicles were driven less than the vehicle charged in a residential setting. However, based on driver trip logs the vehicle charged at home had an average trip mileage of 28 miles versus 25 miles per trip for the three vehicles charged at work, so this is not likely the primary factor.

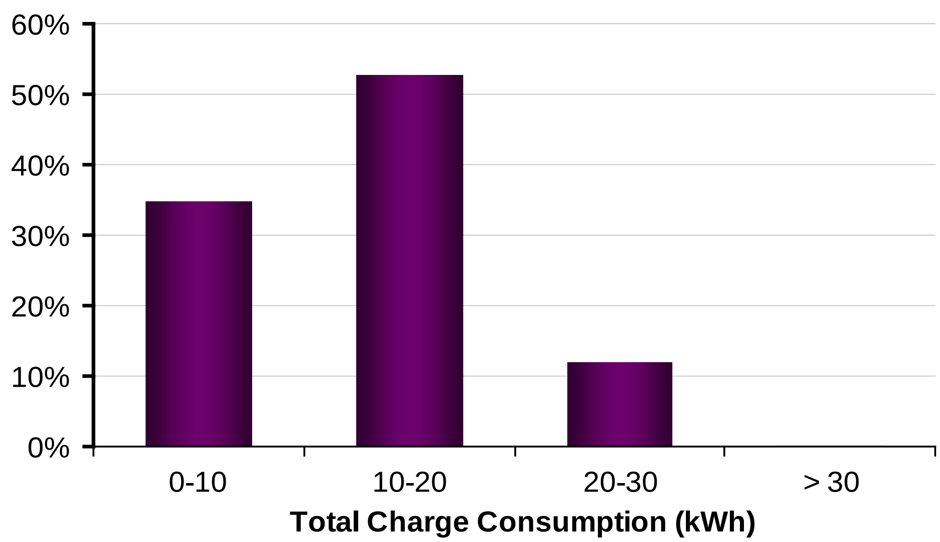

Figure 3-3
Distribution of Consumption during Workplace Charge Sessions

Another contributing factor is that the vehicles charged at work were more likely to charge multiple times in the same day. A likely scenario is that the drivers initiated one charge session when they first arrived at work and then plugged in for a second charge session after returning from a work assignment later that day.

The interval charging data shows that the workplace chargers averaged 1.2 charge sessions on days with charging compared to 1 charge session per day for the residential charger. In addition, the three vehicles using workplace stations were also plugged in at home periodically using 120 V charging in the evening. This reduced the need for charging the next morning, when returning to work.

Although the three workplace-charged vehicles have similar charging needs, there is variation in their usage. Table 3-3 shows vehicle-specific charge session summaries for the three workplace MINI Es. The fast charger (#1), had an average charge session consumption that was 16% higher than the other two chargers (#2, #3), but with a lower average charge duration. Based on the driver trip logs, the vehicle that used charger 1 had a longer average trip (61 miles) compared to about 20 miles per trip for the other two chargers, which contributes to the higher consumption per charge session.

Table 3-3
Workplace Charge Session Summary

	Charger 1, Fast Charger	Charger 2	Charger 3
Number of days with vehicle charging	145	149	178
Number of vehicle charge sessions	180	194	209
Average charge session consumption	14 kWh	12 kWh	12 kWh
Average charge duration	141 min	145 min	176 min
Average plug-in time	10:00 AM	9:00 AM	9:00 AM

If vehicles charge primarily at work during the day, the need for home charging at night is greatly reduced. Under this scenario, smart charging technologies could help manage charging throughout the day as needed during peak periods and system events.

Section 4: Vehicle Consumption and Load Profiles

To get a better understanding of vehicle consumption, a procedure was started in August 2010 to have the drivers complete a journal entry each time the vehicles were driven. These driver logs included the date driven, trip miles, and the state-of-charge (SOC) from the beginning and the end of each trip. This information, along with mileage for each trip was used to determine the average electrical consumption per mile driven. Data from February, March and April of 2011 was used giving an average vehicle consumption of 0.50 kWh/mile. There was variation in this consumption from a minimum of 0.36 kWh/mile up to a maximum of 0.76 kWh/mile. Many factors influence vehicle consumption including whether the miles were highway or city, the use of auxiliary loads such as heat or air conditioning, and even the driving style of each driver. This calculated average consumption for the vehicles, estimated at of 0.50 kWh/mile, may or may not be representative of average vehicle consumption throughout the year for an average driver.

To better understand how these vehicles appear on the grid as a charging load it is beneficial to look at average load profiles and charge duration curves. These charging sessions that averaged 12 to 14 kWh, illustrate vehicle consumption patterns and provide a clearer picture of how the chargers operate as a load.

Figure 4-1 shows the average hourly demand for each of the two locations and two types of chargers being studied. The hourly demand was averaged over all hours when vehicle charging occurred. The Level 2 workplace charging curve is the average hourly demand of the two Level 2 chargers (#2, #3). Since JCP&L's 2010 peak occurred between 4 and 5 PM (hour ending 17), the workplace chargers exhibited a very low coincident peak demand[9] (less than 100 W). The coincident peak demand of the residential charger was about 600 W, which is similar to a room air conditioning (A/C) unit. This is a key finding when considering the impact of vehicle charging and suggests that some type of smart charging would be desirable to manage peak demand. Several control strategies may be considered including delaying charging, interrupting charging, or cycling charging during peak periods. This is discussed further in Section 5.

[9] Assuming that JCP&L's system peak occurs between 4 PM and 5 PM.

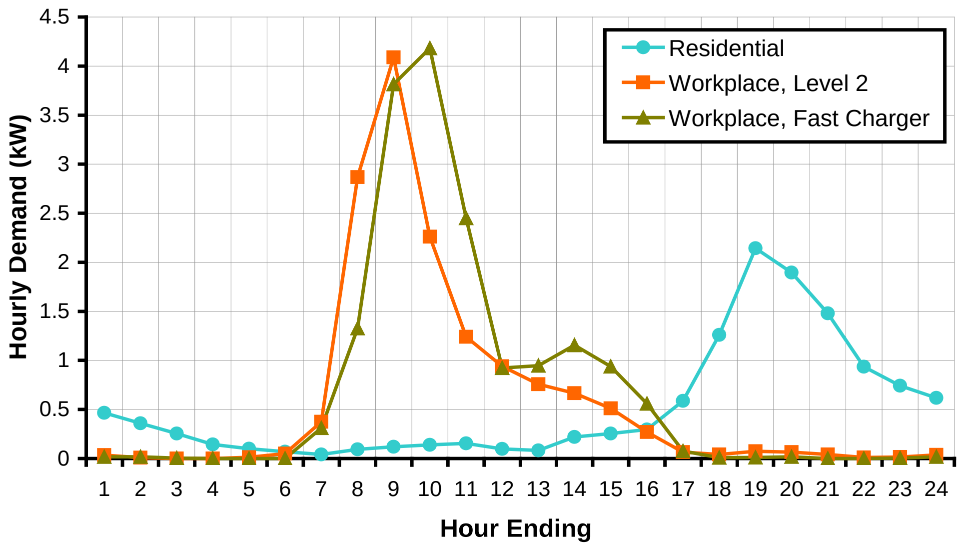

Figure 4-1
Average Hourly Demand for Days with Vehicle Charging

The load profiles provided insights on the expected demand for MINI Es recharging at each location and each type of charger, averaged over all vehicle charging days. The maximum hourly demand for the residential charger was about half the maximum exhibited by the workplace chargers. This was due to the measured diversity in plug-in starting times monitored at the residential location, compared to the more predictable start-time charging patterns measured at the workplace location. The plug-in distributions for residential and workplace charging can be seen in Figure 4-2.

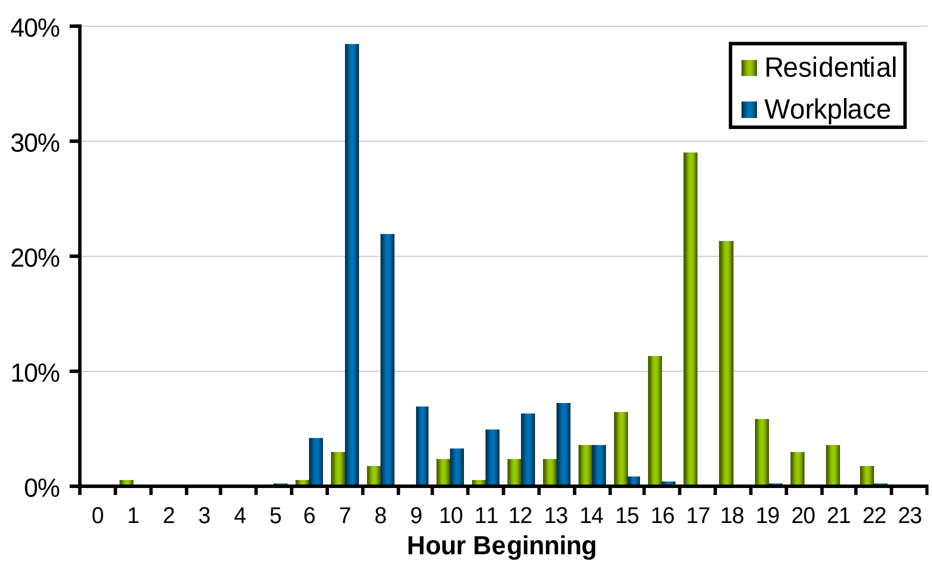

Figure 4-2
Distribution for Hour of Plug-in for Residential and Workplace Charging Stations

The load duration curves shown in Figure 4-3, indicate how much time each charger spent at different power levels. These curves show the proportion of the total charging time that each charger was operating above a given power level (kW). For instance the workplace fast charger operated at 8 kW or higher 21% of the time. The total charging time logged for each charger is shown next to each curve.

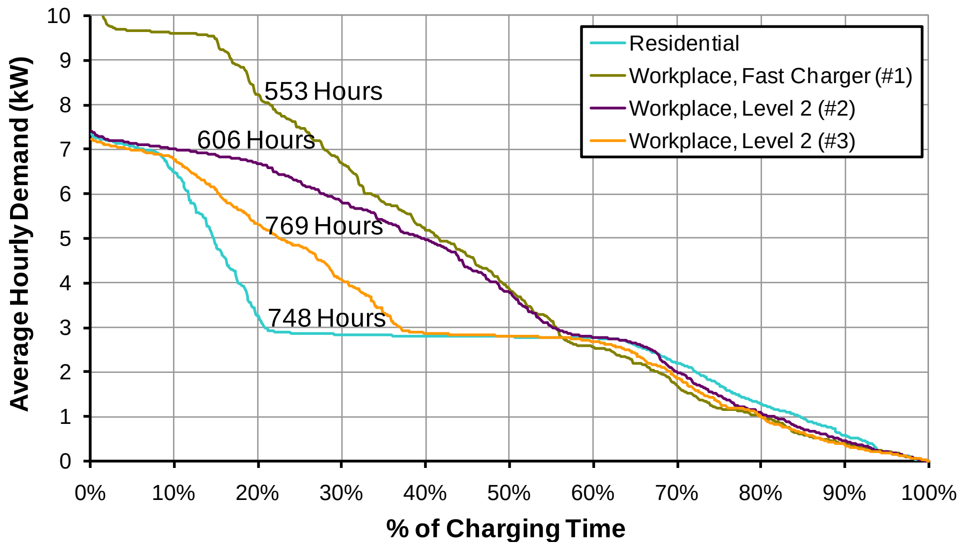

Figure 4-3
Load Duration Curves

Section 5: Vehicle Adoption and Aggregate Charging Load Forecasts

The rate of plug-in electric vehicle (PEV) adoption in the JCP&L territory was estimated using EPRI's Plug-In Electric Vehicle Load Estimator[10], in this case estimating adoption out to 2030. The tool produces three estimates of market adoption of PEVs, which includes both battery electric vehicles and plug-in hybrids, reflecting low, medium, and high penetration scenarios.[11] The low projection is partially based on historical hybrid-electric vehicle adoption in the overall car and truck market, and over the longer term represents a generally unfavorable market for PEVs. The medium scenario reflects a robust adoption of PEVs. The high scenario is optimistic and would generally reflect significant technological or economic breakthroughs in vehicle production and/or external influences (like oil price shocks, etc.) that favor PEVs. There are myriad factors and forces that will influence PEV adoption, a discussion of which can be found in a 2010 EPRI report. [12] In short, vehicle availability, cost, incentives, fuel prices, and societal factors will all play a role in vehicle adoption rates. A high-level description of the approach used in the EPRI forecasting tool are discussed in the following sections and the results found for the JCP&L territory are presented afterwards. This gives some idea of how PEV adoption might look in terms of percentage of new vehicle purchases, cumulative PEV fleet size, and vehicle charging load by county.

Modeling Approach

Vehicle penetration is based on the total projected vehicle-miles traveled (VMT) each year taking into account vehicle turnover and new vehicle purchases; using the average miles driven per vehicle each year the total number of vehicles is calculated. The model incorporates assumptions by vehicle weight class for factors including vehicle aging rates and miles traveled by vehicle age. Figure 5-1 gives an overview of the analysis approach used in the software.

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[10] *PRE-SW Plug-in Electric Vehicle Load Estimator 0.81 Beta*. EPRI, Palo Alto, CA: 2010. 1021635.

[11] An updated EPRI internal version of the tool was used in this study.

[12] *Plug-In Electric Vehicle Adoption Forecasts*. EPRI, Palo Alto, CA: 2010. 1019921.

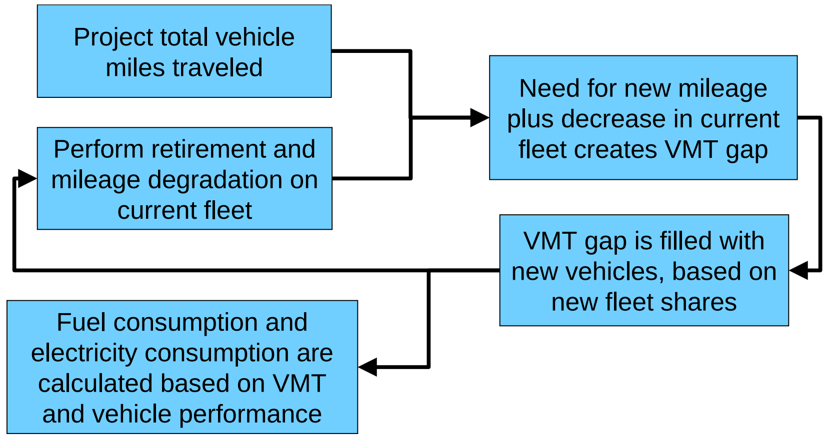

Figure 5-1
Market Adoption Software Analysis Approach

The EPRI model calculates the VMT for the vehicle fleet in a utility service territory using county-by-county forecasts sourced from the U.S. Environmental Protection Agency's MOBILE6 Vehicle Emission Modeling Software[13]. By default, the software provides the majority of the necessary input data including: territory specific PEV penetration forecast (share of annual new vehicle sales), territory specific VMT forecast, and vehicle-level assumptions. The inputs provided by the utility, in this case JCP&L, are the number of residential customers in each of the counties that they serve. Figure 5-2 shows the JCP&L territory in New Jersey; the green areas show JCP&L coverage in each county.

[13] MOBILE6 Vehicle Emission Modeling Software website. http://www.epa.gov/oms/m6.htm.

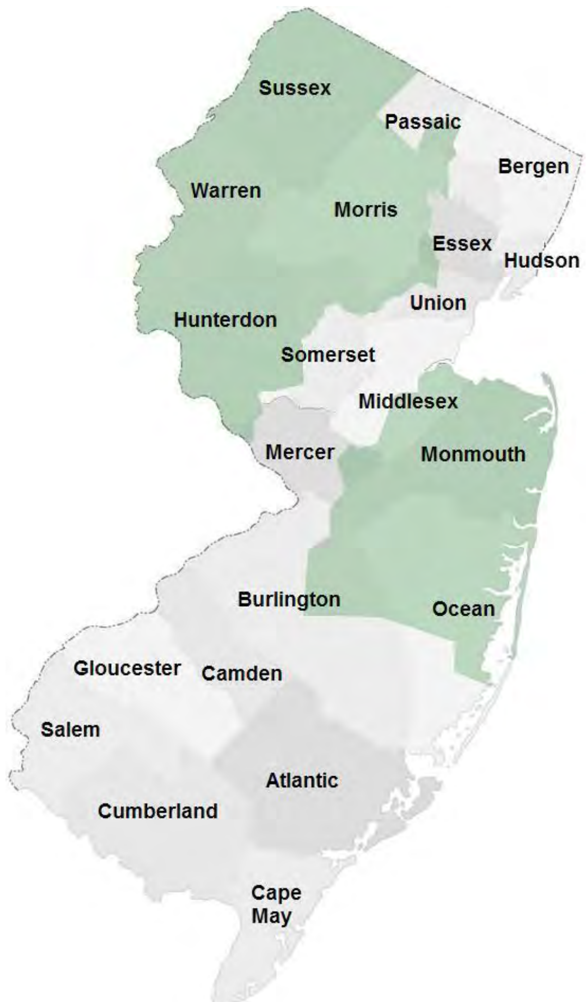

Figure 5-2
Counties within JCP&L Territory

The total number of households for each county leads to the percentage of coverage that JCP&L has within each county, and as a result what portion of the VMT in each county belong to JCP&L. New vehicle purchases are portioned into three categories, PEVs, standard hybrid electric vehicles (HEV), and conventional gasoline vehicles (CV). The PEV category is further divided into three types: full electric vehicles (EV), plug-in hybrid electric vehicles (PHEV) with a 10 mile all-electric range, and PHEV with a 40 mile all-electric range (denoted PHEV 10 and PHEV 40 respectively). The tool currently uses the same efficiency (kWh/mile) for all three types of PEVs. The amount of electricity used in driving the PHEV 10 and PHEV 40 is determined based on the VMT and the utility factor for the vehicles. The utility factors represent the fraction of driving performed by electricity, and are the same as those used in the 2007 EPRI-NRDC study[14].

[14] *Environmental Assessment of Plug-In Hybrid Electric Vehicles, Volume 1: Nationwide Greenhouse Gas Emissions.* EPRI, Palo Alto, CA: 2007. 1015325.

PEV market adoption scenario construction

The market adoption forecasts are based on several factors including historic HEV sales and publicly available vehicle forecasts, and different factors are used at different points in the forecast period. This section describes the factors influencing each of the three adoption scenarios.

Low Scenario

- The PEV market share in 2010-2018 is based on the HEV sales performance in the overall passenger vehicle market in the U.S. from 2000-2008.
- From 2019 onward the PEV share is based on an extrapolation of HEV sales performance 10 years earlier.
- The PEV share in a particular region is biased up or down depending on the 2008 market share of HEVs in the region compared to the U.S. However, based on an assumption that PEV technology becomes mainstream after 15-20 years, the regional bias is partially phased out in later years.

Medium Scenario

- From 2010-2015, the estimate of the PEV share of new vehicle sales is based on "ground-up" sales estimates, which in turn are derived from PEV launch announcements and (where available) production estimates.
  - In 2010-2011, the majority of PEV sales will occur in the launch markets announced by General Motors and Nissan for the Volt and Leaf, respectively.
  - From 2012 through 2015, there is a decreasing residual effect where the launch markets have higher penetration than the U.S. average
  - The PEV share in a particular region is also biased up or down depending on the 2008 market share of HEVs in the region compared to the PEV launch markets
- After 2015, the PEV market share is based partially on an extrapolation of the "ground-up" estimates and partially on the past sales performance of HEVs.
  - The weighting of the "ground-up" extrapolation decreases in later years
  - The weighting applied to past HEV sales performance increases in later years. The effect of past HEV sales, before weighting, is calculated as follows:
    - The PEV market share in 2016-2018 is based on the HEV sales performance in the region from 2006-2008, adjusted for the fact the HEVs were only available in a portion of the passenger vehicle market.
    - From 2019 onward the PEV share is based on an extrapolation of HEV performance in the region 10 years earlier. However, based on an assumption that PEV technology becomes mainstream after 15-20 years, the regional bias is partially phased out in later years.

High Scenario

- The PEV market share is based on an average of publicly available forecasts. This scenario considers only the top third of the available studies.
- The PEV share in a particular region is biased up or down depending on the 2008 market share of HEVs in the region compared to the U.S. However, based on an assumption that PEV technology becomes mainstream after 15-20 years, the regional bias is partially phased out in later years.

The split of PEVs into PHEVs and EVs is the same for all three scenarios. The mix begins with 50% PHEV40s and 50% EVs in 2010. PHEV10s are introduced in 2012 as 10% of the PEV market, ramping to 50% of PEVs by 2016. Over the period of 2012 to 2016, PHEV40s and EVs ramp down from 45% each to 25% each.

JCP&L PEV Penetration Forecast

Figure 5-3 shows the share of new vehicle purchases that are forecast to be PEVs in each county in the JCP&L territory in 2015 and 2030, for the medium adoption scenario.

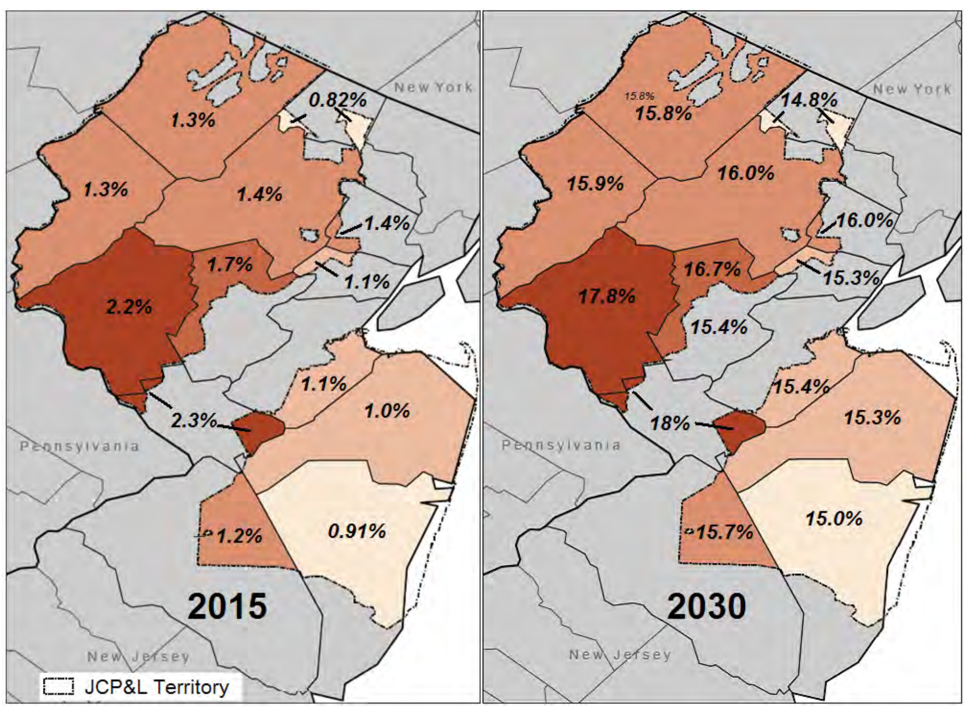

Figure 5-3
JCP&L PEV New-Vehicle Market Share by County for the Medium Scenario, 2015 and 2030

Two counties stand out as having the highest rates of PEV new-vehicle purchases in 2015 and 2030, Hunterdon with 2.2% in 2015 and Mercer with 2.3% in 2015. PEV launch announcements and production estimates are used to create a "ground-up" sales estimate leading up to 2015 in the medium adoption scenario; the share of sales in New Jersey is biased upwards before 2015 since the state is an early launch market for the Chevrolet Volt. The 2008 market share of HEVs in the region also biases this share. The weighting of the "ground-up" extrapolation decreases in later years, which indicates that the persistence of relatively high new PEV sales in these two counties is being driven by higher historical HEV sales compared to the other counties in JCP&L's territory. As a point of comparison, on a national basis HEVs accounted for almost 3% of new-vehicle registrations in 2008, and Washington DC had the highest proportion at about 7%. New Jersey fell below the national average with nearly 2% of new-vehicle registrations as HEVs.

The trend for new-vehicle share for the entire JCP&L service territory can be seen in Figure 5-4 for the three adoption scenarios. The penetration under the low scenarios begins at 0.01% in 2010 reaching 5.8% in 2030. The medium adoption scenario is more than double with a new-vehicle sales share of 0.02% in 2010 increasing to 15.8% in 2030. The high scenario again roughly doubles the medium scenario resulting in a significant PEV new-vehicle share with 0.05% in 2010 and 27.6% in 2030.

The number of new PEVs being purchased each year in all three scenarios increases about one thousand times from 2010 to 2030. In each of the three scenarios the compound annual growth rate (CAGR) is significantly higher from 2010 to 2020—ranging from 74% to 80%—than in the last decade between 2020 and 2030—ranging from 11% to 15%—showing that growth in the share of new-vehicle sales begins to level out over time.

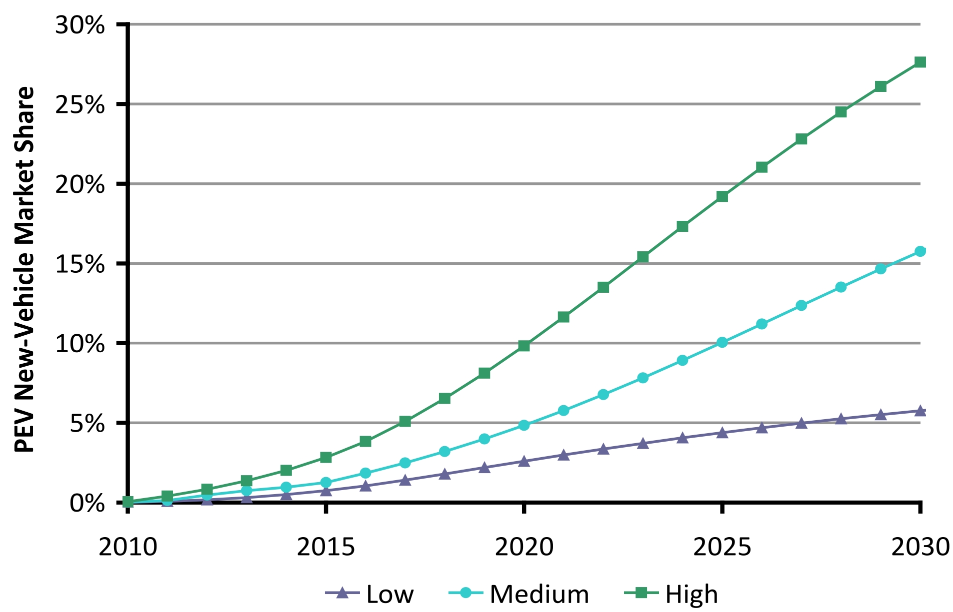

Figure 5-4
Total JCP&L New-Vehicle Market Share for all Three Scenarios, 2010 to 2030

The cumulative PEV fleet resulting from the new PEV purchases each year for the medium adoption scenario can be seen by county in Figure 5-5. There are several counties where adoption is projected to be higher, two of which are Monmouth (1,170 PEVs in 2015) and Morris (1,091 PEVs in 2015). This is due to higher populations and resulting higher base vehicle population than the other counties.

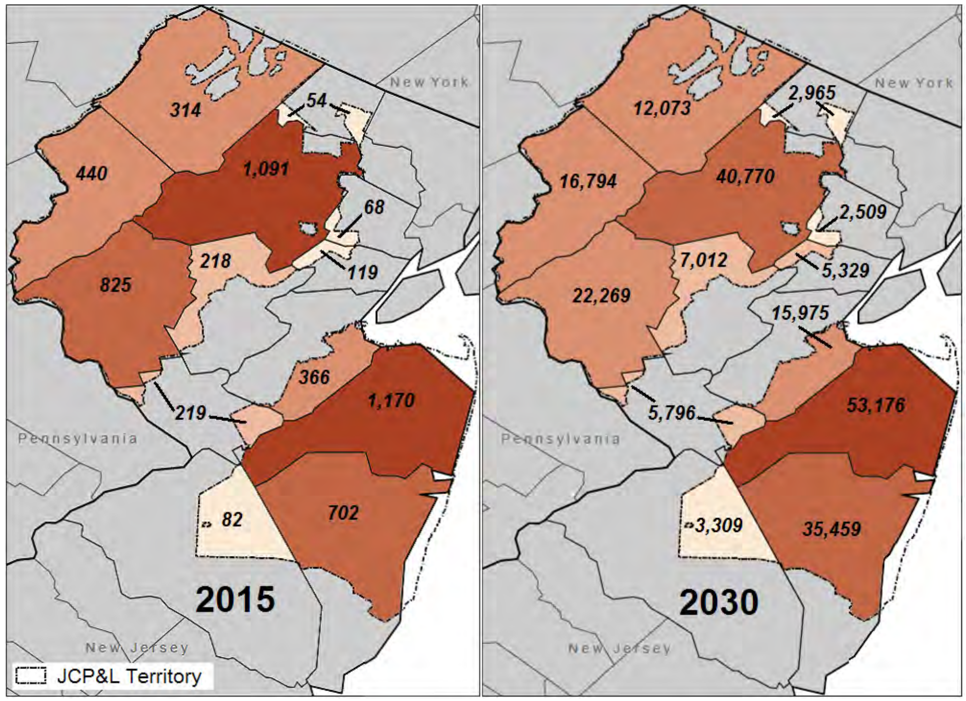

Figure 5-5
JCP&L Cumulative PEV Fleet by County for Medium Scenario, 2015 and 2030

In the medium scenario, JCP&L can expect to have about 223,000 PEVs in its service territory in 2030. The high scenario forecasts around 418,000 and the low scenario forecasts about 95,000 vehicles in 2030. The trend of the cumulative JCP&L PEV fleet growth is shown in Figure 5-6.

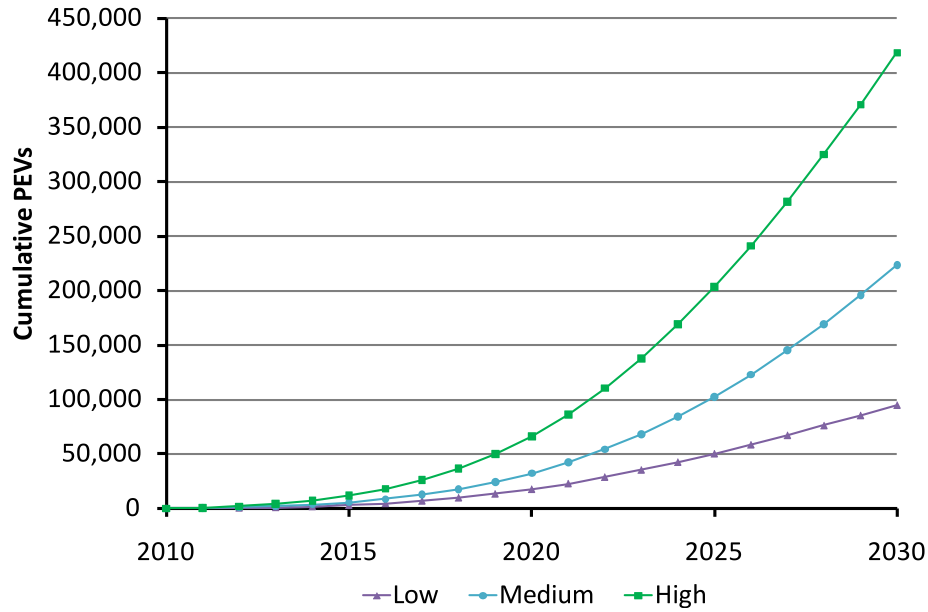

Figure 5-6
Total JCP&L Cumulative Fleet for all Three Scenarios, 2010 to 2030

PEV Charging Patterns

The charging load of PEVs will vary depending on how the vehicles are used, where they charge, and utility programs for managing the charging load. The charge control strategies used to construct an aggregate fleet charging load profile for the forecast penetration of PEVs are described in this section. This study assumes that the vehicles are charging at home only.

Uncontrolled charging

Vehicle home arrival is correlated with peak load, so it is often assumed that vehicle charging could create a large residential charging load coincident with the peak. However, vehicles will not all be connected at the exact same time. EPRI's analysis of National Household Travel Survey (NHTS) data reveals that even without smart charging, the load of vehicle charging is relatively well distributed. The Uncontrolled charging scenario is a plausible high case for PEV charging, which assumes that the PEV fleet will begin charging at full power immediately upon arriving at home.

Set-time charge control

Significant problems could be caused by ill-conceived charge control strategies. For instance, if vehicles were controlled with the algorithm "wait until 9 PM and then turn on," (presumably with the assumption that this would move the load off of the summer peak), the load from charging could quickly ramp from no load to a high load. Based on EPRI's analysis of NPTS data, about 73% of vehicles would be available to charge and had also been driven that day. Even though this load would typically be toward the end of the typical coincident summer peak, this would present a difficult control problem for utilities, even with a relatively small number of vehicles.

Managed off-peak charge control

It is possible to achieve any load shape with sophisticated control; various parties have proposed 'valley filling' strategies, 'renewable matching' strategies, and others. An example of a managed control strategy is to shift the charge load to nighttime, but spread it out relatively evenly over 6 hours. This can be accomplished by staging vehicles to start charging during one of 7 hours from 9 PM to 3 AM. Controlled this way, residential PEV charging most likely would not require additional generation capacity and would have a relatively small system impact. More sophisticated control strategies could optimize this even further.

JCP&L Fleet Charging Load

The total charging load of the fleet of PEVs in the JCP&L territory will vary depending on when and where the vehicles are charged. Assuming all of the PEVs charge at home, the resulting load profiles for the medium adoption scenario in 2020 are shown in Figure 5-7. The results of employing the three different charge control strategies discussed earlier are shown in green, red, and purple. It is clear that without managing the residential charging load, the maximum load would coincide with the summer peak period in the early evening. Specifically, the fleet demand coincident with JCP&L's system peak would be 15.6 MW between 4 PM and 5 PM with no charge control. In 2030 with the medium adoption scenario, the coincident peak would be 105.7 MW. On the other hand if vehicle charging was delayed until 9 PM, the effect would be 68.0 MW of vehicle charging coming online between 9 and 10 PM in 2020. In 2030 under the medium scenario, delaying charging until 9 PM would cause 460.1 MW of vehicle charging to come online between 9 and 10 PM. This emphasizes the need for careful planning in managing vehicle charging.

The drastic shift and increase in that peak if all vehicles were to delay charging to 9 PM illustrates the point that a smarter charging control strategy would be necessary to manage charging during system peak without causing a rebound effect at a different time. The green curve represents a managed off-peak control strategy where vehicle charging is staggered between 9 PM and 3 AM, in this case the rebound effect is avoided and the load is shifted off-peak. Assuming that a mix of several charge control strategies may be employed, a weighted mix of the three charge strategies is shown under the black line in Figure 5-7. This assumes that 70% of the vehicles have no charge control and begin charging when plugged in after arriving home, 15% delay charging until 9 PM, and 15% use managed off-peak charging.

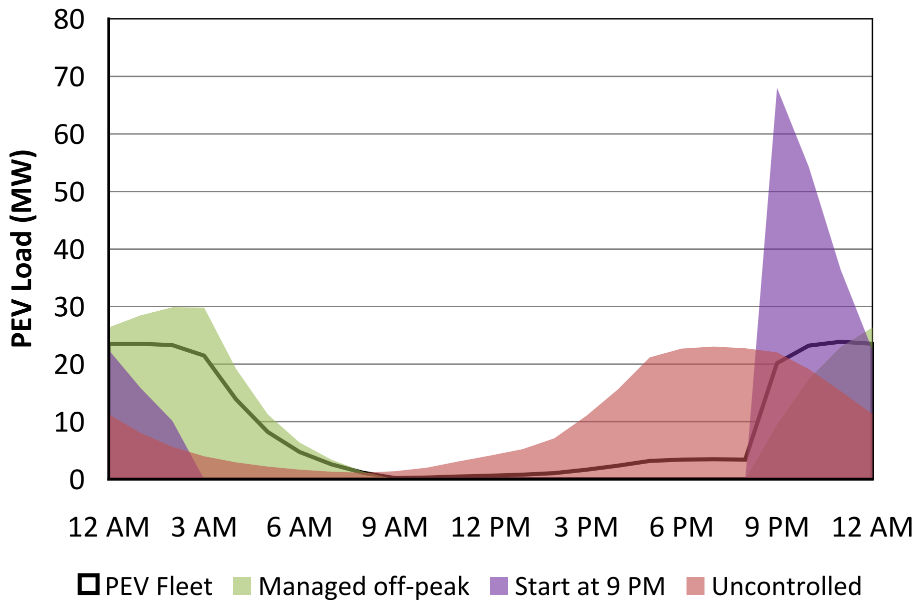

Figure 5-7
Total JCP&L Residential Charging Load Profile for the Medium Scenario, 2020

The total annual electricity consumption for the PEV fleet is shown in Figure 5-8. The expected electricity consumption is independent of where the vehicles are charged and the charge control strategy used.

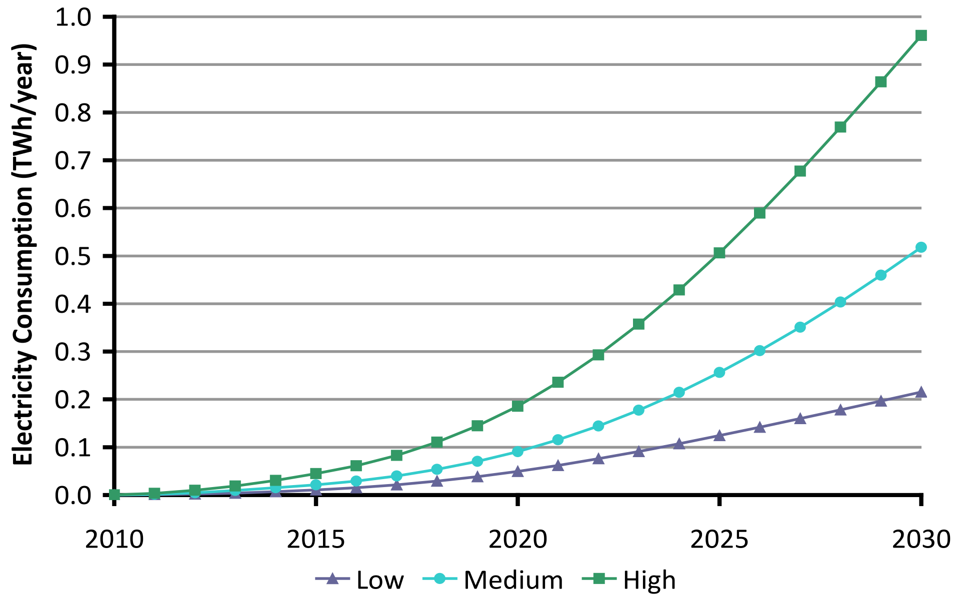

Figure 5-8
Total JCP&L Residential PEV Fleet Electricity Consumption for All Three Scenarios, 2010 to 2030

Electricity consumption per vehicle each year decreases over time, in part because the adoption forecast assumes a greater portion of EVs versus PHEVs in early years, but also due to the assumption that vehicle efficiency improves in later years.

Table 5-1 summarizes the load characteristics per vehicle for the PEV fleet forecast. The maximum demand per vehicle is lower compared to the residential charger data collected from the MINI E, presented in Section 4:. From the data collected from the residential charger between November, 2009 and May, 2011, the maximum hourly demand seen during any one of the charge sessions was 7.35 kW. Considering the average of all of the charge sessions, the maximum hourly demand was 2.14 kW. The maximum demand per vehicle shown in Table 5-1 is lower than the residential charging results from the MINI E data analysis for a couple of reasons:

1. The PEV forecast load assumes that a mix of charging equipment is used in the vehicle fleet with vehicles charging at 120 V (1.4 kW) and 240 V (3.3 or 6.6 kW), and
2. The time that the vehicles arrive at home is dispersed representing average vehicle usage in the U.S., therefore the charging is more spread out.

The coincident peak demand for the different charge control strategies is also shown in Table 5-1, considering JCP&L's 2010 peak in hour ending 17. Using one of the two peak management charge strategies, all of the vehicle charging load is shifted from the summer peak giving a coincident peak of 0 kW. However in both cases this increases the maximum hourly demand compared to uncontrolled charging, when vehicles charge as they arrive home, since all charging is moved into a shorter time frame.

Table 5-1
PEV Forecast Charging Summary

	Units	Un-controlled	Wait until 9 PM	Managed Off-Peak	Mixed Strategy
Daily charging energy	kWh/ vehicle	7.26	6.43	6.39	6.53
Maximum hourly demand[a]	kW/ vehicle	0.72	2.11	0.93	0.74
Coincident peak demand[b]	kW/ vehicle	0.48	0.0	0.0	0.07

[a] Maximum hourly demand is the maximum demand during the 24 hour day.

[b] Coincident peak demand is the hourly demand which coincides with the system peak, here assuming that system peak occurs between 4 PM and 5 PM.

Interestingly the total daily charging energy for the three charge strategies is not the same. This is because with uncontrolled charging vehicles can charge in the middle of the day in between trips taken from home so some of the vehicles (PHEV 10 more than the others) have the potential to drive more all-electric miles and thus use more charging energy in a day.

Section 6: Summary

Electric vehicles have been introduced into the market and are beginning to appear as a new load in the residential and commercial sectors. As vehicle penetration increases, utilities need to be aware of these new load shapes and the impacts that vehicle charging will have on system operations and reliability, particularly the distribution system. Therefore, as consumers begin to purchase PEVs, it is important to assess their usage and behavior as a load on an ongoing basis and plan for future impacts resulting from large numbers of vehicles.

The analysis performed in this study focused on the MINI E electric vehicles, which were available on a limited basis, providing a first look at what might be expected of PEV charging loads. Although the results cannot be extrapolated to a larger population, it is useful to have actual vehicle charging data that results from drivers using PEVs for their normal driving patterns. On average, the vehicle charged at the residential charger consumed 13 kWh during each charge session, compared to an average of 12 kWh per charge session for workplace chargers. In terms of demand, the residential and level 2 workplace chargers (#2, #3) had a maximum average hourly demand of over 7 kW, while the fast charger had a maximum demand of nearly 11 kW. The coincident demand with JCP&L's system peak[15] for the workplace chargers was essentially zero, and the residential charger had a peak demand of 600 W.

With a small number of electric vehicles, it is difficult to get a complete perspective of a much larger PEV population; therefore a forecast of vehicle penetration was also performed as part of this study. The forecast outlined potential PEV fleet growth scenarios in JCP&L's service territory and illustrated the aggregate charging load of these scenarios. Based on the forecast, the PEV fleet could grow from several thousand vehicles in 2015 to several hundreds of thousands of vehicles in 2030. Depending on where and how the vehicles are charged, the impact of PEV charging load could be significant. Simple charge management schemes may be used to shift fleet charging to off-peak periods, but can produce unintended consequences of a much higher peak demand at this new off-peak time. For instance, under the medium PEV penetration scenario in 2020, a fleet of JCP&L drivers that begin charging immediately after arriving home during the day will produce a collective load of 15.6 MW between 4 and 5 PM; if this charging is simply delayed until 9 PM, this results in 68.0 MW of JCP&L PEV charging load occurring between 9 and 10 PM. This example

[15] Assuming JCP&L's system peak occurs between 4 PM and 5 PM.

illustrates the need for proper analysis and planning for vehicle charging loads as PEV penetration increases.

Continued work to forecast vehicle adoption and charging patterns will be necessary to account for the impacts of PEVs. Distribution planners will need to account for where the vehicles will be connecting to the system and how much power they'll consume while charging. This could involve coordination with municipalities to get PEV permitting information or working with automakers to receive information on new electric vehicle sales where customers have allowed the information to be shared. Vehicle usage patterns and consumer preferences will also play an important role in PEV impacts. An integrated approach to planning that accounts for all of these factors is needed to ensure adequate preparation for electric vehicles. Use of charging control strategies to manage this new load, optimize existing assets and minimize new infrastructure requirements is also an important next step in the PEV research process.

Developing "smart charging" technologies, which could manage when and how PEVs are charged, will be instrumental in successful adoption of PEVs as a major transportation choice nationwide. As a result of this pilot project, FirstEnergy will continue to work with EPRI to develop viable smart charging systems to fuel PEVs while maintaining system reliability.

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