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Impact of convenient away-from-home charging infrastructure

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ABSTRACT

This work uses market analysis and simulation to explore the potential impact of workplace and similarly convenient away-from-home charging infrastructure (CAFHCI) in reducing US light duty vehicle (LDV) petroleum use and greenhouse gas emissions. The ParaChoice model simulates the evolution of LDV sales, fuel use, and emissions through 2050, considering consumer responses to different options of electric range extension made available through CAFHCI, fraction of the population with access, and delay in infrastructure implementation. Results indicate that providing a greater fraction of the population access to CAFHCI at level 1 charging rates for a full workday (~16–20 miles of range extension) may lead to more petroleum use reduction than providing level 2 charging to a lesser fraction. This result holds even considering the fraction of the population without at-home charging. 2050 battery electric vehicle sales increase 40% (85%) if the entire population is guaranteed daily access to one full workday of level 1 CAFHCI (half a workday of level 2, ~80 miles of range extension). Plug-in hybrid sales increase when CAFHCI enables range extension below 20–40 miles/day, most significantly in households without at-home charging capability. Faster CAFHCI may decrease plug-in hybrid sales as less expensive BEVs become attractive to a greater fraction of the market.

1. Introduction

Away-from-home charging infrastructure (AFHCI) enables electrified driving. Whether supplementing at-home charging (AHC), providing charging opportunity to those without AHC, or simply providing assurance against range anxiety, AFHCI can empower drivers to get greater range from their existing electric vehicles (EVs) and motivate sales of new ones. Francfort et al. (2015) infer from their three year study of 8000 EVs that workplace charging can be an “effective range extender.” Not only did some full battery electric vehicle (BEV) drivers rely on workplace charging to complete their commutes, 30% of drivers used only workplace charging, indicating that it might be a solution for those without AHC capability. The Workplace Charging Challenge (U.S. Department of Energy, 2016) finds that participating companies’ employees are six times more likely to own an EV than average. Nicholas et al. (2017) find that the few BEV drivers in their study that used workplace charging greatly affect their statistics for BEV use as a function of trip length. Modeling studies demonstrate that it may be possible to facilitate BEV adoption for a large fraction of the population by strategically placing AFHCI in destinations in urban regions where individuals already stop for extended periods during their travel (Xi et al., 2013; Pan et al., 2017). Liu and Lin (2016) similarly demonstrate that infrastructure at relatively small numbers of destinations can cover the AFHCI needs of large populations in urban regions.

While these results certainly suggest a correlation between AFHCI and EV ownership and usage, demonstrating that AFHCI leads to *significant* EV sales and increased electric vehicle miles traveled (eVMT) is more challenging. Francfort et al. (2015) find that half of vehicles in their study charged at home almost exclusively. The U.S. Department of Energy (2016) reports that the average workplace

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charging station in their study provided less than 10 kWh per day, only ~20 miles per day of added electric range across all vehicles served. Nicholas et al. (2017) determine that the majority of BEV owners use other vehicles when their daily travel will exceed the BEV range. Sutherland (2016) finds that level 1 AHC provides the greatest increase in percentage of miles electrified for both plug-in hybrids (PHEVs) and BEVs. González et al. (2014) determine that 81% of vehicles only require daily AHC to complete their trips in Flanders, Belgium. A similar analysis of the Ohio region by Xi et al. (2013) finds that 96% of vehicles can complete their trips with AHC only. So, while desirable to consumers, AFHCI may be neither necessary nor well-utilized.

One must then ask: what impact will increasing AFHCI offerings effect?

In this work, we use market analysis and simulation of the US light duty vehicle fleet to examine the potential impact of conveniently located AFHCI on (1) reducing long-term reliance on petroleum and (2) increasing future EV, specifically BEV, sales. Our market analysis simulation tool is the ParaChoice model, which captures the dynamic feedback between consumer choice, and the energy, fuel, and infrastructure which influences that choice, and projects the fleet into the future given that feedback. ParaChoice captures vehicle utility for a range of vehicle types including BEVs and PHEVs, conventional vehicles, and fuel cell vehicles (FCEVs). Representative consumers for different demographic sets then choose between these vehicles as the simulation progresses. Thus, this analysis avoids some of the pitfalls of former AFHCI analyses, specifically:

- Rather than having EVs assigned to a fixed percentage of the population, in this analysis EV ownership evolves as consumers choose if an EV is appropriate for them. This varies based on consumers' annual mileage, ability to install AHC, away-from-home charging options, and other demographics.
- Consumers choose between different EV ranges and types. BEVs considered are those with 100, 200, and 300 mile electric ranges. PHEVs considered have 20 or 40 mile ranges.
- Causation is captured. Unlike in data analyses where cause and effect are necessarily convoluted, scenarios with convenient AFHCI can be compared directly to scenarios without.
- Sales, eVMT, petroleum use, and GHG emissions are analyzed for the near term and projected into the future, providing insight on long term impacts of AFHCI. While this is a highly uncertain space, many uncertainties can be quantified through Monte Carlo analysis.

One shortcoming present in this analysis is the assumption that drivers will use charging infrastructure when it is made available. This is a concern whether the infrastructure is a single residence at-home charger or a shared charger in a public location. Therefore we stipulate the following for this work. (1) Those who have access to AHC will fully charge their vehicles once daily at-home. (2) We define Convenient AFHCI (CAFHCI) as AFHCI that can and will be used by EV drivers with access as needed, without compunction. As is becoming a frequent siting practice for level 1 and level 2 plugs, we assume that CAFHCI is located at convenient destinations where the vehicle will regularly dwell for extended periods, such as workplaces or universities, and thus will not require a dedicated stop in order to use. However, CAFHCI may only be available to a fraction of the population, following Xi et al. (2013), Liu and Lin (2016), Pan et al. (2017). Additionally, CAFHCI may only enable a limited number of miles of electric range extension, following Sutherland (2016). This last assumption is akin to the stipulation that the charging speed and dwell times may be limited. (3) We assume that vehicle purchasers incorporate the value of additional range into their purchasing decision. While for most purchasers in the real-world extra charging will be a 'soft' benefit contributing towards the vehicle purchase decision, we assign range (or lack thereof) an explicit monetary value in Section 2.

Notably, CAFHCI is fundamentally different from gas station-like charging infrastructure (GSLCI). The gas station model of refueling was initially proposed in Greene (2001) for sparse and relatively slow natural gas fueling infrastructure. Like natural gas refueling infrastructure, GSLCI for EVs is available to everyone, and can provide a full battery of charge per use. However, users are inconvenienced by the time spent waiting to recharge and for infrastructure scarcity. The impacts of national and state-scale incentives to build out GSLCI in advance of market demand are analyzed in depth in Levinson and West (2017). That work finds that DC fast GSLCI in significant quantities (thousands across the US) can impact the EV market and fleet-wide petroleum reduction, however level 1 and level 2 charging speeds make GSLCI too inconvenient to effect significant change. In contrast, CAFHCI incurs no waiting fee or scarcity penalty for those with access, and thus level 1 and level 2 chargers may have a greater potential to impact EV adoption and fleet-wide petroleum use if implemented as CAFHCI rather than GSLCI (e.g. placed in locations where vehicles naturally dwell for long periods).

In this study, DC fast GSLCI is available to all EV drivers, and its availability grows with market demand in all simulations. However, the focus of this study is CAFHCI, the availability and speed of which is probed to test its impact. We isolate three implementation questions which may impact the efficacy of CAFHCI.

- What is the ideal charger type and daily hours of guaranteed access? By proxy, how many miles must each driver feel confident in his ability to receive through CAFHCI for CAFHCI to have an impact on future EV adoption, petroleum use reduction, and GHG emissions reduction?
- What percent of the population needs access to CAFHCI in order to significantly affect the aforementioned goals?
- What are the long term impacts of implementation delays?

We do not analyze the impact of charging price in this analysis. While the value of infrastructure to the population is an interesting an important question, it is significant enough to be deserving of its own work. Suffice to say, that any fee imposed on charging with CAFHCI would dent its impacts on petrol reduction, GHG reduction, and BEV sales. The question remains: by how much? We