



Electric Vehicle Transportation Center

Electric Vehicle Lifecycle Cost Assessment for Hawaii

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HNEI

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Executive Summary

This study builds on the model presented by Raustad and Fairey (2014) for “Electric Vehicle Life Cycle Cost Assessment” and tailors findings for the case of Hawaii. Raustad and Fairey (2014) developed an excel spreadsheet model calculating total lifetime ownership costs for vehicles including purchase/finance, insurance, maintenance, and resale value. The time frames considered are 5, 10 and 15 years of ownership. It also has a module to assess the impact of having access to residential solar photovoltaic (PV) power to reducing EV ownership costs. In this work, extensions are made to assess decisions regarding vehicle leasing as well as to analyze Hawaii’s largest utility’s pilot and proposed “time-of-use” (TOU) rates for households with EVs.

Key findings are as follows:

- EVs on average cost more than their internal combustion engine (ICE) or hybrid electric vehicle (HEV) counterparts, though this gap is substantially reduced with the federal tax credit.
- The Nissan Leaf is cost competitive without the federal tax credit and has the lowest lifecycle vehicle cost when incorporating the federal tax credit (among all vehicles considered).
- Electricity rates in Hawaii are much higher than the national average. Using the Energy Information Administration’s range of forecasts for future oil prices (*low*, *reference* and *high*), a set of future electricity and gasoline prices are determined. The model finds that when oil prices are *low* or *reference*, lifetime fuel costs are higher for EVs than other vehicles. When oil prices are *high*, on the other hand, EVs offer notable cost savings while accounting for Hawaii’s historic relationship between oil prices and electric rates.
- Having residential PV substantially brings down the cost of EV ownership, even considering the capital expenditure for PV panels.
- The pilot and proposed TOU rates offered by the utility reduce lifecycle EV fuel costs, assuming charging only when rates are lowest, by an average of 10%.

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I. 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 the use of fossil-based transportation fuels. A major barrier to widespread adoption, however, is the higher upfront cost in comparison to comparable internal combustion engine (ICE) vehicles and hybrid electric vehicles (HEV). To assist with deployment, the federal government offers a subsidy of up to \$7,500 for the purchase of qualifying EVs. In addition to upfront cost, on-going costs must also be considered. With potentially rising gasoline prices and relatively lower electricity rates, it is possible that the lifecycle costs (LCC) associated with EVs are lower than their comparable ICE/HEV.

This study builds on the model presented by Raustad and Fairey (2014) for “Electric Vehicle Life Cycle Cost Assessment” and tailors findings for the case of Hawaii. Raustad and Fairey (2014) developed an excel spreadsheet model calculating total lifetime ownership costs for vehicles, which includes purchase/finance, insurance, maintenance, and fuel costs as well resale value. The time frames considered are 5, 10 and 15 years of ownership. It also has a module to assess the impact of vehicle owners having access to residential solar photovoltaic (PV) power to reduce EV ownership costs. In this work, extensions are made to assess decisions regarding vehicle leasing as well as to analyze Hawaii’s largest utility’s pilot and proposed “time-of-use” (TOU) rates for households with EVs.

II. Methodology and Data

Raustad and Fairey (2014) developed and made publicly available an LCC model for automotive vehicles. The model accounts for key parameters such as:

- Vehicle purchase price;
- Vehicle characteristics, particularly fuel economy;
- Vehicle resale value, based on vehicle depreciation;
- Insurance and maintenance costs;
- Battery degradation;
- Daily miles driven;
- Economic factors including the finance, inflation, and discount rates;
- Gasoline price; and
- Electricity rates.

To adapt the model for Hawaii, vehicle purchase price is based on average price paid as reported by Edmunds.com for the Honolulu, 96822 zipcode, as well as typical insurance and maintenance costs. Vehicle characteristics are collected from manufacturers websites as well as Fueleconomy.gov. The vehicle depreciation rate over time is adopted from Raustad and Fairey (2014). As in the initial model, batteries are assumed to have an 11-year life and thus battery replacement is important within the 15-year time frame. It is assumed that it is replaced after the 11th year of ownership.

The average annual driving range in Hawaii is approximately 10,000 miles per year and is approximately equivalent to a daily commute of 27 miles/day.¹ Economic factors include the finance rate (3.25%), inflation rate (2.53%), and discount rate (4.53%)² (Raustad and Fairey, 2014).

In addition the updated model accounts for installation of home charging infrastructure and is assumed to cost \$1,000 (Aeroenvironment, 2015). This is based on the cost of a Level 2 (240V) charger for the Nissan Leaf.

Fuel Price Forecasts

Gasoline

Gasoline prices and electricity rates are calibrated within the model for Hawaii and, as an important extension to the original model, vary over time. The prices follow one of three possible price pathways: *low*, *reference* and *high*, based on the U.S. Energy Information Administration (EIA)'s Annual Energy Outlook (AEO) (EIA, 2015a).

Historic data (1990-2010) for annual regular and premium gasoline prices are provided on the EIA Form 782B, which reports motor gasoline sales through retail outlet prices by state and by type (EIA, 2015b). The statistical relationship between historic regular/premium gasoline prices in Hawaii and the historic average imported cost of crude oil (EIA, 2015c; EIA, 2015d) are estimated using an ordinary least squares regression, transforming both gasoline and crude oil prices into log form. Equation 1 below shows the relationship, and results are provided in table 1.

$$\log(gas_t) = \alpha + \beta \log(imported\ crude_t) + \varepsilon_t \tag{1}$$

Table 1. Gasoline and Crude Oil Price Relationships

	Ln(regular gas)	Ln(premium gas)
Ln(imported crude oil)	0.613*	0.523*
	[0.039]	[0.036]
Constant	-1.565*	-1.135*
	[0.151]	[0.139]
Observations	21	21
Adjusted R-squared	0.909	0.926

Robust standard errors in brackets. * p<0.01,

Though the sample size is small, because historic data are most readily available on an annual basis, both regular and premium gasoline prices are strongly related to the price of imported crude oil. For every 1% change in the price of imported crude corresponding to roughly a

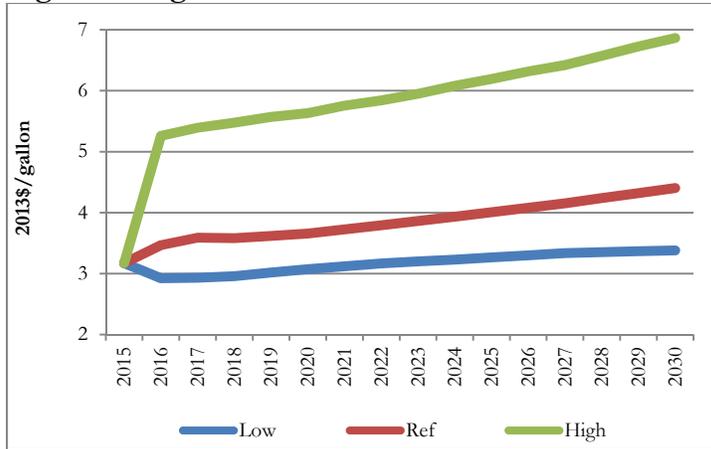
¹ The average US driver travels 29 miles per day (AAA, 2015). Hawaii has shorter commute distances so 27 miles per day for the typical driver is assumed, equivalent to approximately 10,000 miles per day. This is slightly higher than the Hawaii State Databook estimate of 9,000 miles annually (though this is likely an underestimate).

²Applying a discount rate is a commonly used economic method to better capture a person's rate of time preference.

0.6% and 0.5% change in the price of regular and premium gasoline, respectively. The coefficients are both statistically significant at the 99% level.

Once the coefficients for the relationship between imported crude oil prices and regular/premium gasoline are estimated, the AEO forecast for imported crude oil under *low*, *reference* and *high* price pathways are used to project gasoline prices into the future. Most vehicles considered use regular gasoline. The Chevrolet Volt is the only EV that takes premium gasoline. The forecast for regular gasoline is shown below in figure 1.

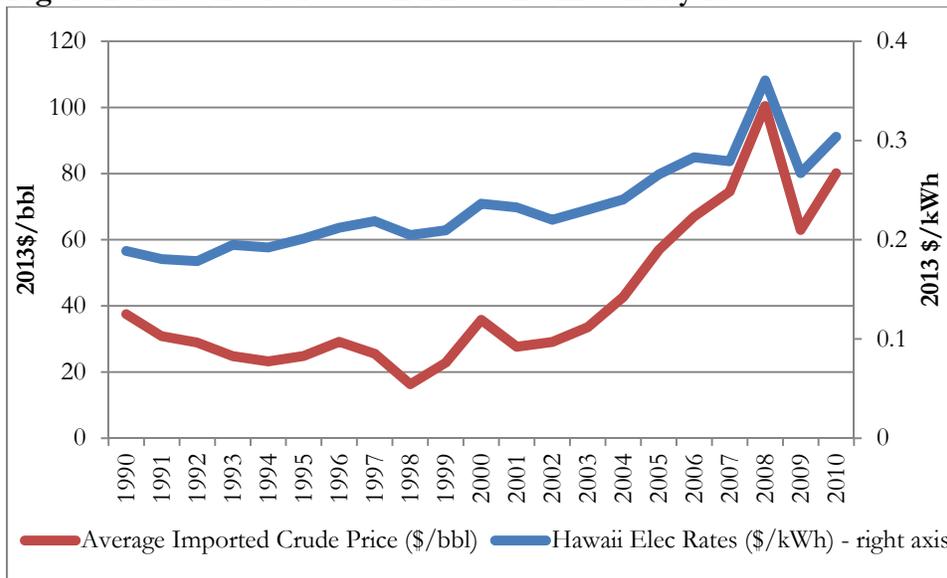
Figure 1. Regular Gasoline Price Forecast



Electricity

Electric rates are similarly estimated. Hawaii is oil-dependent for electricity, meeting about 70% of its generation through oil-fired sources (DBEDT, 2015). This means that rates in Hawaii are three times the national average (DBEDT, 2015). As such, Hawaii’s electric rates tend to follow world oil prices, as shown in a historic trend from 1990 to 2010 in figure 2.

Figure 2. Historical Crude Oil Price and Electricity Rate



A simple regression can well-capture the historic relationship between oil prices and electricity rates, as shown in equation 2. The results are shown in table 2. Every 1% change in the price of imported crude oil results in a 0.3% change in Hawaii’s electricity rates.

$$\log(elec_t) = \alpha + \beta \log(imported\ crude_t) + \varepsilon_t \tag{2}$$

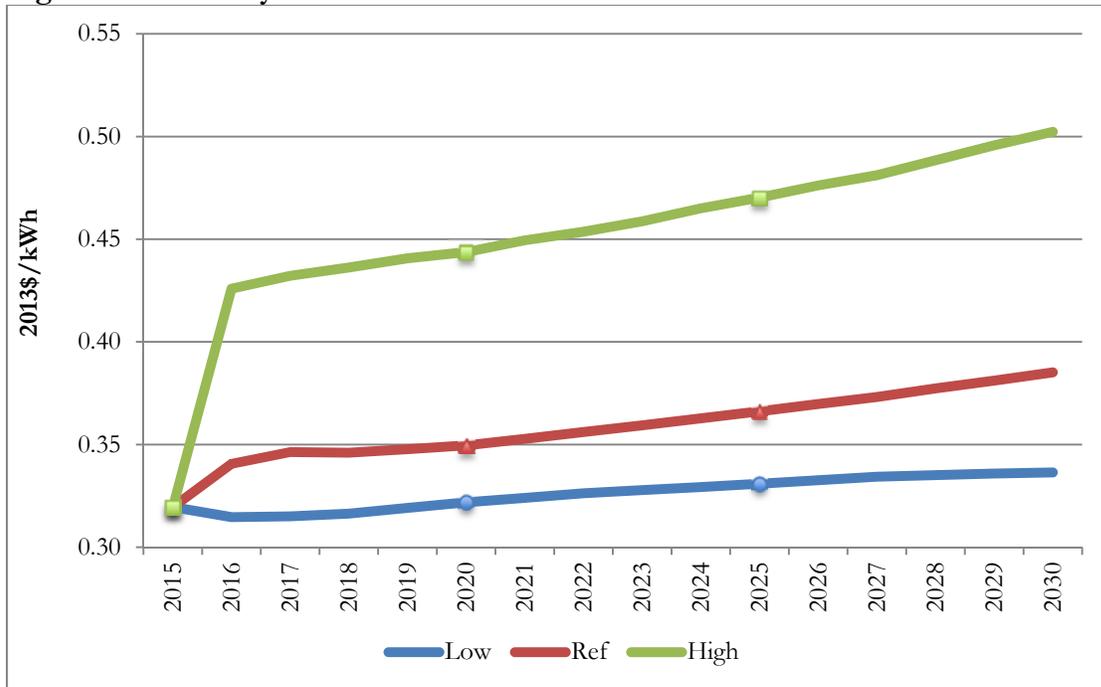
Table 2. Log-Log Electricity Rates Regression Results

	Ln(electric rate)
Ln(imported crude oil)	0.325*
	[0.043]
Constant	-2.644*
	[0.161]
Observations	21
Adjusted R-squared	0.734

Robust standard errors in brackets. * p<0.01

Forecasting future electricity rates based on this historic relationship may, however, be difficult to defend. Hawaii’s recent renewable portfolio standard for the electric sector requires that 100% of net electricity sales be met through renewable sources by the year 2045, with aggressive interim goals. Over the next 15 years, which is the maximum time horizon within this analysis, the standard mandates achieving 40% renewable sources of electricity. This is roughly 15% more renewable sources of electricity than exists today. As such, the relationship between oil and electricity prices should weaken into the future. Whether this will cause electric rates to relatively rise or fall, however, is much less clear. A recent study commissioned by the Hawaii Natural Energy Institute (2015) on the production cost impacts of the renewable portfolio standard suggests that introducing renewable energy does not tend to add considerable cost, and can even lead to slight cost savings (GE Consulting, 2015). Moreover, the language within the State’s renewable portfolio standard law highlights the importance of meeting the targets in a way that does not raise costs to consumers (and provides this as a reasonable stipulation for non-compliance). This suggests that electricity rates should not in the future cost more than using oil-based generation as a baseline. As such, this study relies on the oil-based electricity price forecast as a proxy for future residential electric rates. This results in the *low*, *reference*, and *high* residential electricity price forecasts shown below in figure 3.

Figure 3. Electricity Rate Forecast³



Additional Model Extensions and Scenarios

In addition to calibrating the model to the economic conditions of Hawaii, including making the electricity rate and gasoline price forecast dynamic over time, this study also provides an extension of the model for a lease option (on top of purchase and finance). This study utilizes the existing modules assessing the impacts of the federal subsidy and having residential PV. It also builds in Hawaii-specific analysis regarding the utility's TOU rates.

Lease

This work extends the original model to capture the LCC associated with vehicle leasing by assuming that there is a three-year lease term, at the end of which the consumer returns the vehicle and leases another, identical vehicle. Following standard lease payment calculations, monthly payments are derived using a money factor equivalent to a 3% interest rate (Edmunds, 2014a), residual value⁴ and a 12% down payment made at the beginning of the lease term⁵ (Edmunds, 2014b). Hawaii's 4.17% sales tax is added to the monthly payments.

In addition, there is pass-through of the federal tax credit within lease terms for certain vehicles. Based on calling dealerships in Honolulu, some manufacturers choose to roll the value of the federal tax credit within their lease terms (Nissan and Ford) while others do not

³ For simplicity due to the numerous electric rate schedules considered, the model takes electric rates in 5-year increments. This means that the price in 2015 is captured from 2015-2019 and the price in 2020 is used from 2020-2024.

⁴ The residual value follows that of the depreciation schedule used to calculate the vehicle resale value in the original model (See Raustad and Fairey, 2014).

⁵ Based on an analysis by Edmunds on new and used car purchases in 2013.

(Chevrolet and Toyota). The model accounts for the federal tax credit within lease terms such that manufacturers who do pass along the tax credit to consumers do so for the first two lease terms (i.e. covering 6 years) with the assumption that manufacturers will reach the 200,000 EV sold limit under the federal tax credit terms by the third lease negotiation. After this time, the tax credit is taken out of lease terms for all vehicles.

The purchase option assumes that the vehicle is purchased outright and the finance option assumes a 5-year finance term.

Solar PV

The PV module within the model is recalibrated for the case of Hawaii. This is an important consideration in the LCC of EVs because Hawaii has tremendously high rates of residential PV installation – with nearly 12% of residences with PV (Hawaiian Electric Companies, 2015a). The relationship between PV and EV is also quite notable. For example, of the 238 participants in the utility’s pilot EV TOU rates (as of 2013), 73% of them also have PV (Hawaiian Electric Companies, 2014).

Households are assumed to have enough PV on their rooftop such that all vehicle charging occurs through PV and are grandfathered into the current “net-metering” agreement. PV systems are sized specifically for charging EVs (and not household consumption). Vehicles with a battery size greater than 4 kWh but less than 9.5 kWh are assigned a 1 kW PV system—this captures most PHEVs.⁶ A 2 kW PV system is allotted for battery sizes exceeding 16 kWh, and thus includes all BEVs that generally have a battery size in the low 20 kWh’s. Hawaii’s net-metering agreement for distributed generation allows households with PV to 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. Thus if a person is not home to charge the EV during peak sun hours, as is often the case, PV still achieves essentially zero marginal electricity costs due to the net-metering agreement. The cost of the PV system is accounted for within the LCC model – and discounted because PV panels are expected to last longer than the 5, 10 or 15-year time-frame. This means that for the 5-year time frame, for example, only one fifth of the cost of the PV system is allocated to the LCC of the vehicle.

EV Time-of-Use Rates

This study assesses the pilot and proposed TOU rates for EV charging in terms of impacts to LCC for EVs. The rates are proposed by the largest electric utility, the Hawaiian Electric Industries, which operate on Oahu, Maui County and Hawaii Island. While electric rates actually vary by island, they are used in this analysis as a statewide average.

The utility launched a pilot TOU rate program for residential charging of EVs in 2010. The voluntary programs gave EV owners two rate schedules from which to choose. The first is based on use of a single home electric meter and the second requires installation of a separate second meter specifically to manage EV charging.

⁶ The exception is the Chevy Volt which has a battery size of 16.5 kWh, closer to the capacity of BEVs.

The first program, here called “Pilot Household Use and EV Charging TOU,” provides a \$0.06 reduction relative to normal residential electric rates for post-peak nighttime charging, meaning from 9pm to 7am. It also incorporates a \$0.055 increase in rates for any household consumption of electricity on-peak from 5 to 9pm on weekdays and an increase of \$0.025 from 7am to 5pm on weekdays and 7am to 9pm on weekends.

The second program, here called “Pilot EV Charging Only TOU,” provides a \$0.07 reduction relative to normal residential electric rates for post-peak nighttime charging and a \$0.02 increase in the mid-peak rate. In this study it is assumed that a household charges optimally, post-peak. This means that the increased mid-peak rate is here irrelevant due to the installation of the second meter (i.e. it no longer affects the rate of household electricity use). Adding the second meter does, however, add cost. It requires the household to engage a licensed contractor and this cost is assumed to be \$1,000.

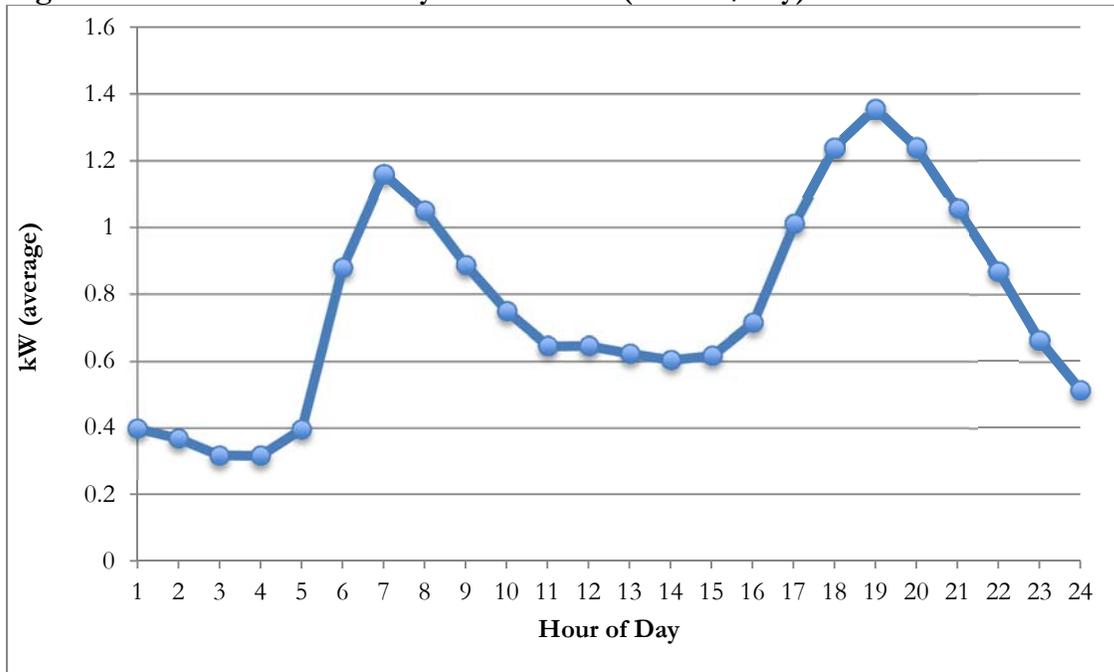
The pilot program is scheduled to sunset in October 2015 and the utility has proposed new TOU rates (Hawaiian Electric Companies, 2015b) though they still need to go through regulatory approvals. The “Proposed Household Use and EV Charging TOU” rate proposes a substantial change to morning and early afternoon charging, in response to high levels of solar PV penetration. It proposes to reduce electric rates from the typical residential rate by \$0.061 in the post-peak nighttime, morning and early afternoon hours and increase the rate by \$0.126 during peak hours from 3 to 9pm. Relative to the pilot program, this extends the benefit of a lower rate from just nighttime loads to a total of eighteen hours of the day. The “peak” rate, however, faces a penalty over twice as high relative to the pilot program.

The “Proposed EV Charging Only TOU” reduces off-peak charging rates by \$0.061 and increases by \$0.126 between peak hours of 5 to 9pm. This is similar to the proposal for the rate structure with a single meter, though the “peak” hours begin two hours later. This, however, is again irrelevant with the assumption of only off-peak charging.

To assess the impact of these pricing schemes, a number of assumptions are made. The first as discussed is that EVs are only charged when rates are at their lowest. In reality, households may choose to charge when rates are relatively higher for convenience. The sensitivity of households to prices for EV charging is an area that needs further study.

The second major assumption, which is made for simplicity and to keep the focus on EV costs (rather than broad household electricity usage), is that patterns of other household electricity consumption do not change with adopting a TOU rate program. A residential electricity load curve is used to estimate the change in cost during the various periods of pricing. These data were collected based on a sample of 63 apartment complexes in Honolulu in February through April 2012 (Lynham et al., 2014). There is no air conditioning available in these apartments, so it under-represents typical household electricity consumption. To address this, the shape of the load curve is applied to a more typical four-person household’s electricity demand of 18 kWh per day. Figure 4 shows the residential load curve used in this study.

Figure 4. Residential Electricity Load Curves (18 kWh/day)



The change in cost of consuming household electricity for purposes other than the EV, as a result of signing up for Household Use and EV Charging TOU rates with a single meter, is accounted for within the EV LCC calculation.

Vehicle Selection

All EVs available in Hawaii are included in this analysis, subject to data availability. Edmunds.com “True Cost to Own” provides maintenance and insurance costs specific to geographic area; data for Honolulu were not available for several EVs—BMW i3 (BEV and PHEV), BMW i8, Cadillac ELR, Mitsubishi iMiEV, and Tesla Model S—and therefore these models were excluded. While the Porsche Panamera is available upon special order, it was also excluded because of its extremely high cost.

To make the analysis most relevant to Hawaii, this study also includes the top-selling cars⁷ sold in Hawaii based on a 2014 report sponsored by the Hawaii Automobile Dealer’s Association (HADA) (Autolook, 2014). The conventional gasoline models in descending order include the Toyota Corolla, Honda Civic, Honda Accord, and Toyota Camry. The Toyota Prius was the 4th most popular car overall, following the Honda Accord.

Table 3 details all model parameters for each vehicle assessed as part of this study. For all cars, tires are replaced every 50,000 miles at \$450. Batteries are placed after 11 years for EVs and HEVs at a cost of \$180/kWh.⁸

⁷ Light truck/SUV models are excluded.

⁸ This follows Raustad and Fairey’s (2014) traction battery cost estimate, which is conservative compared to DOE’s EV Everywhere Grand Challenge goal of reaching \$125/kWh by 2022 (Energy.gov, 2015).

Table 3. Vehicle Parameters

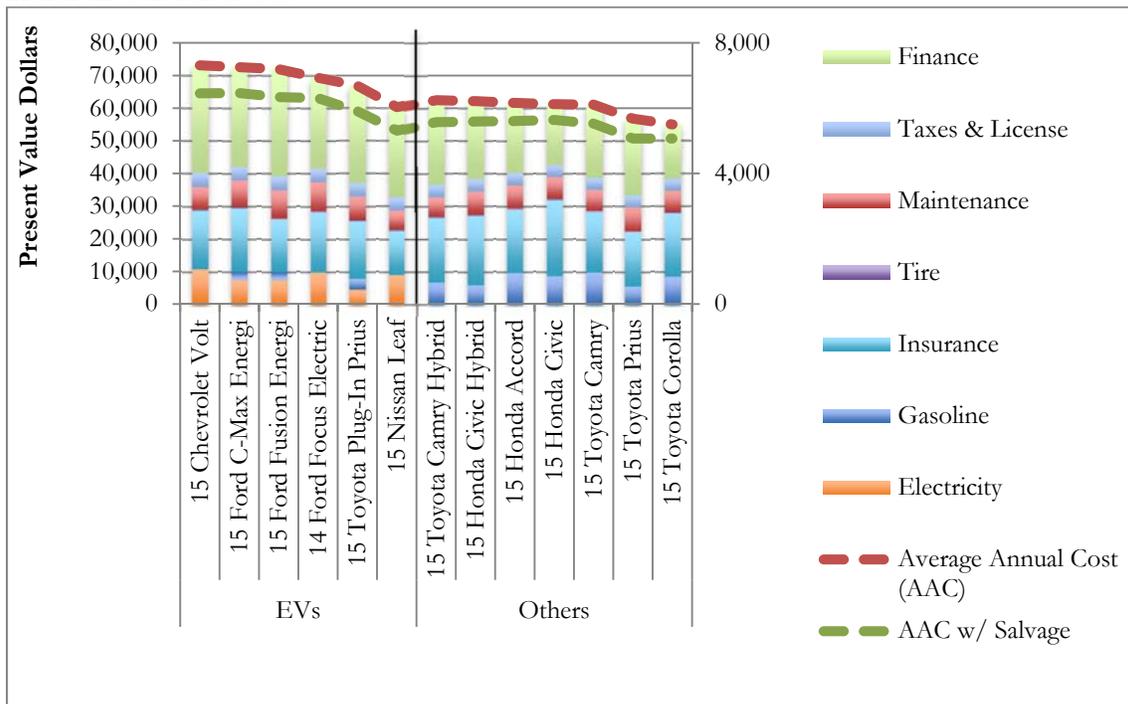
Year	Make	Model	Type	Avg Price Paid	Range (mi)	MPGe	Batt. (kWh)	Batt. Cost	Main.	City MPG	Hwy MPG	Gas	City kWh/mi	Hwy kWh/mi	Insurance	Fed. Incentive
2015	Nissan	Leaf	BEV	\$29,080	75	114	24	\$9,600	\$529	126	101		0.27	0.33	\$1,528	\$7,500
2014	Ford	Focus Electric	BEV	\$29,247	76	105	23	\$9,200	\$892	110	99		0.31	0.34	\$2,038	\$7,500
2015	Chevrolet	Volt	PHEV	\$34,650	38	98	16.5	\$6,600	\$640	35	40	Prem	0.36	0.37	\$2,043	\$7,500
2015	Toyota	Plug-In Prius	PHEV	\$31,367	11	95	4.4	\$1,760	\$693	51	49	Reg	0.35	0.35	\$1,981	\$2,500
2015	Ford	C-Max Energi	PHEV	\$32,050	19	88	7.6	\$3,040	\$822	40	36	Reg	0.37	0.37	\$2,192	\$4,007
2015	Ford	Fusion Energi	PHEV	\$34,482	19	88	7.6	\$3,040	\$848	40	36	Reg	0.37	0.37	\$1,819	\$4,007
2015	Toyota	Prius	HEV	\$24,559	595	50	1.3	\$520	\$689	51	48	Reg			\$1,888	
2015	Toyota	Camry Hybrid	HEV	\$27,034	697	41	1.3	\$520	\$561	43	39	Reg			\$2,247	
2015	Honda	Civic Hybrid	HEV	\$25,056	594	45	1.3	\$520	\$651	44	47	Reg			\$2,424	
2015	Honda	Civic	ICE	\$19,521	409	31			\$652	28	36	Reg			\$2,640	
2015	Toyota	Corolla	ICE	\$17,563	409	31			\$633	28	37	Reg			\$2,186	
2015	Honda	Accord	ICE	\$22,435	482	28			\$693	24	34	Reg			\$2,194	
2015	Toyota	Camry	ICE	\$23,406	476	28			\$626	23	35	Reg			\$2,076	

III. Key Findings

Total Lifecycle Cost and Federal Subsidy

The LCC of EVs are considerably more than their ICE and HEV counterparts – largely due to their up-front cost. Figure 5 below shows the 10-year LCC of EVs and other vehicles, broken down by the cost of the vehicle (in this case, financed), taxes & license, insurance, tires, maintenance, and gasoline or electricity (including the cost of a home charger). The total present value of vehicle ownership is shown on the bar graph relative to the left-hand axis and average annual cost (AAC) and AAC with salvage, meaning incorporating vehicle trade-in value at the end of 10 years, are provided as a line graph relative to the right-hand axis.

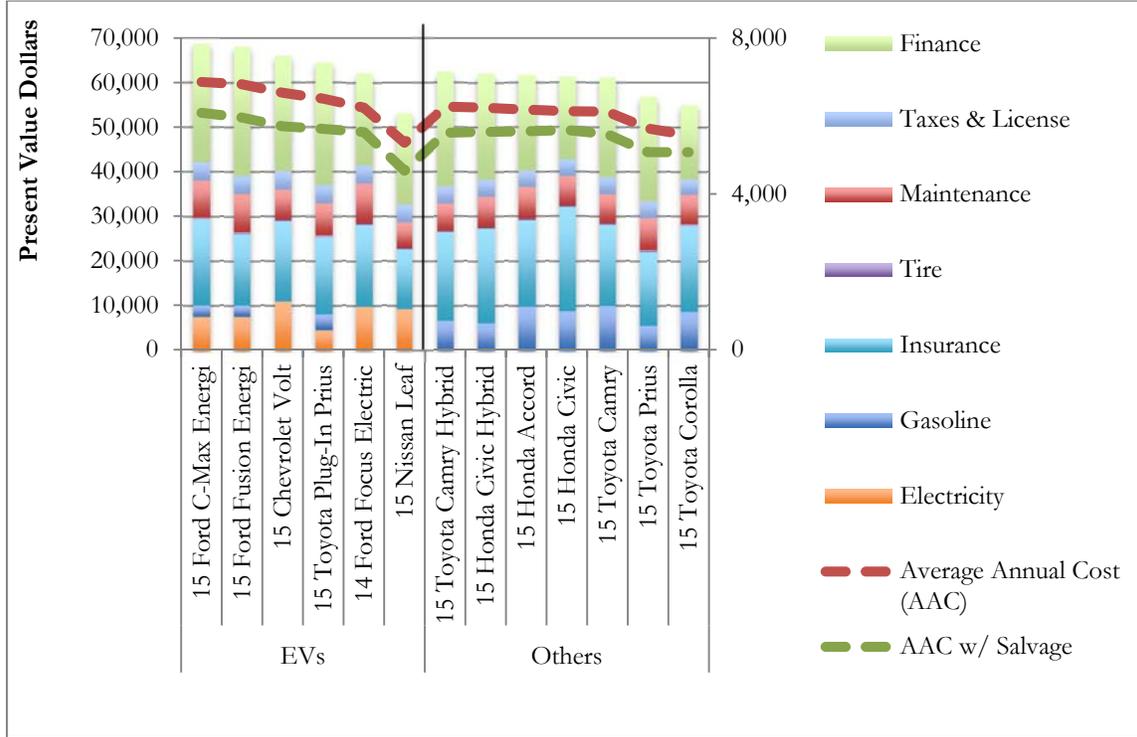
Figure 5. 10-year LCC for Financed Vehicles without the Federal Tax Credit Reference Fuel Costs



On average, the LCC of EVs considered for this study is \$69,000 in present value (2015) dollars compared to ICE/HEVs at \$60,000. The lowest cost EV is the Nissan Leaf. Its cost is nearly identical to the average ICE/HEV LCC, even without the federal tax credit.

Accounting for the federal tax credit substantially brings down the capital cost of EVs and makes the LCC of the average EV much more similar to the ICE and HEV counterparts. The 10-year LCC of EVs and other vehicles, accounting for the federal tax credit, is shown in Figure 6.

Figure 6. 10-year LCC for Financed Vehicles with the Federal Tax Credit Reference Fuel Costs

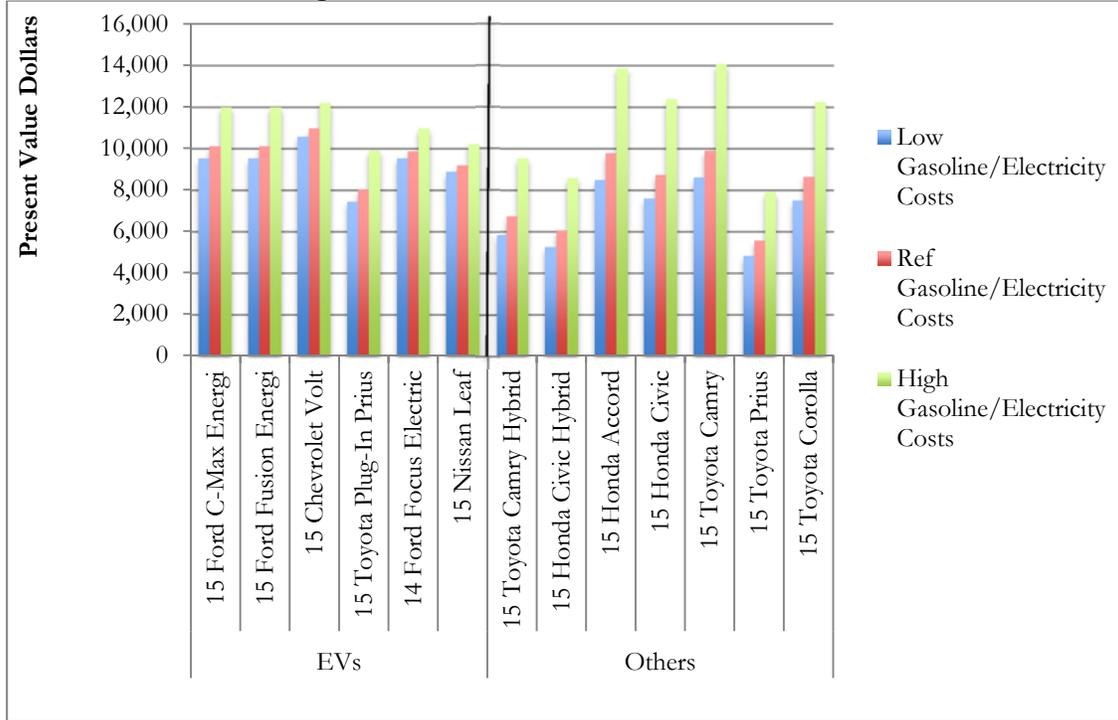


Accounting for the federal tax credit, the average EV LCC is \$63,800. This is still slightly higher than the average ICE/HEV LCC. Once accounting for the federal tax credit, the Nissan Leaf has the lowest LCC of any vehicle considered in this analysis at \$53,200.

Fuel Costs

In addition, due to Hawaii’s high electricity rates, the fuel cost component of EVs tends to be higher than ICE and HEVs. This is generally true in the *low* and *reference* fuel cost scenarios. It does not, however, hold when fuel costs are *high*. Figure 7 shows 10-year fuel costs (gasoline and electricity) for each vehicle under the *low*, *reference*, and *high* price forecasts. The cost of the home EV charger is calculated as a component of electricity fuel costs.

**Figure 7. 10-year LCC Fuel Costs
Low, Reference, and High Fuel Costs**



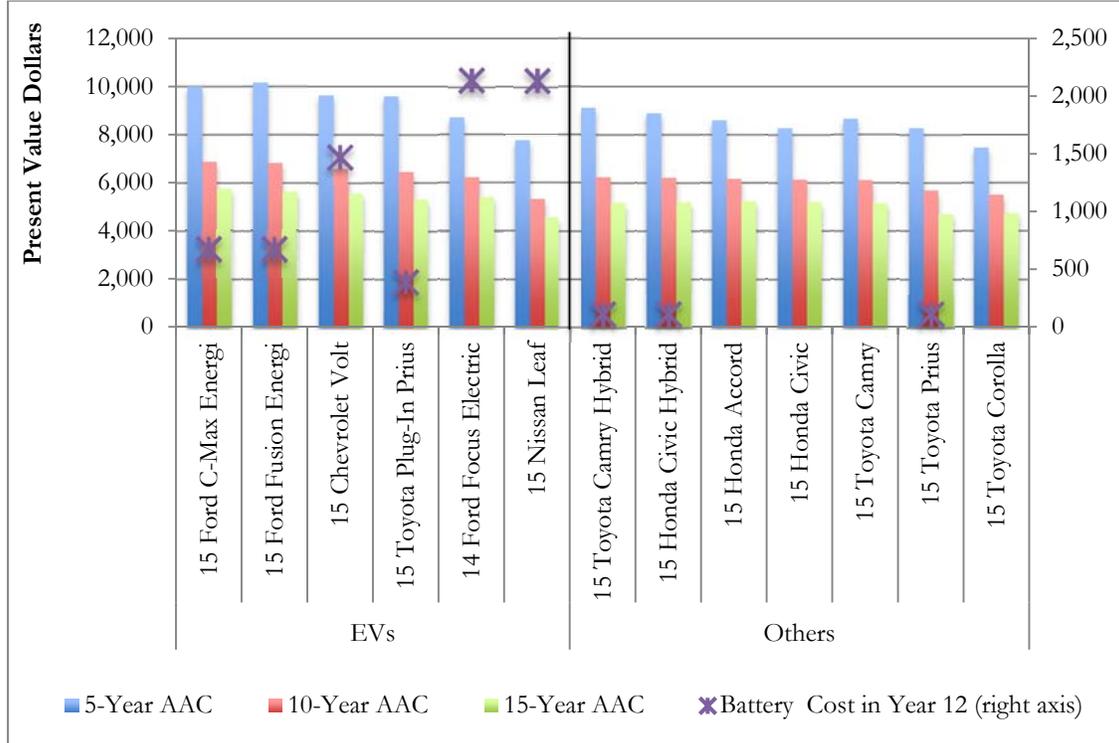
When fuel prices follow the *reference* pathway, the average 10-year LCC fuel cost for an EV is \$9,700 whereas for the ICE/HEVs it is \$7,900. Breaking this down further, the average fuel cost for ICEs is \$9,300 and for HEVs, \$6,100. The PHEV with the lowest combined fuel cost is the Toyota Plug-in Prius, at \$8,000, and the BEV with the lowest electricity cost is the Nissan Leaf, at \$9,200. The Toyota Prius is the lowest cost vehicle in terms of fuel price, at \$5,600. When fuel prices are *low*, these findings are further magnified.

When fuel prices are *high*, however, EVs on average accrue lower 10-year fuel costs than ICEs but not HEVs. The average 10-year fuel cost for EVs is \$11,200. For ICEs it is \$13,200 and for HEVs it is \$8,700. The Nissan Leaf's estimated fuel cost is \$9,100. Again the lowest cost vehicle in terms of fuel price is the Toyota Prius at \$7,900.

5,10 and 15-Year LCC

The average annual LCC of owning a vehicle declines with time, even factoring in the purchase of a new battery at the end of year 11. Figure 8 shows the 5, 10 and 15-year average annual LCC of vehicles, assuming the vehicle is financed over a 5-year period (left hand axis). It also shows the cost of battery replacement (right hand axis).

Figure 8. 5, 10, and 15-Year Financed Average Annual LCC Comparison Reference Fuel Costs with the Federal Tax Credit

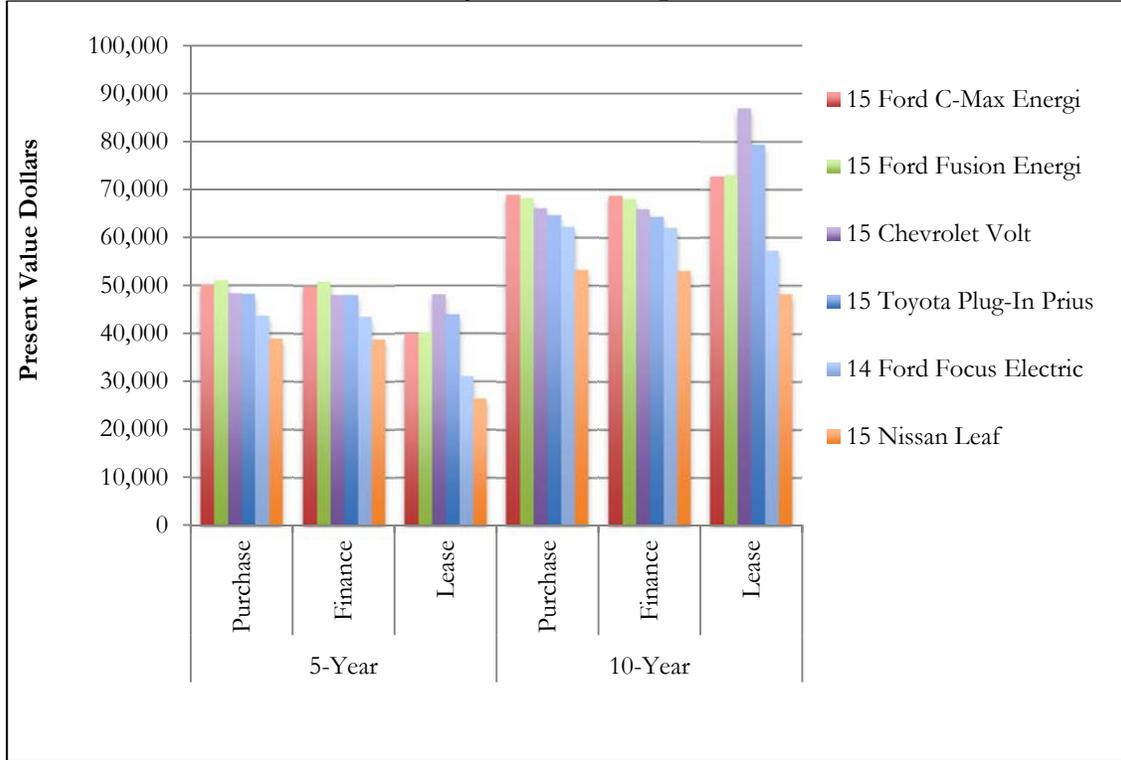


Unsurprisingly, the longer the simulation period, the lower the average cost of ownership. This is true even considering battery replacement costs at the end of year 11, though the relative difference between the 10 and 15-year simulations is much narrower than between the 5 and 10-year simulations due to the initial vehicle purchase.

Purchase, Finance or Lease

With the assumed rates of interest, finance and discount, it is economically advantageous to finance a vehicle than purchase it outright because the finance charge is lower than the discount rate. A higher finance charge in the future or a different rate of time preference could easily change this result. The lease results are mixed and are largely driven by whether the dealership passes the federal tax credit along to consumers. For vehicles in which this is the case, Nissan and Ford, the lease option is actually the most appealing but only considering the 5-year case where the lease is assumed to renew twice, both times with the federal tax credit. Once accounting for longer periods of vehicle ownership, lease terms look considerably less attractive. Figure 9 shows the LCC of the 5 and 10-year vehicle ownership simulations under purchase, finance and lease, accounting for the federal tax credit where appropriate.

Figure 9. Purchase, Finance and Lease Comparison With Federal Tax Credit, Reference Fuel Costs and 5 and 10-year Ownership

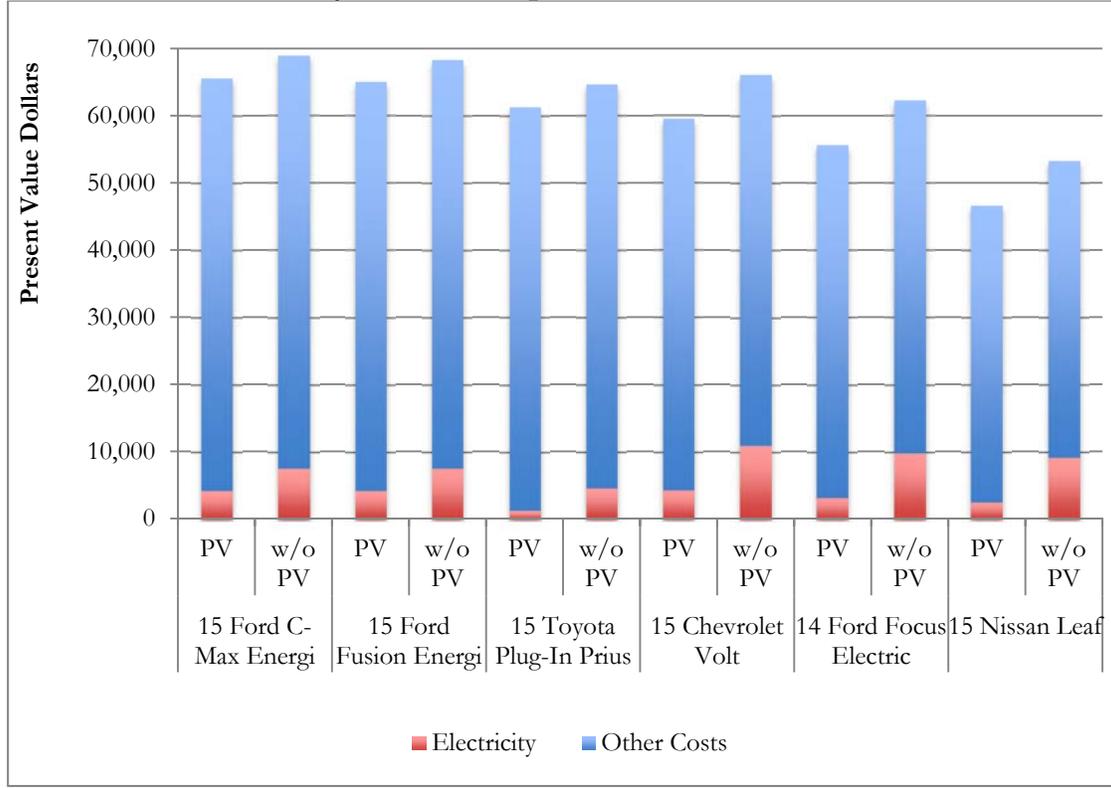


Lease terms are more attractive than financing or purchasing (which are only slightly different) assuming 5 years of vehicle ownership. Unsurprisingly, if car ownership is expected for only a short period of time, leasing can be a good option. In the 10-year consideration, however, leasing is never as advantageous as either purchasing or financing unless the federal tax credit is passed on to the consumer. Within the two makes that are currently passing the federal tax credit onto consumers in Hawaii (Nissan and Ford), leasing the Nissan Leaf and Ford Focus is relatively favorable. These two models not only have the lowest purchase price among EVs, but are also eligible for the maximum tax credit amount. Though there is assumed to be pass-through of the tax credit to consumers for the Ford C-Max Energi and Ford Fusion Energi, their higher purchase price and tax credit eligibility make the lease terms relatively less attractive. Although it is unclear whether certain dealers will continue to pass through the federal tax credit to car buyers within lease terms, leasing may be an attractive option for consumers who do not have adequate tax liability.

Adjusting for Residential PV

Having residential PV substantially brings down the LCC ownership costs of EVs, even accounting for the upfront cost of PV panels. Figure 10 shows the LCC of EVs with residential PV, assuming 10-year ownership of the vehicle.

**Figure 10. LCC EVs with Residential PV
Reference Fuel Costs, 10-year Ownership**

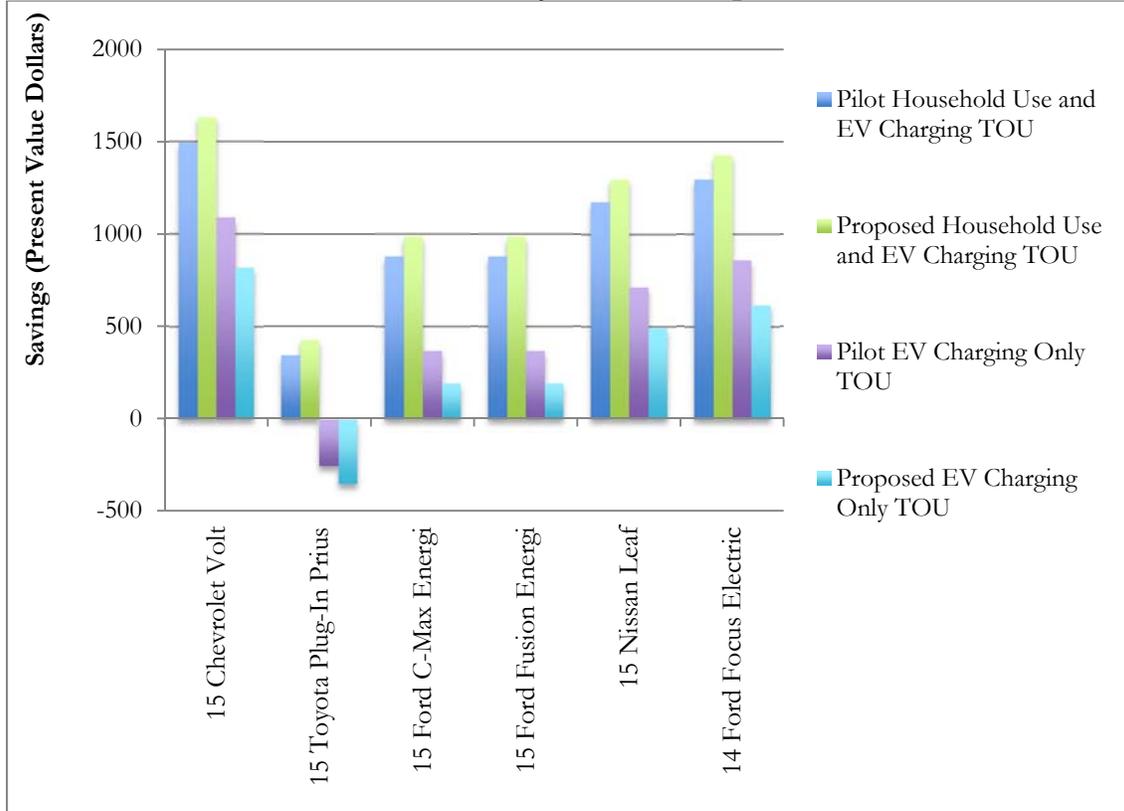


The benefit of PV varies and depends on the size of the EV battery. For vehicles with larger batteries, meriting a 2 kW PV system, the average savings is \$6,600. With smaller batteries and a 1 kW PV system, it is \$3,300. These computations account for the cost of PV systems, assumed to be \$4/watt (and discounted based on a 25-year expected lifetime of PV panels).

Assessing the Utility’s Time-of-Use Rates

Given a typical four-person household electricity demand profile (up to 18kWh/day) and assuming the best-case in EV charging such that it takes place only during optimal rates, the utility’s pilot and proposed TOU rates generally make the customer better-off. As an illustration, the LCCs of EVs are shown below in Figure 11 under different time of use contracts.

**Figure 11. LCC Impacts of Utility’s Pilot and Proposed Time of Use Rates
Reference fuel costs, Purchased and 10-year Ownership**



Relative to the standard flat rate for residential customers, the Pilot Household Use and EV Charging TOU provides customers with a present value fuel cost saving of about \$1,000 over the life of the vehicle. The Proposed Household Use and EV Charging TOU is slightly higher, at \$1,100. Both offer a fuel costs savings in the magnitude of about 10% on average (in the *reference* fuel price scenario). Although the proposed rate program offers a reduction in electricity rates for morning and daytime use (in comparison to the pilot which increased daytime rates), this is nearly offset by the much higher charge for on-peak hours. Factoring in price sensitivity and subsequent load shifting would result in higher savings (though based on shifts in household electricity demand and not EV electricity demand).

The addition of a separate meter is less beneficial to the household given the upfront cost of installation. The pilot program provides an average net benefit of \$520 and the proposed program only \$320.

EVs with larger batteries, like the Nissan Leaf and Chevrolet Volt, benefit on average more while those with smaller batteries (Toyota Plug-In Prius) benefit less. The Toyota Plug-In Prius, for example, actually accrues a net loss under the EV Charging Only programs. In general, the cost savings for vehicles with smaller batteries does not justify the expense of the installation of the second meter.

IV. Discussion Conclusions

This study extends the LCC model for 5, 10 and 15-year vehicle ownership developed by Raustad and Fairey (2014) to represent Hawaii's EVs as well as popular and comparable ICE/HEVs. It extends the model for a vehicle lease option as well as assesses EV ownership costs for households with residential PV and under the utility's pilot and proposed TOU rates.

Key findings are as follows:

- EVs on average cost more than their ICE/HEV counterparts, though this gap is substantially reduced with the federal tax credit.
- The Nissan Leaf is cost competitive without the federal tax credit and has the lowest lifecycle vehicle cost when incorporating the federal tax credit (among all vehicles considered).
- Electricity rates in Hawaii are much higher than the national average. Using the EIA's forecast for future oil prices, a set of future electricity and gasoline prices are determined. When gasoline fuel costs are *low* or *reference*, lifetime fuel costs are higher for EVs than other vehicles. When fuel costs are *high*, on the other hand, EVs offer notable cost savings while accounting for Hawaii's historic relationship between oil prices and electric rates.
- Having residential PV substantially brings down the cost of EV ownership, even considering the capital expenditure for PV panels.
- The pilot and proposed TOU rates offered by the utility reduce lifecycle EV fuel costs by about 10% on average (about \$1,000). It is most beneficial for a household with average electricity consumption (modeled as 18 kWh/day) to opt for the single-meter (for both EV charging and household electricity use) and EVs with smaller batteries benefit much less from the current TOU program.

As of December 2014, only 11% of EV owners have signed up for the pilot EV TOU rate program (Hawaiian Electric Companies, 2015b). The question of how to best structure electricity rates, for EVs as well as other uses, is important as utilities in Hawaii and around the country increase their share of renewable energy. In the case of Hawaii, where wind and solar are abundant, there may be a desire to shift EV load charging to either nighttime (to capture potentially excess wind energy) or during midday (to capture potentially excess solar energy). While the pilot TOU rates discouraged daytime charging, the newly proposed rates would rather encourage daytime charging with equal rates to post-peak nighttime charging. There is, in addition, an effort toward "critical peak pricing," where on-peak prices are raised by \$0.12/kWh. How consumers react, both in terms of willingness to sign on to what is now a voluntary program as well as whether load shifting is possible and in what magnitude, are areas in need of further research.

VI. Acknowledgements

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