INL/EXT-14-33700

DRIVING AND CHARGING BEHAVIOR OF NISSAN LEAFS IN THE EV PROJECT WITH ACCESS TO WORKPLACE CHARGING

Don Scoffield, Shawn Salisbury, John Smart

November 2014

The INL is a U.S. Department of Energy National Laboratory
operated by Battelle Energy Alliance

INL/EXT-14-33700

DRIVING AND CHARGING BEHAVIOR OF NISSAN LEAFS IN THE EV PROJECT WITH ACCESS TO WORKPLACE CHARGING

Don Scoffield, Shawn Salisbury and John Smart

November 2014

Idaho National Laboratory

Idaho Falls, Idaho 83415

http://www.inl.gov

Prepared for the
U.S. Department of Energy
Office of Energy Efficiency and Renewable Energy
Under DOE Idaho Operations Office
Contract DE-AC07-05ID14517

Charging and Driving Behavior of Nissan Leaf Drivers in The EV Project with Access to Workplace Charging

November 2014

Key Conclusions

- A sample of 622 Nissan Leaf drivers participating in The EV Project with access to workplace charging charged at work on 53,351 vehicle days between March 2011 and December 2013.
- On nearly a quarter of those days, drivers drove far enough that they could not have completed their daily driving without workplace charging, even if they fully charged at home.
- On about half the days, drivers fully charged at home and "topped off" at work. On about a quarter of the days, drivers only charged at work, even though they had access to home charging.
- While 14% of vehicles needed workplace charging to complete their daily commutes most of the time, 43% of vehicles needed it some of the time (i.e., on at least 5% of commuting days). This shows that workplace charging is valuable as a range extender for drivers who live far from work, as well as drivers who sometimes need additional driving range beyond their typical commute.
- On days when drivers charged at work, they drove an average of 15% farther than days when they did not charge at work. This demonstrates that workplace charging provides a significant benefit for increasing electric vehicle miles traveled.
- In fact, on days when drivers needed workplace charging, they drove 15 more miles, on average, than they would have been able to drive without workplace charging. The average commute on those days was 73 miles.

Which Vehicles Are Being Studied?

Over 6,400 private owners of Nissan Leafs in 17 regions across the United States participated in The EV Project. They agreed to allow project researchers to electronically monitor the usage of their vehicles throughout the project.

Of The EV Project vehicles, 622 were identified as frequently having access to charging at one or more of 248 work sites known to offer workplace charging. The distribution of vehicles by region can be seen in Appendix A. Data collected from these Leafs from March 2011 through December 2013 were analyzed to determine how these vehicles were driven and charged on days when they went to work. To simplify the analysis, days were selected when the vehicle started and ended the day at its home location and spent over 4 hours parked at work. Also, the day could only include charging at the vehicle's home and work locations; days when the vehicle charged at other locations were excluded. The days when the vehicles were charged at locations other than home and/or work accounted for only 4% of the total days, which is consistent with previous findings [1]. Finally, care was taken to only include days that fell within the time period when charging equipment was installed for use at the work locations where the vehicle parked. This resulted in 76,321 total vehicle workdays, 53,351 of which included workplace charging.

All participants in The EV Project had AC Level 2 charging units installed in their homes. Therefore, the vehicles in this data set represent those who had access to charging at both home and work.

Classifying Daily Charging Behaviors

Drivers with access to both home and workplace charging may use their charging opportunities in different ways; therefore, it is helpful to categorize charging behaviors. In this analysis, days were assigned to one of the five following daily charging behaviors:

1. *Enabling*: Days when the driver needed to charge at work in order to complete their daily driving, even if they charged to the fullest extent at home.
2. *Top Off*: Days when the vehicle was fully charged at home before and after work and drivers "topped off" at work.
3. *Some Home*: Days when the vehicle was fully charged at home before or after work, but not both. The vehicle was also charged at work.
4. *Only Work*: Days when the vehicle was only charged at work; the driver did not do any home charging.
5. *Everything Else*: Days when the vehicle was charged at work and some amount of home charging was performed, but the home charging did not fit into the above categories.

For *Enabling* days, workplace charging enabled driving beyond the range provided by home charging alone. Drivers could not have performed all of the driving they did on *Enabling* days without charging at work. For days in all of the other categories, home charging could have provided enough range to complete driving on those days; therefore,

workplace charging was not strictly needed. However, if a driver did not fully charge at home, workplace charging could have had an enabling effect.

Percent of Days in Each Daily Charging Behavior

The dominant daily charging behaviors can be determined by looking at how often each of the behaviors occurs. Figure 1 shows the percentage of days in each charging behavior.

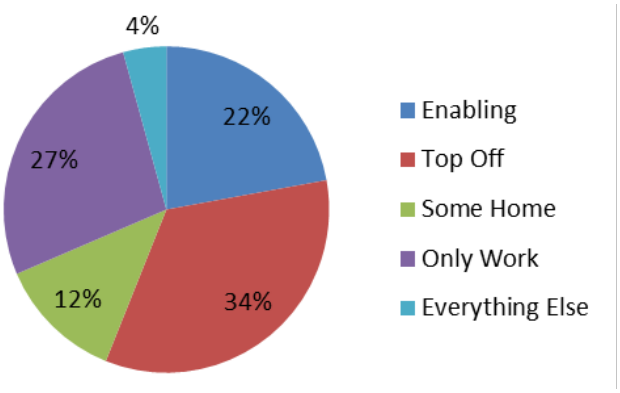

Figure 1. Percent of vehicle workdays in each behavior classification.

For nearly a quarter of the days analyzed (i.e., 22%), the daily driving could not have been completed without workplace charging. On these days, drivers were using workplace charging to extend their driving range beyond what could be achieved from home charging alone.

When considering vehicles with access to home charging, it would be natural to think that most vehicles would charge at home every night and add workplace charging when necessary; this is true for the *Top Off* and *Enabling* days. This sentiment is shared by many in the electric vehicle community. However, this behavior only includes 56% of days. The remaining 44% of days showed that other behaviors were prevalent. In fact, on over one quarter of the days (i.e., 27%), drivers only charged at work. Presumably, a driver would do this to reduce charging costs, because many workplaces offer free charging for employees.

Classifying Vehicles Based On Dominant Daily Charging Behavior

After the days had been classified, the vehicles themselves could be classified, based on each vehicle's dominant behavior. If at least half of a vehicle's work days fell into one of the five daily charging behaviors, the vehicle was assigned to that behavior. Those vehicles that did not have a majority of their days in any one behavior are classified as *Mixed*. The breakdown of the 622 vehicles into each category is shown in Figure 2.

As explained in the previous section, *Top Off* (35%) and *Enabling* (14%) behaviors align with commonly held beliefs about drivers with access to workplace charging, yet less than half of the vehicles fall into these categories. Almost one third (i.e., 29%) of the vehicles did not even charge at home most of the time and regularly offset home charging with work charging instead. This behavior may provide monetary benefit to the driver, but it also may have an adverse effect on the electric grid.

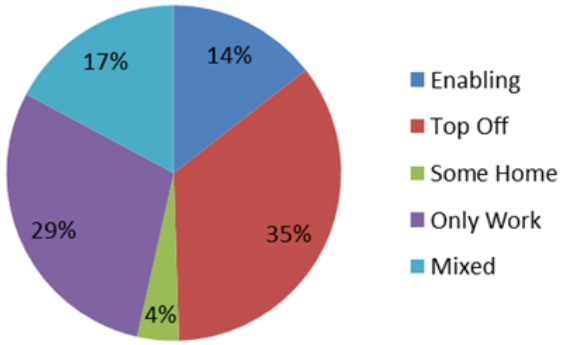

Figure 2. Percent of Leafs in each behavior classification.

About one sixth (i.e., 17%) of the vehicles did not have a dominant behavior and were categorized in the *Mixed* category. These results illustrate that not only is there wide variation in behavior from vehicle to vehicle, but there is also day-to-day variation in behavior for individual vehicles. Because of this variation, dominant vehicle behaviors do not always tell the whole story. It is also important to understand that drivers of many vehicles exhibit certain behaviors some of the time.

This idea is evident when looking at the *Enabling* classification. While 14% of vehicles needed workplace charging most of the time, 43% needed it some of the time (i.e., on at least 5% of commuting days). This shows that workplace charging is valuable as a range extender for a large portion of drivers, whether they consistently need it because they live far from work, or they sometimes need additional driving range beyond their typical commute.

Applying the same idea to the *Some Home* behavior can provide different insights. It is the dominant behavior for very few drivers, but drivers of 64% of vehicles exhibit *Some Home* behavior on at least 5% of their days. Many of these drivers frequently charged at home, but occasionally forgot to or were not able to charge at home overnight. Not charging at night sometimes made workplace charging necessary to complete the next day's driving. Therefore, whether a driver regularly uses it or not, workplace charging can provide them with peace of mind, knowing

they can still accomplish their daily driving if they forget to, or cannot, charge at home.

Miles Enabled By Workplace Charging

For all of the days in which workplace charging is classified as *Enabling*, some portion of the miles driven in that day could not have been driven without charging at work. There are a few ways of looking at how many miles workplace charging enabled. The first method takes the difference between the actual distance driven and the distance that could have been driven without workplace charging. This method can be thought of as a lower bound of the miles that workplace charging enabled. For example, consider a day when a vehicle drove 120 miles and the vehicle left home with a full battery capable of driving 85 miles. Workplace charging was required to provide energy for the remaining 35 miles; therefore, workplace charging enabled 35 miles for that day. The second method is based on the idea that if a vehicle could not have completed its daily driving without workplace charging, then that vehicle would not have been taken to work at all. Therefore, the entire commuting distance would be enabled by workplace charging. This method can be thought of as an upper bound of the miles that workplace charging enabled. The results of these methods can be seen in Table 1.

Table 1. Miles enabled by workplace charging.

Metric	Lower Bound	Upper Bound
Total miles enabled	187,030	882,961
Average enabled miles per vehicle day on days when workplace charging was needed	15	73

On days when drivers needed workplace charging, they drove 15 more miles, on average, than they would have been able to drive without workplace charging. The average commute on those days was 73 miles. This demonstrates that workplace charging provides a significant benefit for increasing electric vehicle miles traveled.

Effect of Workplace Charging on Daily Miles Driven

Up to this point, only days when workplace charging was performed have been analyzed. However, it is important to understand how these days compare to workdays without workplace charging. In order to do so, data from vehicles that had workdays with and without workplace charging were analyzed. For each vehicle, average daily driving distance was calculated for both types of days. It was determined that on those days when drivers charged at work, they drove an average of 15% farther than days when they did not charge at work. When looking at days when drivers did not need to charge at work but charged anyway (*Top Off, Some Home, Only Work*, and *Everything Else* days), they drove an average of 12% farther than days when they did not charge at work. This shows that even on days when workplace charging is not needed, it still increases electric vehicle miles traveled.

About The EV Project

The EV Project was the largest plug-in electric vehicle infrastructure demonstration project in the world, equally funded by the United States Department of Energy (DOE) through the American Recovery and Reinvestment Act and private sector partners. The EV Project deployed over 12,000 AC Level 2 charging stations for residential and commercial use, as well as over 100 dual-port direct current fast chargers, in 17 U.S. regions. Approximately 8,300 Nissan LEAFs™, Chevrolet Volts, and Smart ForTwo Electric Drive vehicles were enrolled in the project.

Project participants gave written consent for The EV Project researchers to collect and analyze data from their vehicles and/or charging units. Data collected from the vehicles and charging infrastructure represented almost 125 million miles of driving and 4 million charging events. The data collection phase of The EV Project ran from January 1, 2011, through December 31, 2013. Idaho National Laboratory is responsible for analyzing the data and publishing summary reports, technical papers, and lessons learned on vehicle and charging unit use.

Company Profile

Idaho National Laboratory is one of DOE's 10 multi-program national laboratories. The laboratory performs work in each of DOE's strategic goal areas: energy, national security, science, and the environment. Idaho National Laboratory is the nation's leading center for nuclear energy research and development. Day-to-day management and operation of the laboratory is the responsibility of Battelle Energy Alliance.

For more information, visit avt.inl.gov/evproject.shtml.

References

1. See "Where do Nissan Leaf drivers in The EV Project charge when they have the opportunity to charge at work?" at http://avt.inel.gov/pdf/EVProj/ChargingLocation-WorkplaceLeafsMar2014.pdf.

Appendix A

Figure A1 shows the number of vehicles included in this study in 13 of the 17 areas where Nissan Leafs were enrolled in The EV Project.