Electric Vehicle Transportation Center

Electric Vehicle Greenhouse Gas Emission Assessment for Hawaii

Dr. Makena Coffman
Dr. Paul Bernstein
Sherilyn Wee
Aida Arik
University of Hawaii, Economic Research Organization
E-mail: makena.coffman@hawaii.edu

for
Hawaii Natural Energy Institute,
University of Hawaii at Manoa
1680 East West Road, POST 109
Honolulu, HI 96822
E-mail: makena.coffman@hawaii.edu

Submitted to:
Dr. David Block
Florida Solar Energy Center
University of Central Florida
1679 Clearlake Road
Cocoa, FL 32922
E-mail: block@fsec

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Executive Summary

This study estimates greenhouse gas (GHG) emissions of electric vehicles (EVs) compared to that of other popular and similar cars in Hawaii, by county over an assumption of 150,000 miles driven. The GHG benefits of EVs depend critically on the electricity system from which they derive their power. The analysis shows that EVs statewide are an improvement in GHG emissions over similar and popular internal combustion engine vehicles (ICEVs). Due to Oahu's relatively high dependence on fossil fuels, including coal-burning, however, hybrid electric vehicles (HEVs) offer an improvement over EVs. Notably, Oahu also has the most EVs on the road. Hawaii Island, where there are few EVs on the road, shows a clear GHG benefit from EVs because of its high penetration of low carbon sources for electricity. This difference in benefits suggests that policies supporting EV uptake should consider impacts per island, based on available types of electricity generation. For example, because EVs on Hawaii Island provide near to mid-term GHG benefits, there should be assessment of provision of fast-charging stations to overcome potential range anxiety. Until Oahu substantially transitions towards greater penetration of renewable sources for electricity, it may be too early to tout EVs on Oahu as a GHG emissions reduction strategy. This of course depends on the type of vehicle from which drivers switch to EVs. If EV drivers largely pull from potential HEV consumers, as is suggested in prior studies, then there is no gain in GHG emissions reduction. On the other hand, if EV consumers switch from ICEVs, there are GHG emissions savings. Oahu's electricity generation mix must become similar to that in carbon intensity of Kauai and Maui to make high performing EVs at least comparable to high performing HEVs in GHG emissions.

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I. Introduction

This study extends a prior report that analyzed the total cost of ownership (TCO) of electric vehicles (EVs) in Hawaii in comparison to other similar or popular vehicle models (Coffman et al., 2015). This study looks at the same set of vehicles and driving assumptions to estimate lifetime greenhouse gas (GHG) emissions. 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 and GHG emissions. The potential for reducing GHG emissions by EVs depends on the sources of electricity generation. Hawaii provides an interesting illustration on the GHG impacts of EVs because its islands have varied sources for electricity generation with no current ability for power-sharing. In addition, Hawaii has an aggressive Renewable Portfolio Standard (RPS) goal to meet 40% of its net electricity sales through renewable energy by 2030 and 100% by 2045.

This study estimates, by county, GHG emissions from EVs and other popular vehicles driven in Hawaii. It highlights the differences in electricity generation among counties and its impacts to EVs as a potential GHG abatement strategy. This report is organized as follows. Section II discusses the methods and data used to assess GHG emissions impacts of vehicles. Section III details the key findings regarding GHG emissions by vehicle within each county. Section IV provides discussion and concluding remarks.

II. Methods and Data

In the prior study, the TCO for vehicles is assessed for a 15-year ownership period, translating to 150,000 miles driven.[1] To complement that work, this study similarly uses a 150,000 miles driven assumption in the estimation of lifetime GHG emissions of a vehicle. The prior study looked at EVs available for sale in Hawaii, subject to data availability on insurance and maintenance costs provided by Edmunds.com 2014.[2] For comparison, any like-models as well as the top-selling cars in Hawaii were also included (Hawaii Dealer, 2014). Conventional gasoline models include the Toyota Corolla, Honda Civic, Honda Accord, and Toyota Camry. The Toyota Prius was the fourth most popular car overall, following the Honda Accord. For detail on assumptions regarding fuel efficiency, see Coffman et al. (2015).

Electricity Generation by County

In this study, electricity generation is disaggregated at the county level – primarily due to ease in data reporting by the Energy Information Administration and major utilities. Hawaii has four counties: City and County of Honolulu (Island of Oahu), Kauai County (Island of Kauai), Maui County (Islands of Maui, Molokai and Lanai), and Hawaii County (Island of Hawaii). With the exception of Maui, each county represents its own electric grid. For Maui County, the Island of Maui dominates the generation portfolio because it has over 90% of the population. There are two electric utilities in

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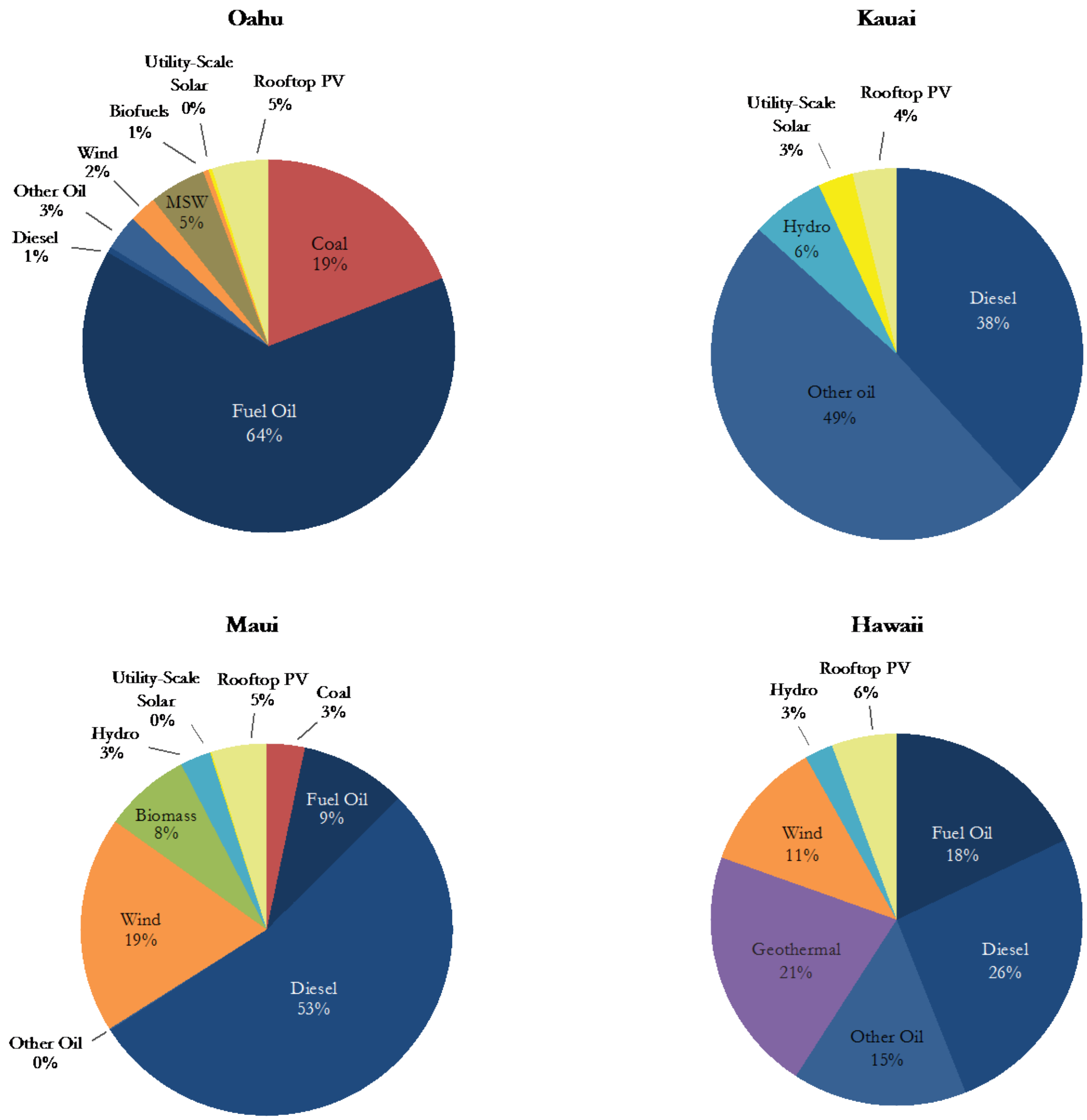
[1]In Hawaii, the average annual vehicle miles traveled is roughly 10,000 miles. The TCO, a measure of cost-effectiveness, includes the costs for vehicle financing, taxes, insurance, annual registration, fuel, maintenance, and replacement battery costs (for HEVs and EVs). It also accounts for vehicle depreciation through a salvage value. Gasoline and electricity prices are forecasted throughout the 15-year horizon of the analysis using future fuel prices from the Energy Information Administration's Annual Energy Outlook 2015. The results presented here are based on their reference price pathway. For more detailed documentation of the TCO method and data, refer to Coffman et al. (2015).
[2] While the BMW i3, BMW i8, Cadillac ELR, Mitsubishi iMiEV, and Tesla Model S are available Hawaii, they were excluded since maintenance and insurance costs for Honolulu were unavailable. The Porsche Panamera was also excluded because of its extremely high cost.

Hawaii: a utility that operates on Oahu, Maui County, and Hawaii, and another that operates on Kauai. Each is mandated to meet the RPS. Figure 1 below shows Hawaii's electricity generation portfolio by technology/fuel, disaggregated by county.

Figure 1. Hawaii's Electricity Generation Portfolio by County (2014)



Source: EIA, 2015; Hawaiian Electric Companies, 2015; KIUC, 2015.

Figure 1 highlights the importance of considering the GHG impacts from EVs at a disaggregated level, as the electricity generation portfolios are markedly different. For instance, Oahu is likely the least favorable location for EVs since mostly fuel oil and coal are burned. On the other hand, Hawaii Island has the largest share of renewable sources because of the geothermal plant, which meets 21% of its generation. Additional renewable energy sources on Hawaii Island include wind (11%), hydro (3%), and rooftop PV (6%). Kauai has the lowest share of renewables, followed by Oahu, and Maui. Aside from hydropower (6%), Kauai's renewable portfolio includes utility-scale solar (3%) and rooftop PV (4%). Oahu's renewable portfolio is the most diverse, comprised of municipal solid waste (MSW) (5%), rooftop PV (5%), wind (2%), biofuels (1%), and utility-scale solar (0.3%). On Maui, wind generation (19%) is the largest renewable resource, followed by biomass (8%), rooftop PV (5%), hydro (3%), and utility-scale solar (0.1%). While Oahu relies heavily on fuel oil (64%) and coal (19%), the counties of Maui, Kauai, and Hawaii's primary fossil fuel are diesel as well as other oil (waste oil, other gas, kerosene).

GHG Emissions Factors

The EPA's CO_2 emission factors for combustion of gasoline and fuel for power generation are used to estimate GHG emissions impacts of EVs and other vehicles (EPA, 2014). For electricity, fuel used (in MMBtu) for electricity generation in 2014 is multiplied by its respective emission factor and the sum is divided by total power generation to derive an emission factor based on each county's 2014 electricity generation mix (EIA, 2015; Hawaiian Electric Companies, 2015; KIUC, 2015).

Table 1 presents the mobile and stationary combustion CO_2 emission factors assumed for this study. CO_2 emission factors are for out-of-stack emissions, with the exception of biodiesel and biomass. Because biofuels burn similarly to their fossil fuel counterparts, but absorb carbon within the feedstock growing phase, biodiesel is assumed to be an approximately 25% improvement over gasoline (Wang, 2001) and biomass (agricultural byproducts), 50%.[3] The emission factor for residual fuel oil no. 6 applies to fuel oil, and distillate fuel oil no. 2, to diesel fuel. Geothermal is treated as a zero carbon source, along with wind, solar, and hydro.

[3] Among the California Air Resource Board's certified carbon intensity pathways, sugar ethanol ranges from 22% (78% reduction) to 85% (15% reduction) of gasoline with an average of 63% or a 37% reduction (see ARB,2016). However, since these values represent finished biofuel which is more energy intensive, biomass is assigned a slightly higher reduction of 50%. To have an accurate representation of either biodiesel or biomass requires a much more in-depth GHG study, which is outside the scope of this analysis.

Table 1. CO_2 Emission Factors

Mobile Combustion (kg/gallon)	
Motor Gasoline	8.8
Stationary Combustion (kg/MMBtu)	
Bituminous Coal	93
Municipal Solid Waste	91
Residual Fuel Oil No. 6	75
Distillate Fuel Oil No. 2	74
Other Oil	74
Agricultural Byproducts[a]	59
Biodiesel (100%)[b]	55

Source: EPA, 2014.
[a] 50% reduction from EPA's reported values.
[b] 25% reduction from EPA's reported values.

The motor gasoline emission factor in kg CO_2/gal is almost 9.[4] Based on each county's respective 2014 electric fuel consumption, Oahu has the highest emission factor at 0.70 kg CO_2/kWh, and Hawaii Island has the smallest at 0.46 kg CO_2/kWh. Maui and Kauai have an emission factor of 0.54 and 0.60 kg CO_2/kWh, respectively.[5] Note that although Kauai has the lowest share of renewable energy, because the fossil fuels burned on Kauai are less carbon-intensive than the substantial share of coal burned on Oahu, Kauai's emission factor is lower than that of Oahu's.

Lifetime GHG emissions by vehicle are calculated as a function of total fuel consumption (determined within the model based on fuel efficiency and miles traveled), the motor gasoline emission factor, and each county's respective electricity generation emission factor. This relationship is represented in Equation 1 below:

$$E_v = (gal_v * gasEF) + (kwh_v * elecEF_c) \tag{1}$$

where E_v denotes total emissions by vehicle; gal_v is gasoline consumption in gallons; $gasEF$ is the emission factor for gasoline; kwh_v represents electricity consumption in kWh; and $elecEF_c$ is the county-level emission factor for electricity generation.

III. Key Findings

The sources for electricity generation per county determine the extent to which EVs provide a mechanism for GHG emissions reductions. Figure 2 below shows vehicle GHG emissions in $MTCO_2$ per 150,000 miles driven, given the county's existing mix of electricity generation. Figure 3 focuses on the results for BEVs and PHEVs.

[4] 9 kg CO_2/gal for a 30 mpg vehicle equates to 0.3 kg CO_2/mile. The range in emission rates per mile by island for an EV with an efficiency of 0.3 kWh/mile is from about 0.14 kg CO_2/mile to 0.18 kg CO_2/mile.
[5] To double check this methodology, electric sector emissions were also calculated statewide for the year 2007, when the State completed a comprehensive GHG inventory report (ICF, 2008). The approach used in this study leads to similar results as the 2008 study.

Figure 2. Lifetime Vehicle GHG Emissions by County

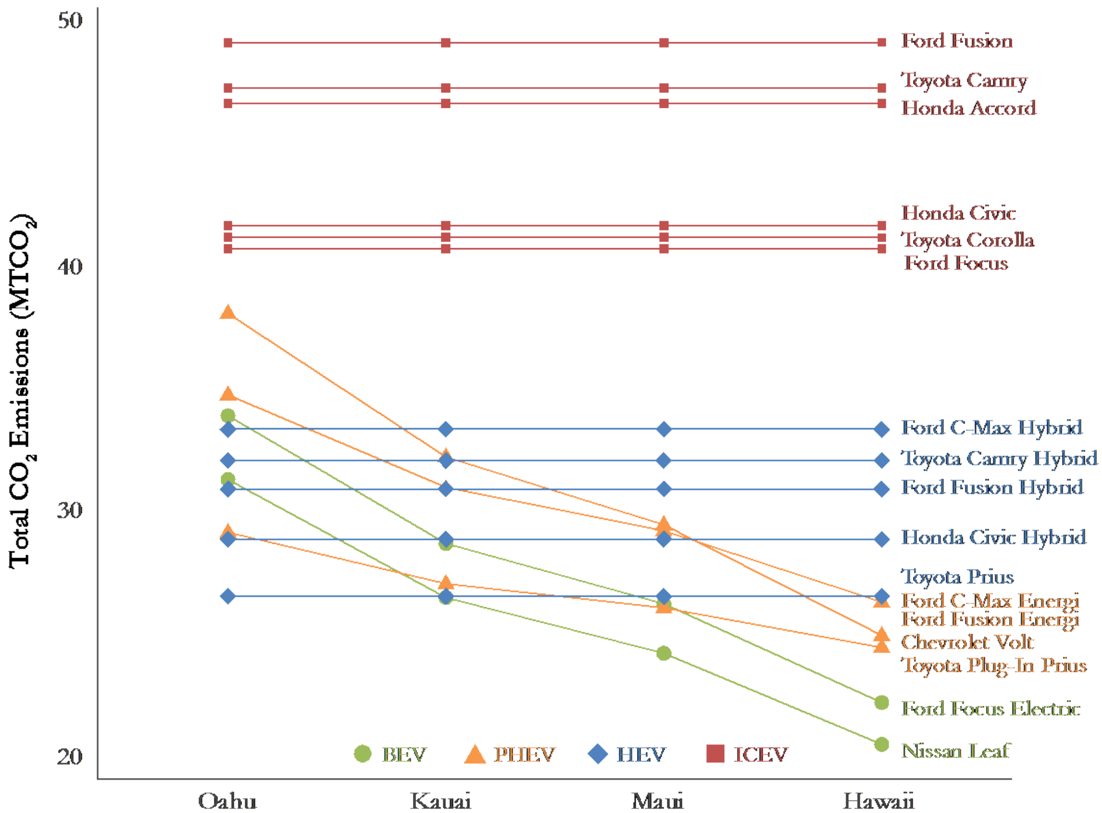
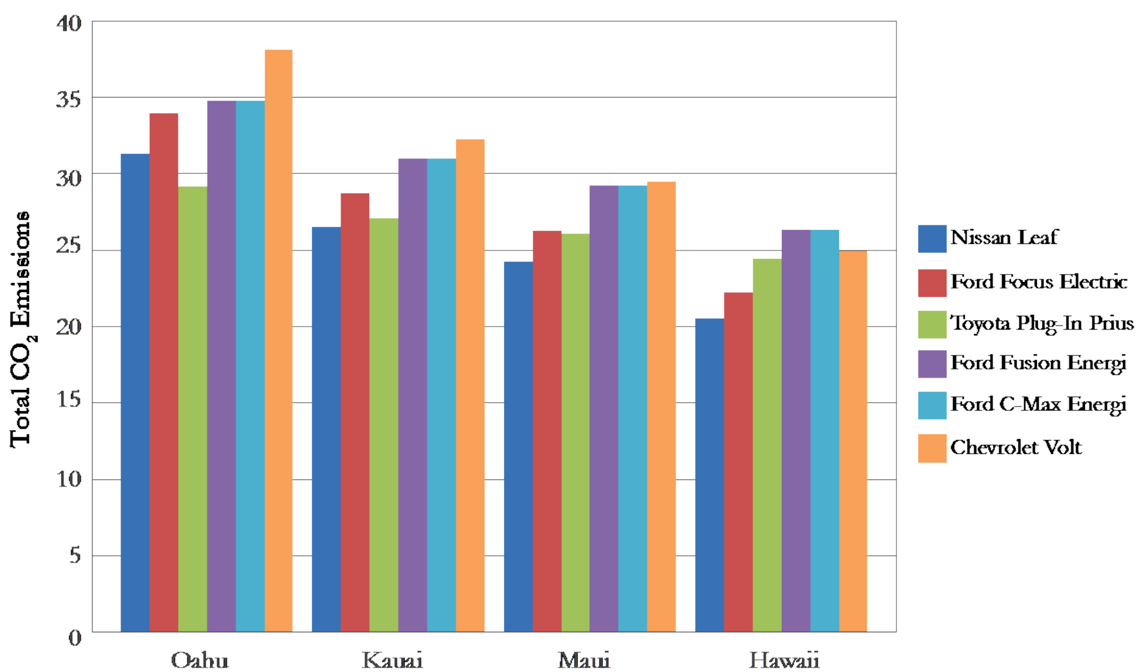


Figure 3. Lifetime EV GHG Emissions by County



EVs are an improvement over ICEVs statewide. The Ford Focus, followed by the Toyota Corolla, are the lowest GHG emitting ICEVs due to their relative fuel efficiency. HEV's are yet more efficient. The Toyota Prius, the highest performing HEV within this study, emits 27 $MTCO_2$ over 150,000 miles driven. Under the same driving assumptions, the Nissan Leaf would produce 31 $MTCO_2$ on Oahu, 24 $MTCO_2$ on Maui, and 21 $MTCO_2$ on Hawaii Island. Therefore, the Nissan Leaf offers an improvement over the Toyota Prius on Hawaii Island and Maui but not on Oahu. The Nissan Leaf and the Toyota Prius perform similarly to one another on Kauai. In terms of cost, Coffman et al. (2015) found that the Nissan Leaf has a TCO that is $10,000 higher than that of the Toyota Prius. On Oahu, this implies that Nissan Leaf drivers are paying more to emit more GHG emissions, relative to the Toyota Prius. This relationship remains true even factoring in the $7,500 federal tax credit. On Hawaii Island, however, the Nissan Leaf emits almost 6 $MTCO_2$ less than the Toyota Prius over 150,000 miles driven. Normalizing this emissions savings by the increase in TCO implies a GHG emissions abatement cost of about $1,700/$MTCO_2$. While the Nissan Leaf offers a clear improvement over the Toyota Prius in terms of GHG emissions on Hawaii Island, it remains a costly abatement strategy.[6]

How PHEVs fare on the different islands relative to BEVs and ICEVs depends on their share of operation in electric mode and their emissions in electric mode relative to their emissions in gasoline mode. PHEVs like the Toyota Plug-in Prius tend to have fewer GHG emissions on Oahu than BEVs. Extended range PHEVs like the Chevrolet Volt perform the worst. Their lower performance is both because of the Chevrolet Volt's low efficiency and reliance on electricity. However, while the Chevrolet Volt has the highest emissions of EVs overall on Oahu, Kauai, and Maui, it performs relatively better on Hawaii Island where it is assumed to operate mostly in EV mode. Because the assumed daily average driving range is 27 miles and the Chevrolet Volt can travel 38 miles exclusively on electricity, it is akin to a BEV that is now being charged with a relatively low carbon intensity sources of electricity. A higher efficiency BEV like the Nissan Leaf, however, would still have lower GHG emissions on Hawaii Island.

IV. Discussion and Conclusions

This study extends Coffman et al. (2015)'s comparison of the TCO for EVs and other cars in Hawaii to a comparison of GHG emissions based on 150,000 miles driven. Given the current electricity generation mix, this study finds:

- Statewide, EVs provide an improvement in GHG emissions over ICEVs.
- On Oahu, the best performing EV (Nissan Leaf) emits 5 $MTCO_2$ more over its lifetime than the best performing HEV (Toyota Prius).
- On Hawaii Island, all EVs perform better than HEVs. The Nissan Leaf's lifetime emissions are 6 $MTCO_2$ less than that of the Toyota Prius. But at about $2,000/$MTCO_2$ abated, it is a costly GHG emissions reduction strategy.
- On Kauai, GHG emissions produced by EVs fall in the same range as HEVs, while some EVs on Maui perform better than HEVs.

[6] Most emissions abatement programs (e.g., Regional Greenhouse Gas Initiative, California's cap-and-trade program, and the European Union's emission trading system) have costs under $25/$MTCO_2$.

The vast majority of EVs in Hawaii are located on Oahu. Figure 4 shows registered EVs by county from 2010 to 2015, and Figure 5 shows the same information per 1000 persons.

Figure 4. Registered EVs in the State of Hawaii, by County

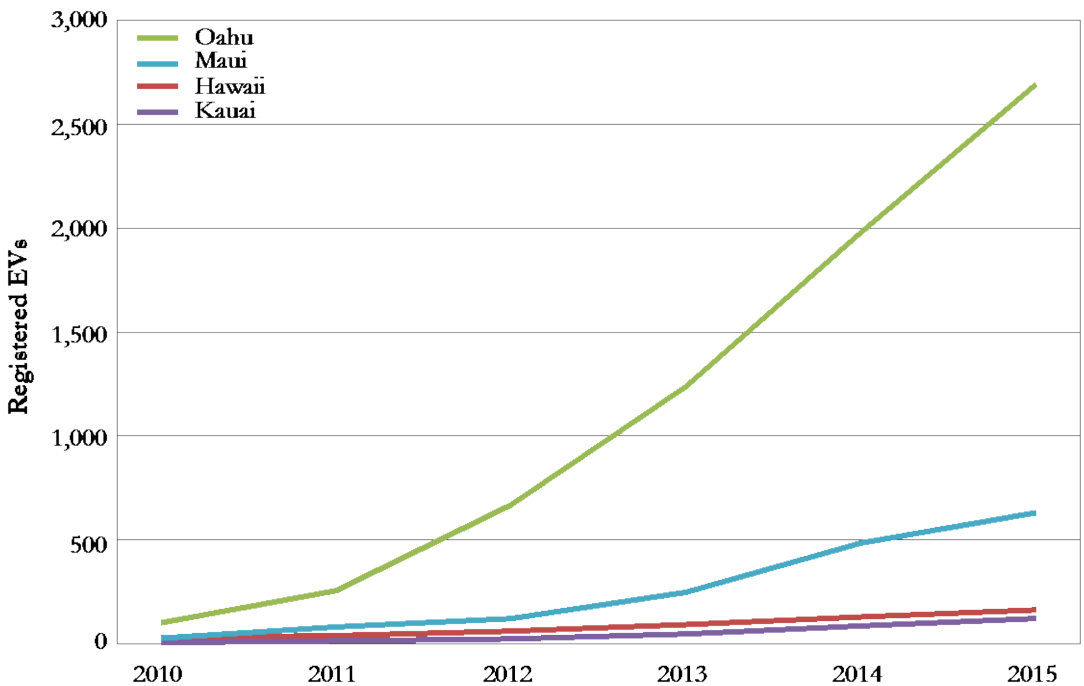
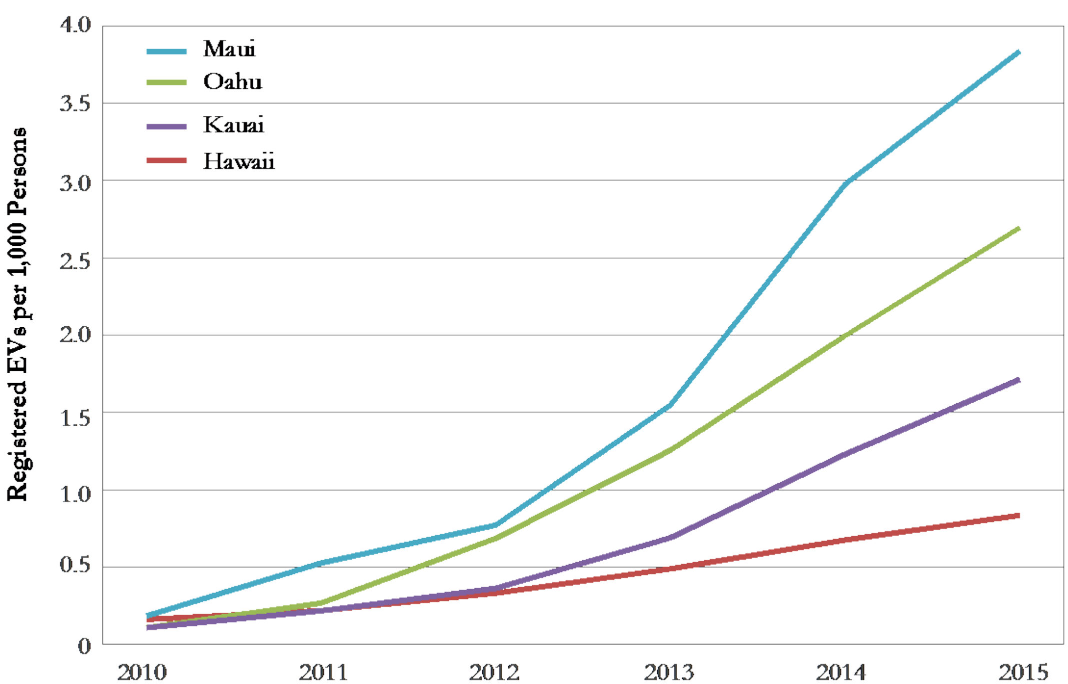


Figure 5. Registered EVs per 1000 Persons in the State of Hawaii, by County



Although Hawaii Island's electricity generation mix is most favorable to supporting EVs as a GHG emissions reduction mechanism, it has the lowest rate of EV uptake per capita and 160 vehicles on the road as of 2015 (DBEDT, 2016). This is likely due to the size of the island at about 4,000 square miles and thus longer driving distances. Maui, on the other hand, spans 730 square miles, and Oahu, 600 square miles. Given that the limited driving range of EVs is a major barrier to adoption (Carley et al., 2013; Hidrue et al., 2011), the longer driving distances and more sparsely located urban cores on Hawaii Island likely exacerbates "range anxiety." The availability of adequate charging infrastructure is therefore crucial to EV adoption (Bakker et al., 2014; Lopes et al., 2014; Campbell et al., 2012; Egbue and Long, 2012; Schroder and Taber, 2011), with considerations for reasonable charging time (Hackbarth and Madlener, 2013; Hidrue et al. 2011). Whereas Hawaii Island has 58 charging station ports, Oahu and Maui host 275 and 117, respectively (HSEO, 2016); Kauai has the least number of ports, totaling 34. Maui has the most fast-charging ports (35)—reducing recharging time for a larger population of EV drivers—compared to Oahu (15), Hawaii Island (2), and Kauai (1). Maui also has the highest penetration rate for EVs on a per capita basis.

The findings of this study suggest that strategies like provision of fast-charging stations may have greater benefit on Hawaii Island to overcome range anxiety and pursue GHG emissions reductions – albeit a costly strategy relative to current carbon markets. Until Oahu substantially transitions towards greater penetration of renewable sources for electricity, it may be too early to tout EVs on Oahu as a GHG emissions reduction strategy. This of course depends on the type of vehicle from which drivers switch to EVs. If EV drivers largely pull from potential HEV consumers, as suggested is likely in Carley et al. (2013) and Hidrue et al. (2011), then there is no gain in GHG emissions reduction. On the other hand, if EV consumers switch from ICEVs, there are GHG emissions savings. Oahu's electricity generation mix must become similar to that in carbon intensity of Kauai and Maui to make high performing EVs at least comparable to high performing HEVs in GHG emissions. Given Hawaii's RPS law allows for pooling of electricity grids between Oahu, Maui and Hawaii Island, this may not occur until after the 2030 time-frame.

VI. Acknowledgements

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