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Integrating electric vehicles and residential solar PV

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ABSTRACT

This study compares the lifecycle costs and greenhouse gas (GHG) emissions of electric vehicle (EV) ownership to that of other popular and similar cars in Hawaii. It focuses on the interaction of EV costs with Hawaii's rapid solar PV uptake, using a scenario planning approach for future fuel and electricity prices. EVs include battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs). We find that the total cost of ownership (TCO) of EVs tends to be higher than their internal combustion engine vehicle (ICEV) or hybrid electric vehicle (HEV) counterparts. Once accounting for the federal tax credit, however, some EVs become relatively cost-effective. Moreover, access to residential solar PV makes EVs quite attractive. Layering the federal EV subsidy with solar PV charging makes the full lifecycle cost of the Nissan Leaf about $1200 less expensive than the next lowest cost vehicle, the Toyota Corolla (over a 150,000-mile lifetime). Nonetheless, it may be too early to tout EVs in Hawaii as a GHG abatement strategy. Based on today's mix of electricity generation, the best performing PHEV and BEV emit 2 and 5 $MTCO_2$, respectively, more over their lifetime than the best performing HEV. However, many EVs become on par with the high performing HEVs when considering Hawaii's adoption of aggressive renewable energy goals for the electric sector. If the electric sector meets its 2030 Renewable Portfolio Standard (RPS) target of 40% renewables through low carbon sources like wind and solar, the Toyota Plug-in Prius, Nissan Leaf and Toyota Prius become comparable in terms of their GHG impacts. Integrating residential solar PV, even for just weekend charging, makes all EVs outperform the Toyota Prius in regards to lifetime GHG emissions. In addition, at this level of charging from renewable sources of electricity, all BEVs now outperform PHEVs. The environmental benefits of EVs depend critically on the electricity system from which they derive their power. Given the wide variation in the mix of electricity generation throughout the U.S., and even throughout the day with the adoption of intermittent sources of renewable energy, additional policy tools are needed to match places and times with high levels of renewables with EV charging. In particular, we suggest that 1) a regional approach to EV subsidies that can account for the emissions intensity of electricity systems may be more appropriate than the current blunt federal tax credit; and 2) adoption of time-of-use pricing that accounts for GHG impacts may be critical to supporting EVs as a GHG abatement tool. Currently, however, EVs are a relatively costly GHG abatement strategy.

1. Introduction

Electric vehicles (EVs), either in the form of plug-in hybrid electric (PHEV) or all battery (BEV), could play an important role in reducing petroleum use. Electrification of transportation provides an opportunity to switch to renewable energy sources like solar photovoltaic (PV) energy. Whether EVs prove a promising technology depends on vehicle and fuel costs as well as vehicle attributes such as driving range and charging infrastructure costs. The value of attributes across vehicles of similar size is largely a location-specific question. In an island environment like Hawaii, "range anxiety" is likely to be a less prominent barrier to adoption than in continental areas where people may drive far distances. While electricity rates are quite high in Hawaii, so is the prevalence of solar photovoltaic (PV). This study looks at the interaction between EV and PV adoption from a total cost of ownership (TCO) perspective. This approach has the benefit of being able to draw comparisons between vehicles in regards to important attributes like fuel consumption and maintenance. It lacks the ability to hold constant attributes of vehicle performance that are not explicitly related to cost, like acceleration. As such, we focus on comparisons of vehicles of similar size and, where possible, like makes and models. Performance outliers, like the Tesla, are

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excluded. A range of projections for future fuel costs in Hawaii are developed to better capture uncertainty in future world oil prices. Vehicle greenhouse gas (GHG) emissions are also estimated based on projected development of renewable energy for electricity generation.

This study is organized as follows. Section 2 provides background on EV and PV adoption in Hawaii. Section 3 presents the methodology and data, including the regression models used to forecast future fuel and electricity prices. It also presents the assumptions for estimating GHG emissions impacts. Section 4 presents key findings, and Section 5 provides concluding remarks.

2. EV and PV deployment in Hawaii

EVs were reintroduced in the U.S. on a more commercial scale in 2010 with the Nissan Leaf (BEV) and the Chevrolet Volt (PHEV) and in Hawaii in 2011. In a survey of consumers within 21 large U. S. cities, Carley et al. (2013) found that the two largest impediments to EV adoption is the higher upfront purchase price and limited all-electric driving range. To assist with deployment in the U.S., the federal government offers a subsidy of up to $7500 for the purchase of qualifying EVs.

An early effort was made in Hawaii to encourage EV adoption. The state considered Hawaii an ideal candidate for EV deployment because of its limited driving range and ambitious renewable energy goals for the electric sector. Hawaii has a Renewable Portfolio Standard (RPS) that requires 40% of net electricity sales be met through renewable sources by the year 2030 and 100% by 2045. As such, the State developed an "EV-ready" program that established early adoption subsidies and supported legislation requiring EV charging infrastructure in public parking lots. Between 2010 and 2012 the State offered a purchase subsidy of up to $4500 (US DOE, 2014). Even though "range anxiety" is likely to be lower in an island setting (other than perhaps on the Big Island of Hawaii), public charging infrastructure was seen as critically important to encouraging adoption. In 2012, a law was passed that requires public parking lots to provide at least one EV charging station for every 100 stalls (Act 168).

The initial goal of the State, established in 2011, was to reach EV sales of 4000 per year and to have 10,000 EVs on the road by 2015 (Braccio and Finch, 2011). As of the end of 2015, only 3600 EVs were on Hawaii's roads (DBEDT, 2016) (Fig. 1). The lower penetration of EVs compared to initial goals mirrors the national experience, where in 2009 the U.S. federal government set a goal of having a million EVs on the road by 2015. As of the end of 2015, approximately 395,000 EVs have been purchased in the U.S. (AFDC, 2016).

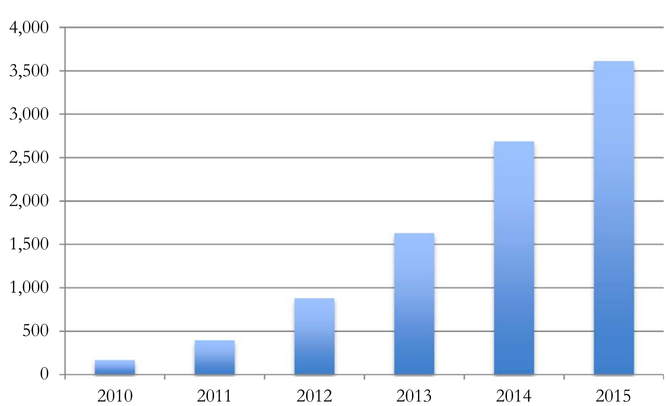

Fig. 1. Number of EVs deployed in Hawaii 2010–2015.
Source: DBEDT (2016).

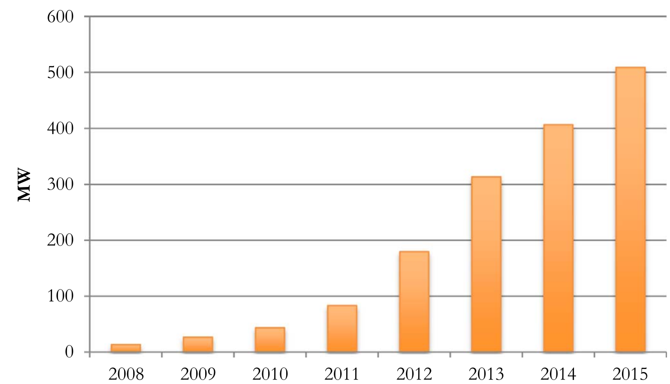

Fig. 2. PV installed capacity 2008–2015.
Source: Hawaiian Electric Companies, 2008–2016. KIUC, 2009–2016.

It is possible that Hawaii's barriers to adoption have less to do with upfront costs, but rather higher than average electricity rates for the U. S. Due to oil-dependence within the electric sector, Hawaii has electricity rates two to three times the national average (EIA, 2015a). In response to a combination of high electricity rates, large government subsidies and declining capital costs, solar PV installations in Hawaii have soared since 2009. The federal and state governments provide a 30% and 35% income tax credit for the up-front cost of PV systems, respectively. Households grandfathered under Hawaii's net-metering agreement for distributed generation receive a one-for-one credit for excess PV power sent to the electric grid, where the credit can rollover between months and up to a one-year time period. This allows a household to "bank" credits in the summer months with high sun to offset usage in winter months. Newer PV systems (since October 2015) under the "grid-supply tariff," however, cannot carry-over credits month-to-month throughout the year and are compensated at a lower than retail rate, equivalent to the average on-peak avoided cost (PUC, 2015). About 17% of homes in Hawaii have solar PV (Trabish, 2016). Residents with access to PV will face dramatically different electricity costs and thus decision-making regarding EV purchase and use. Moreover, EVs that are charged with renewable energy will provide superior GHG emissions outcomes than from oil-burning generation. This of course requires that people charge their EV during high sun hours. Fig. 2 shows the cumulative installed capacity of PV in Hawaii.

It is impossible to use publicly available data to match the number of households with PV to those also with EVs. While PV permit holders are publicly identified, vehicle registration data are not made public at the household level. Nonetheless, there is some evidence that there is a relationship between PV and EV households. For example, of the 238 participants in the utility's pilot EV time-of-use rates (as of 2013), 73% of them also have PV (Hawaiian Electric Companies, 2014). The financial benefit of PV to EV owners in terms of electricity costs is clearly positive. What is less clear is how the upfront cost of PV might factor into the decision to invest in a system large enough to also charge a vehicle.

3. Methodology and data

3.1. Total cost of vehicle ownership

TCO models generally adopt a consumer perspective in assessing the cost to purchase, own and operate a vehicle over a specified lifetime. Gass et al. (2014), for example, use a TCO model to compare EVs and ICEVs in Austria under varying fuel taxes. Inclusion of environmental impacts external to the consumer's direct financial perspective, such as the value of greenhouse gas emissions abatement, can also be factored in. Prud'homme and