BEYOND THE PARADISE TAX: ASSESSING THE POTENTIAL FOR RENTAL CAR ELECTRIFICATION IN KAUA‘I COUNTY, HAWAI‘I

By

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ABSTRACT

ASSESSING THE POTENTIAL FOR RENTAL VEHICLE ELECTRIFICATION IN KAUA‘I COUNTY, HAWAI‘I

Derek Kiyoshi Ichien

Rental car fleets have high potential to contribute to electric vehicle (EV) adoption within the Hawaiian Islands as part of the state's efforts to fully decarbonize its ground transportation by 2045. Of the four main islands, Kaua‘i County's small and simple road network, high penetration of renewable energy, and low speed limits make it an ideal candidate for a pilot EV rental program. This research seeks to accomplish three primary goals: a) quantify the relative economic and environmental benefits of rental electric vehicles over internal combustion rentals, b) identify crucial locations for additional charging infrastructure, and c) provide policy recommendations aimed at improving EV adoption both within Kaua‘i County and the State of Hawai‘i. Across all three examined categories, EVs appear to cost more than internal-combustion vehicles for rental car companies, requiring additional measures to achieve cost parity. Previous studies suggest that in tourist-heavy destinations, partnering with local businesses and attractions to offer benefits to EV rental program participants may increase the appeal of switching away from a conventional rental car. The Plug-in Electric Vehicle Infrastructure (PEVI) model highlights a near-term need for DC Fast Chargers on the north and west sides of the island, and predicts a significant need for additional chargers

in the urban core of Kapa‘a by 2025. Composing an EV rental fleet of exclusively long-range (>200 miles/full charge) electric vehicles can help eliminate the common problem of “range anxiety”, especially when coupled with a reliable, wide network of DC Fast Chargers.

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INTRODUCTION

The Hawaiian Islands have committed to fully decarbonizing their electric grids by 2045 to move toward a full divestment from imported petroleum. As a subsequent step toward energy independence, the state is beginning to examine the potential for automobile electrification. The primary intent of this thesis is to conduct a current, Kauaʻi-specific assessment of two factors commonly linked to battery-electric vehicle (BEV) adoption in scientific literature: the geographic and power suitability of existing public charging infrastructure, and environmental or economic benefits to BEVs over internal combustion vehicles. The secondary objective of this work is to develop policy recommendations to increase the attractiveness and adoption rate of BEVs, particularly examining how a BEV rental program may prove beneficial to Kauaʻi County.

Background: Energy and Transportation within Hawaiʻi

Due to its heavily isolated location in the Pacific Ocean and lack of naturally-occurring fossil energy resources, for most of its modern history, Hawaiʻi has relied on burning imported fossil fuels- primarily petroleum-based fuels- to meet its growing demand for electricity (EIA 2018). This heavy dependence means that the cost of electricity in Hawaiʻi has historically been closely tied to the cost of crude oil, and as a result, subject to stronger fluctuations than seen on the mainland, as shown in Figure 1 and Figure 2.

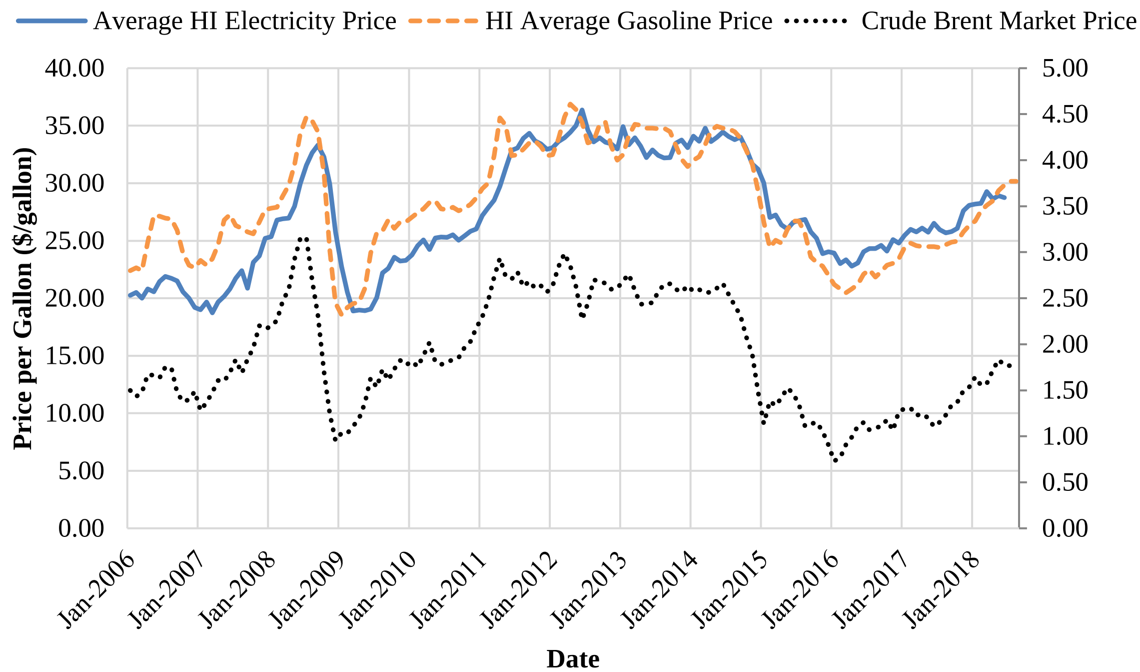

Figure 1: Average price of electricity in Hawai‘i, by month, and Brent spot market price of crude oil, by month, between January 2006 and August 2018. Hawai‘i data from Hawai‘i DBEDT Data Clearinghouse (2018), crude pricing from Energy Information Administration (2018).

The costs of physically shipping crude petroleum and natural gas to Hawai‘i for local use in transportation and electricity generation - costs not present on the mainland - are passed on to the end consumers through higher retail prices for electricity and liquid fuel. Thus, Hawai‘i consistently trends above the national average in both the per-kilowatt-hour cost (kWh) of electricity and the per-gallon cost of gasoline. The islands typically rank as the most expensive state in which to purchase either commodity, as shown in Figure 2 and Figure 3 and cited in Lincoln (2015). Between 2006 and 2018, Hawai‘i gasoline averaged $0.63 higher per gallon than the US mean; electricity averaged $0.17 higher per kilowatt-hour (kWh) than the US mean (Energy Information Administration, 2018).

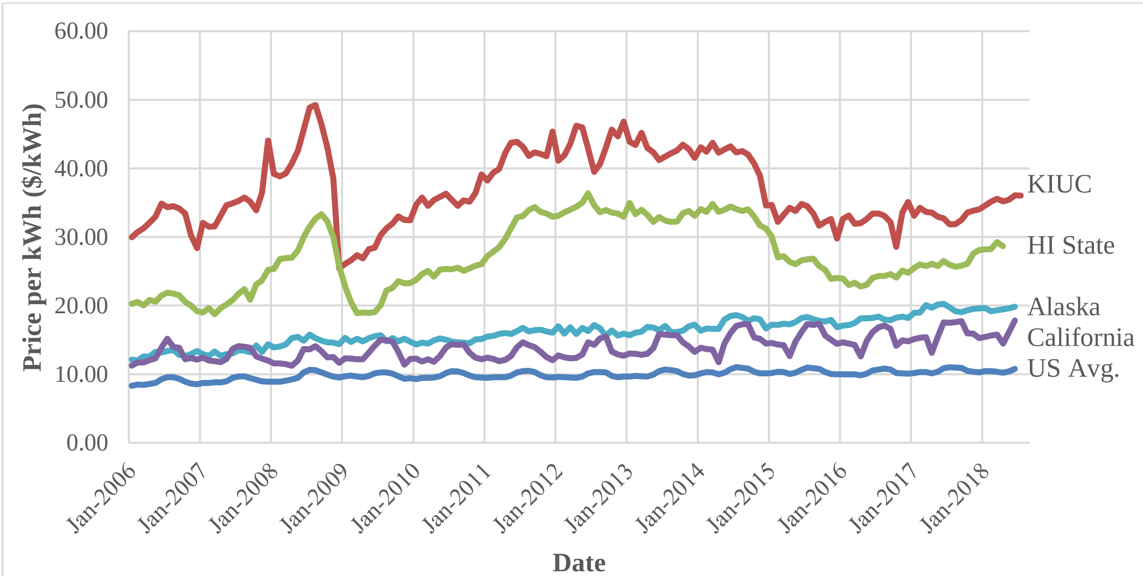

Figure 2: Monthly average all-sector electricity prices for Kaua‘i Island Utility Cooperative (KIUC), the State of Hawai‘i, Alaska, California. and the US average between January 2006 and August 2018. Hawai‘i State and KIUC data from Hawai‘i DBEDT Data Clearinghouse (2018); Alaska, California, and US average data from EIA (2018).

Figure 3: Average price of regular-grade gasoline for the state of Hawai‘i, California, and the entire U.S., plotted by month between January 2006 and July 2018. Hawai‘i data from Hawai‘i DBEDT Data Clearinghouse (2018); US and California data from EIA (2018).

Sustained high crude prices pushed the US petroleum market to its highest annual average closing price in 2012. As a result, average per-kWh price of Hawaiian residential-service electricity reached an all-time high of $0.3752 in April 2012. Gasoline prices reached an average of $4.619 the same month (EIA 2012b, Gasbuddy.com 2018). These values significantly exceeded the national averages: gasoline prices peaked at 24.8% higher than the average of $3.700 per gallon, and per-kWh residential electrical prices were a staggering 222% higher than the US average of $0.1165/kWh (EIA 2012a, EIA 2012b). In 2012 alone, $6.2 billion left the Hawai‘i state economy to purchase enough petroleum to meet both electrical generation and transportation demand (DBEDT 2017).

Perhaps galvanized by the soaring costs of fuel and electricity, a 2008 initiative committing to 70% renewable energy by 2030 was quickly supplemented by several high-profile pieces of legislation aimed at moving toward statewide energy independence. In 2015, the signing of House Bill 623 made Hawai‘i the first state in the nation to commit to generating all its electricity from renewable sources by 2045, mandating each electrical utility selling power within the state to generate from renewable energy sources:

> …thirty percent of its net electricity sales by December 31, 2020…forty percent of its net electricity sales by December 31, 2030… Seventy percent of its net electricity sales by December 31, 2040…and one hundred percent of its net electricity sales by December 31, 2045. (H.B. 623, 2015)

Since approximately 2006, both the number of kilowatt-hours generated in Hawai‘i and the percentage of total electricity generation sourced from petroleum have trended downward, as shown in Figure 4. By the end of 2017, Hawaiian Electric Industries (HEI), which governs electric service in Honolulu, Maui, and Hawai‘i Counties, had reached an overall 27% renewable portfolio standard (RPS), with Hawai‘i Island reaching a state-best 57% renewable generation (Hawaiian Electric Company, 2018). Kaua‘i Island Utility Cooperative (KIUC), which exclusively serves the County of Kaua‘i, reported a 44.36% overall renewable generation at the end of 2017, with a newly installed solar-storage project delivering up to 13 megawatts (MW) of power to the grid during evening peak demand (KIUC, 2018).

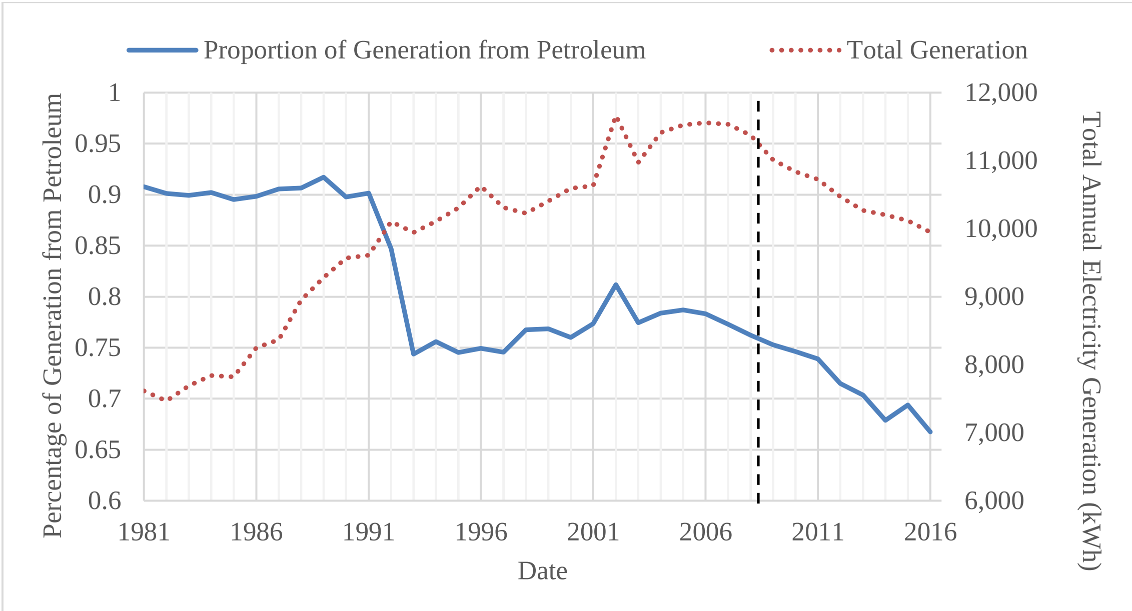

Figure 4: Percentage of Hawai‘i statewide electricity generation sourced from petroleum, and total electrical generation, between 1981 and 2016. Dashed line indicates the date of formal commitment to a 70% renewable portfolio standard by 2030. Data from DBEDT Data Clearinghouse (2018). The dip in 1990 corresponds with a coal plant coming online in Honolulu.

While impressive strides have been taken toward a fully renewable grid in Hawai‘i, electricity generation is only one part of the state’s push toward energy independence and deep decarbonization. The growing production of renewable power within each county means that electrifying ground transportation has increasing potential to keep more money in the local economy, rather than sending funds to the mainland to pay for petroleum imports. In 2016, ground transportation accounted for an estimated 28% of the total petroleum usage throughout the state- slightly higher than electric power generation’s 25% (Hawai'i State Energy Office, 2018). The increased penetration of renewable energy into the Hawaiian electricity sector positioned electricity generation as a lower consumer of petroleum than ground transportation starting in 2012, as shown in Figure 5.

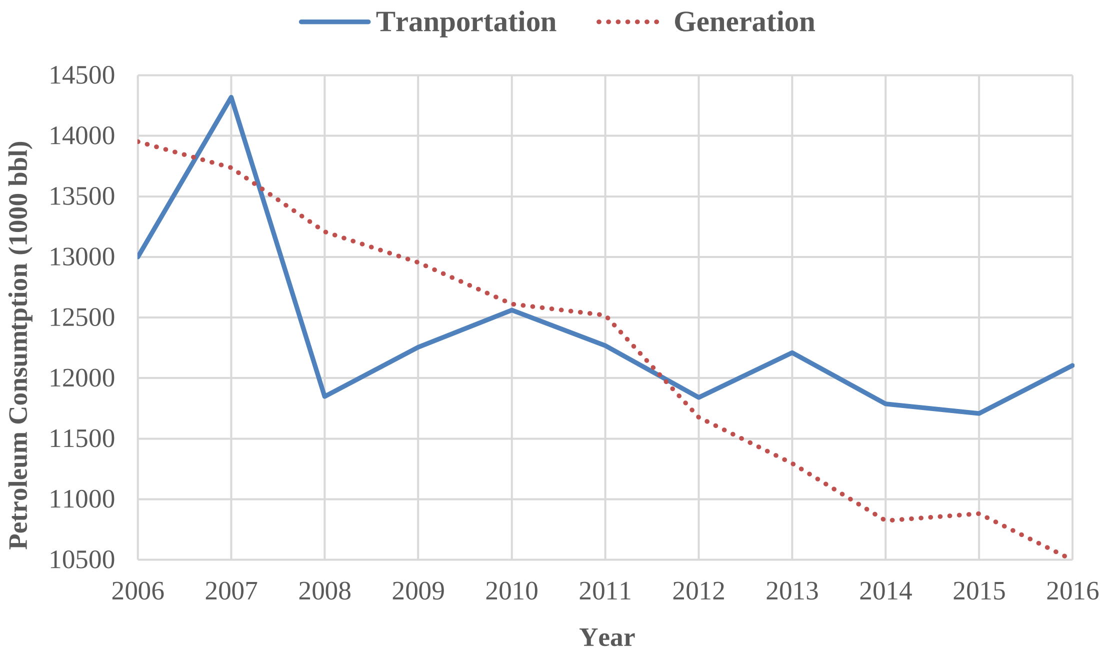

Figure 5: Total petroleum product consumption of the ground transportation sector (all transportation, excluding maritime and aviation) and the electricity generation sector, in units of 1000 bbl, between 2006 and 2016. Data from DBEDT Data Clearinghouse (2018).

As utilities continue to bring new renewable generation online to meet HB623 goals, if no action is taken to reduce ground transportation petroleum consumption, the state of Hawai'i will continue to be reliant on oil imported from the mainland, and carbon neutrality will be an impossible achievement.

Fuel-switching ground transportation to battery-electric vehicles (BEVs) is one method of reducing petroleum consumption, especially when combined with an electrical grid rapidly shifting toward renewables, as is the case in Hawai‘i. BEVs have been shown to be more energy-efficient than their internal-combustion counterparts: the U.S. Department of Energy (2018a) estimates that between 77% and 82% of the energy used to charge a BEV goes to moving the vehicle. This is a substantial gain when compared to a typical internal combustion vehicle's 12%-30% energy efficiency (U.S. Department of Energy, 2018b). EVs are able to achieve miles-per-gallon equivalent[1] (MPGe) of over 130 MPGe (U.S. Department of Energy, 2018), more than five times higher than the 2016 US average fuel efficiency of 24.7MPG (Shepardson & Carey, 2018). This efficiency is due to several factors, including the relative lack of internal friction inherent in an electric motor compared to an internal combustion engine, increased mechanical efficiency due to simplified transmission systems, and the use of regenerative braking to recharge the onboard battery by converting portions of the vehicle's kinetic energy back to electricity (U.S. Department of Energy, 2018b).

Policy Background

In late 2017, the mayors of all four Hawaiian counties met on the deck of the voyaging canoe Hōkūleʻa and signed pledges to convert all public and private ground transportation in their counties to renewable fuel by 2045. The state government had previously been active in proposing legislation to make electric vehicles (EVs) more attractive, giving EVs single-occupant access to high-occupancy vehicle (HOV) lanes and exemptions from parking meter fees in 2012, echoing similar legislation from

[1] The EPA (2019) equates 33.7 kilowatt-hours (kWh) to the energy content of one gallon of gasoline; thus, a vehicle that uses 33.7 kWh to travel one mile achieves 1 MPGe.

California and Massachusetts (Act 168, 2012). Parking lots with more than one hundred spaces were mandated to designate some spaces as EV-exclusive, and to install one EV charging station per hundred parking stalls (Act 89, 2012). However, after Act 89 was passed in 2012, statewide legislation incentivizing EVs largely stalled, and several subsequent bills aimed at increasing EV adoption at the state level failed to pass into law during the 2018 legislative session (Hawai'i State Legislature, 2018). Regardless of whether statewide legislation is passed, to ultimately achieve the goals set at the Hōkūleʻa meeting, individual plans will need to be developed to best suit the unique geography and infrastructure of each individual county. Some regions are already better-suited for vehicle electrification than others. A public-private partnership on Maui successfully saw the installation of thirteen public DC Fast Charging (DCFC) stations capable of bringing an electric vehicle from completely depleted to 80% state of charge in less than an hour (Imada, 2017). In 2017, HEI received permission from the Hawaiʻi Public Utilities Commission to continue its DC Fast Charger program on Oʻahu, Maui, and Hawaiʻi Island. This program allowed HEI to both offer EV-specific electrical rates at chargers and to financially incentivize local businesses to install public DCFC stations (Pacific Business News 2017). Despite these measures, EV adoption rates throughout the state remain on par with the rest of the nation, with approximately 0.68% of all registered vehicles classified as electric (DBEDT, 2018).

Current EV climate within Hawaiʻi

Given the state's heavy tourism industry, rental fleets represent the largest passenger-car fleets in the state, though the exact proportion is difficult to quantify due to a lack of publicly available data. More than 9 million people visited Hawai‘i in 2017 according to the Hawai‘i Tourism Authority (HTA, 2018). Assuming that the average party size is 2.2 people to align with HTA (2018) findings and that 89% of parties statewide rent a vehicle to match observations of rental rates on Kaua‘i (Steinmetz 2018, pers. comm), this means that roughly 3.6 million vehicle rentals occur each year within the archipelago. With Hawai‘i committing to a full decarbonization of ground transportation by 2045, these fleets will eventually need to be electrified. A pilot EV rental program undertaken by Enterprise on Maui and O‘ahu in 2011 was ultimately unsuccessful and was quietly phased out sometime after 2013. In 2018, a law firm representing Enterprise submitted testimony against a proposed bill that would require rental fleets to make EVs available for public rental, stating that

> Enterprise tried to encourage its customers to rent electric vehicles, but was unsuccessful. As a practical matter, the rental car industry is driven by market demand. When Enterprise incorporated several electric vehicles into their fleet, the vehicles were ultimately not selected by consumers to rent. (SanHi Government Strategies, 2018)

However, both EVs and the infrastructure they rely upon have experienced significant technological progress since the pilot rental program’s inception in 2011. Current EV models have longer ranges and a wider range of bodystyles than their counterparts from early in the decade (Department of Energy, 2019); lithium-ion battery prices have decreased precipitously (Bloomberg New Energy Finance, 2019); and the availability and geographic density of public electric vehicle charging stations has surged (Electric Vehicle Charging Association, 2017).

With BEVs models proliferating across the industry in order to appeal to a wider variety of consumers, a robust network of 240V/Level 2 and 480V/DCFC chargers is critical in allaying the growing demand for quick, efficient charging. As of December 2016, Hawai‘i had 277 public Level 2 and DCFC charging locations, allocated between counties as shown below in Table 1. The table also shows the number of registered EVs present in each county.

Table 1: Public charging stations, registered vehicles, and site-to-vehicle ratios by county. Charging station data from AFDC (2018); registered EV data from DBEDT (2018). All data is specific to early 2017.

County	Public Level 2 Charging Sites	Public DCFC Sites	Registered EVs	Vehicles per Charging Site
Honolulu	166	10	5717	32.5
Maui	45	13	990	17.1
Hawai‘i	30	5	386	11.0
Kaua‘i	20	1	256	12.2

Each of the four Hawaiian counties (Honolulu, Maui, Hawai‘i, and Kaua‘i) represents a uniquely challenging environment for electrified rental vehicles. Privately owned EVs are most prevalent on O‘ahu (Honolulu County) and within Maui County, but a relative shortage of chargers means that renters would be fighting with local drivers for charger spots, decreasing the functional availability of the charging network. The Big Island, or Hawai‘i Island (Hawai‘i County) has the highest ratio of vehicles per charging site. However, its sheer size and low overall geographic coverage of charging stations (most chargers are located within urban clusters) may pose problems for relatively inexpensive, shorter-range BEVs.

Rugged and lacking the heavy urban development present on Oʻahu and Maui, Kauaʻi County is defined by unique environmental circumstances that make the island a strong candidate for electric vehicle penetration. With the second-highest proportion of renewable energy generation in the state, KIUC is aggressively pursuing renewable technologies to meet the statewide goal of 100% renewable energy by 2045 (KIUC, 2018). Higher penetrations of renewable energy translate directly into a decreased reliance on petroleum for EV mobility, partially alleviating the common concern that EVs simply shift fossil fuel consumption to a different point in the mobility process rather than abating it. Additionally, the county's mountainous terrain naturally limits the sprawl of the road network. Rather than the typical grid pattern seen in major metropolises, Kauaʻi has a relatively simple road network defined by a single "backbone" arterial highway connecting major towns, without connectivity around the whole island, leaving two "ends" separated by a 17-mile stretch of rugged terrain on the Nā Pali Coast, as illustrated in Figure 6.

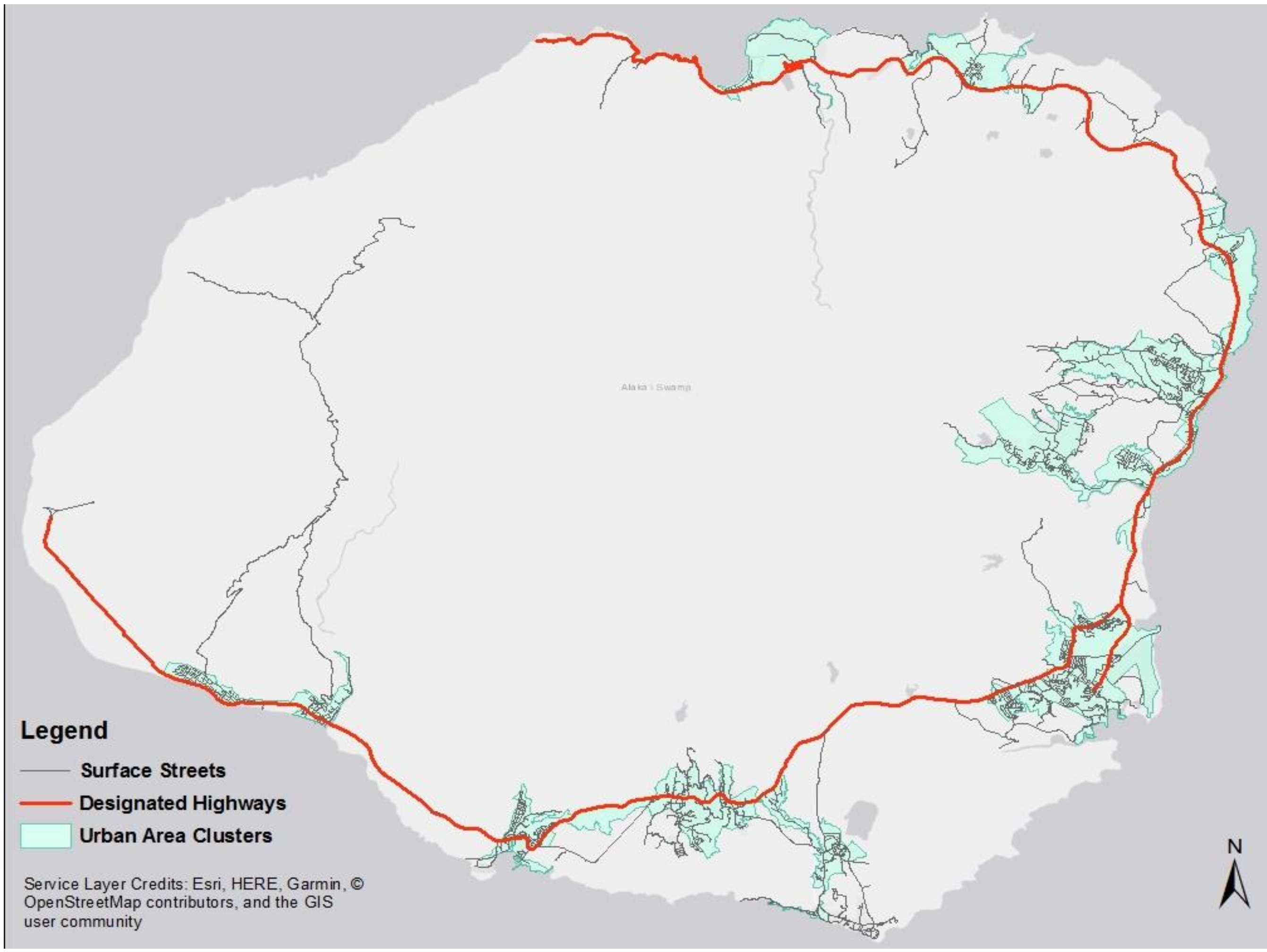

Figure 6: Kaua'i County urban zones (green) overlaid by its road network, with the arterial highway symbolized in red and surface streets in gray. Map image by author; road network and urban zones from State of Hawai'i (State of Hawai'i Office of Planning, 2017).

The limited number of routes associated with this simple road network makes siting charging stations along heavily trafficked road corridors relatively easy. The compact road network also means that a relatively low number of charging stations will be needed to achieve an acceptable geographic coverage; a key component of alleviating range anxiety (National Renewable Energy Laboratory, 2017). Road speeds are also limited; the maximum speed on the arterial highway is 50 miles per hour, which reduces aerodynamic drag and in turn increases EV range relative to the higher speed limits common on the mainland. A 2012 internal study from Tesla shows range curves for their Model S sedan and first-generation Roadster sports car at constant speeds: both exhibit an approximately 24% reduction in expected mileage when speed increases to 65 miles per hour (mph) from 50mph (Musk & Straubel, 2012).

However, as with the other islands, Kaua‘i County faces some additional challenges that may hinder rental EVs. These challenges can be categorized into three primary areas: infrastructure, utility, and tourism.

<u>Infrastructure Challenges.</u>

In 2012, Hawai‘i Act 089 mandated that all parking lots with 100 or more public parking spaces were required to have at least one parking space reserved for EVs and equipped with a charging station (Abercrombie, 2012). Due to a lack of penalties for noncompliance and high upfront costs for station installation, many owners of large parking lots simply ignored the law (Mykleseth, 2017). The relatively low occurrence of large parking lots on Kaua‘i resulted in the few installations that occurred primarily being concentrated in the developed commercial core of Līhu‘e.

Even in cases where lot owners complied with the law, the legislation has no requirement that the stations be functional. As such, station outages are common, with some locations non-functional for months (Rad, pers. comm, 2017). As of November 2018, 27 of the island's 43 installed charging outlets (63%) had either been recently noted as non-functional, could not be confirmed as functional, or had been noted as having limited access (Plugshare 2018). The lack of maintenance on many of the stations and property owner reluctance to invest in updated infrastructure were frequently cited as major hindrances in providing convenient access to vehicle charging (Kass, pers. comm, 2017). A 2013 assessment of the state of EV adoption on Kaua'i specifically mentioned the narrow geographic spread of the existing charging infrastructure, noting that "the island lacks charging stations in key locations", making it inconvenient for EV drivers to access popular destinations (Elkind & Ku, 2013). This is a particular problem for rental EVs. As a result of the relatively high upfront cost of installing charging infrastructure and the limited existing infrastructure, the majority of drivers are currently unlikely to have access to charging at their lodging. Though vehicles commonly come with an included Level 1 charging adapter (household outlet/120V), this can be prohibitively slow, replenishing roughly 1.6kW each hour, or around 6 miles of range, and should be relied upon only as an emergency power source or if the vehicle will have extremely long dwell times (>10 hours).

Of the estimated 47 resorts on the island, only five have any accessible charging infrastructure. In the absence of EVSE availability data for private vacation rentals such as AirBnB or VRBO, both the technical model and market analysis included in this report assume that most visitors renting EVs will need to rely nearly exclusively on public charging.

Extending the range of BEVs is typically accomplished by using larger batteries, which in turn require longer charging times. The currently installed Level 2 chargers, though adequate for meeting demand from shorter-range BEVs with smaller batteries, may prove inconvenient for longer-range EVs that require significantly more energy to reach the same percentage of full charge. Rental customers' likely reliance on public charging, at least for the short-term, may additionally exacerbate the inconvenience of Level 2 charging as the slower charging speed is more likely to delay travel itineraries.

Utility Challenges.

Specific to Kaua'i County and the Kaua'i Island Utility Cooperative (KIUC) are some primary challenges facing widespread EV adoption. These include the small budget and co-op structure of the local utility, a lack of attractive EV-specific electricity rate plans, and high demand charges on DC Fast charging (KIUC, 2018). Based on the analysis within this document, to effectively build out the island's charging infrastructure to support the county pledge of 100% renewable ground transportation by 2045, it is extremely likely that these barriers will need to be circumvented or removed.

KIUC, as an independent electric utility cooperative servicing only one island, operates with a smaller overall budget than Hawai'i Electric Industries (HEI), which serves all of the other islands. For the financial year ending in 2017, HEI's net revenue reached $165.3 million versus KIUC's $7.6 million (Hawaiian Electric Industries, 2018; KIUC, 2018). A smaller budget increases the difficulty of funding capital-intensive projects, particularly those that may only benefit a small number of ratepayers. Additionally, the co-op model may disincentivize spending seen as non-crucial to basic electrical generation and distribution, as this may be perceived as only benefiting a small portion of the ratepayer base and reducing the organization's overall annual profits, which are returned to co-op members annually as patronage capital (Tokioka, pers. comm).

After completing a pilot program examining a potential time-of-use (TOU) rate, KIUC was unable to conclude that publicly offering such a rate would incentivize load shifting in a meaningful way (Tokioka 2018, pers. comm). The current lack of a dedicated EV rate may decrease the attractiveness of operating an EV relative to HEI-governed neighbor islands, which offer both time-of-use off-peak kWh pricing and less expensive EV rates. Additionally, KIUC levies per-kW demand charges against all accounts that exceed 30kW demand or 100,000 kWh of electricity consumption in a month (KIUC, 2018). Most DC Fast Chargers operate at 50kW or higher, which would automatically incur hefty fees upon the initiation of the first charging session of the month. These demand charges, if passed on to the consumer, translate to an extremely high per-kWh cost, especially when a low amount of electricity is being dispensed from an account. This advantage is a major benefit for the development of DC Fast Charging infrastructure on the other Hawaiian islands, where HEI's companies offer rates for electric vehicle chargers that feature no demand charges, an important step in a successful initial rollout of DCFC stations wired directly to the grid. Figure 7 illustrates the results of this demand charge: for a single charger dispensing at 50kW on Kaua'i, approximate per-kWh cost parity with the other islands' time-of-use rates is reached at around 5000kWh of electricity sold – roughly equivalent to 80 full Chevrolet Bolt charges.

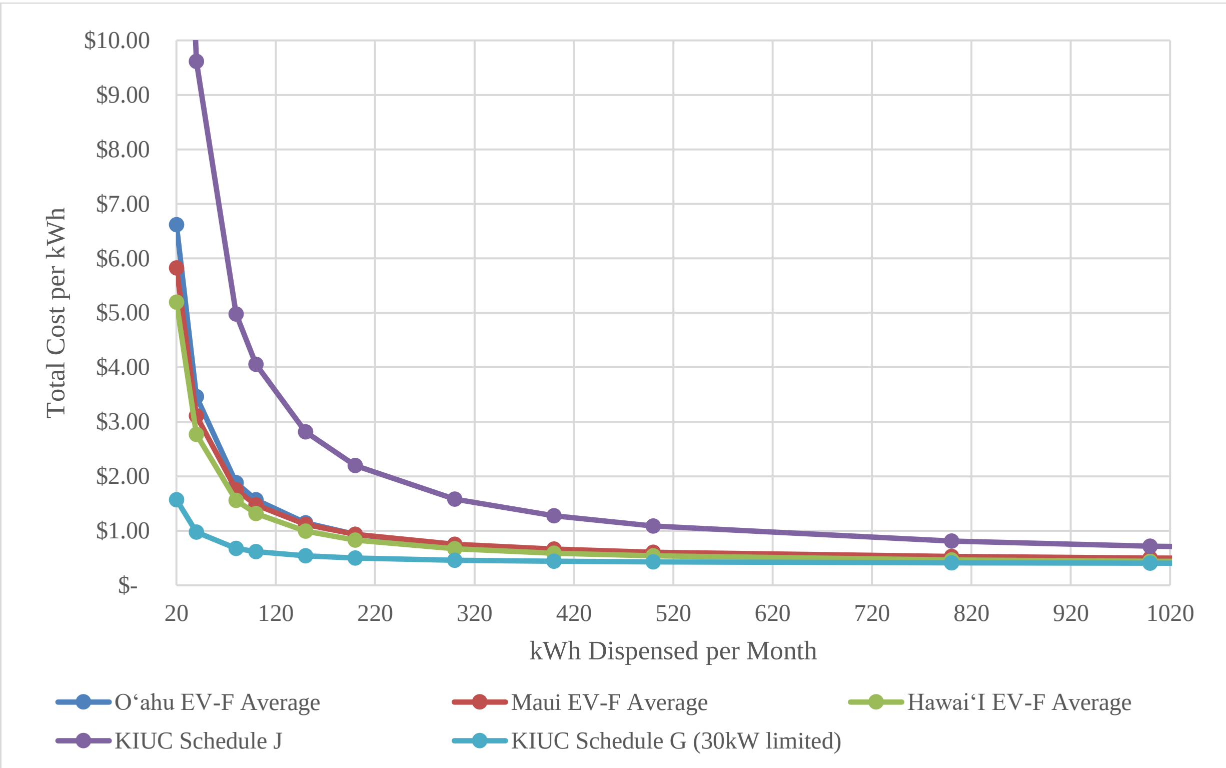

Figure 7: Effective total per-kWh monthly cost of electricity dispensed from a single 50kW DC Fast Charger across Hawaiian utilities, calculated by summing all fees and dividing by the total number of kWh dispensed. O'ahu, Maui, and Hawai'i island time-of-use EVSE rates are designated by the "EV-F" rate code, KIUC small commercial (<30kW demand and <100,000kWh) rates by "Schedule G", and KIUC Large Commercial (30kW < 100kW demand and <100,000kWh) rates by "Schedule J". Data from KIUC and Hawaiian Electric Industries.

There is a secondary option for DCFC that avoids the aforementioned demand charge on Kaua'i. This is KIUC's Rate Schedule G, which limits maximum demand to 30kW, carries a lower base charge, and does not have a demand charge associated with the rate. Throttling a DC Fast Charger's power delivery to 30kW would provide a significantly cheaper service at the expense of a longer charging time- roughly 50 additional seconds per kWh dispensed. Throttling DCFC stations to comply with Schedule G may be a suitable avenue for the short term. However, as EV batteries get larger and long-range EV penetration into the vehicle market increases, 50kW and faster DC Fast Chargers will face an increasing need to be a reliable option for consumers looking to extend their vehicle's range without significant downtime.

Tourism Challenges.

The key challenge to overcome is making BEVs attractive to customers who would otherwise be inclined to rent a conventional vehicle. A major consideration of many travelers is value-for-money: as a 2016 study examining EV rentals in Canada found, "…[the] coefficient of rental cost was found to have negative significant impact on rental decision, implying that all things being equal, respondents are rational decision makers and would [choose] low-cost vehicles" (Dimatulac & Maoh, 2016). In the case of renting a vehicle, if an internal-combustion car can be procured less expensively than a comparable EV and is additionally perceived to be more convenient and/or attractive, renters may not see an incentive in foregoing what they already know and are familiar with. Many of the island's main attractions are based around outdoor recreation, with certain destinations that can only be reached with a high-clearance, four-wheel-drive vehicle. At this point in time, no rugged or four-wheel-drive BEVs exist, though all-wheel-drive can be found at higher price points. Visitors who put a premium on those attributes, or who want to access those destinations, must use an internal combustion vehicle. A final consideration is the necessary step of helping potential drivers understand the unique experience of driving an electric vehicle, particularly the process of finding compatible chargers and understanding charging etiquette. Drivers who view charging as an inconvenience or too difficult will be less inclined to rent an EV over a comparable ICE vehicle. However, Dimatulac and Maoh (2016) note that drivers interested in the experience of driving an EV are typically willing to overlook many of these characteristics, as additionally suggested in Prochazka (2015).

General climate

Overall, there is a general interest in both electric vehicles and fuel-switching within Kaua‘i County. The county government has committed to converting its transportation fleet to run entirely on alternative fuels by 2035 (Else, 2017). A local electric vehicle owner’s association has been instrumental in lobbying for EV policy and budget consideration, actively maintaining existing infrastructure, and partnering with external agencies to offer EV ride-and-drive events. On Kaua‘i, there is a nascent, privately-held fleet of EVs available through the Turo peer-to-peer car-sharing service that is popular despite only six shorter-range vehicles being available (Turo, 2018). Combined with a robust tourism industry and the statewide commitment to 100% renewable ground transportation, these factors open the door for an examination of how the rental industry may be able to further catalyze EV adoption on the island, expand the existing infrastructure, and serve as a demonstration of the potential for widespread vehicle electrification throughout the state.

Developing Markets: Electric Vehicles and Infrastructure

Electric vehicles offer several primary advantages over internal-combustion vehicles. With far fewer moving parts in their motors, they require significantly less periodic maintenance: EVs require no oil changes, air filters, or spark plugs. In the absence of petroleum combustion, EVs have no tailpipe emission during their normal operation, though there are “upstream” emissions associated with the generation profile of the electricity used to fuel the vehicle. Electric vehicles additionally offer some performance benefits. Because electric motors can offer full torque from 0 RPM, EVs are typically able to accelerate more rapidly from a standstill than similar internal combustion models, even in moderately powered applications (Beganovic & Dacic, 2012).

Most major automobile manufacturers offer at least one model with an electrified powertrain. Several factors have combined to create a favorable environment for innovation, diversity, and competition within the EV sector. Most prominent is the precipitous decline in the cost of lithium-ion (Li-Ion) batteries: between 2010 and 2016, the per-kWh price of Li-Ion batteries fell by 73%, from approximately $1,000 USD per kilowatt-hour (kWh) to $269 per kWh (Curry 2017, McKinsey and Company 2017). Declining battery costs have allowed manufacturers to add more range while keeping consumer costs stable. Less expensive batteries also decrease the maintenance cost of replacing the battery when it reaches the end of its useable life.

Growing demand for electric vehicles has persuaded major manufacturers to produce no fewer than 20 different models of battery-electric vehicles (BEVs), representing a wide diversity of body styles and performance metrics (DOE Fuel Economy, 2017). While most of the BEVs produced before 2013 conform to the versatile five-door hatchback body style, manufacturers have recently begun to broaden the selection of vehicle body types. Hyundai’s announcement of its small crossover Kona EV for the 2019 model year positions it as the first EV of its body style available in the U.S., with sister company Kia promising an EV version of its larger Niro crossover by late 2018 (Hyundai Motors, 2018). Jaguar’s iPACE SUV and Tesla’s Model X offer fully electric options in the luxury SUV field, with Volvo set to market its slightly smaller XC40 EV starting in 2019 (Kane, 2018). The Karma Revero and Tesla Roadster both position themselves as electric sports cars. As of writing in late-2018, the only major body styles not currently represented by production light-duty BEVs are pickup trucks, minivans, and truck-based sport utility vehicles, though companies such as Tesla, Rivian, and Ford promise fully electrified models within the next 5 years. Figure 8 shows both the increasing number of battery-electric vehicle models and increase in full-charge range over time.

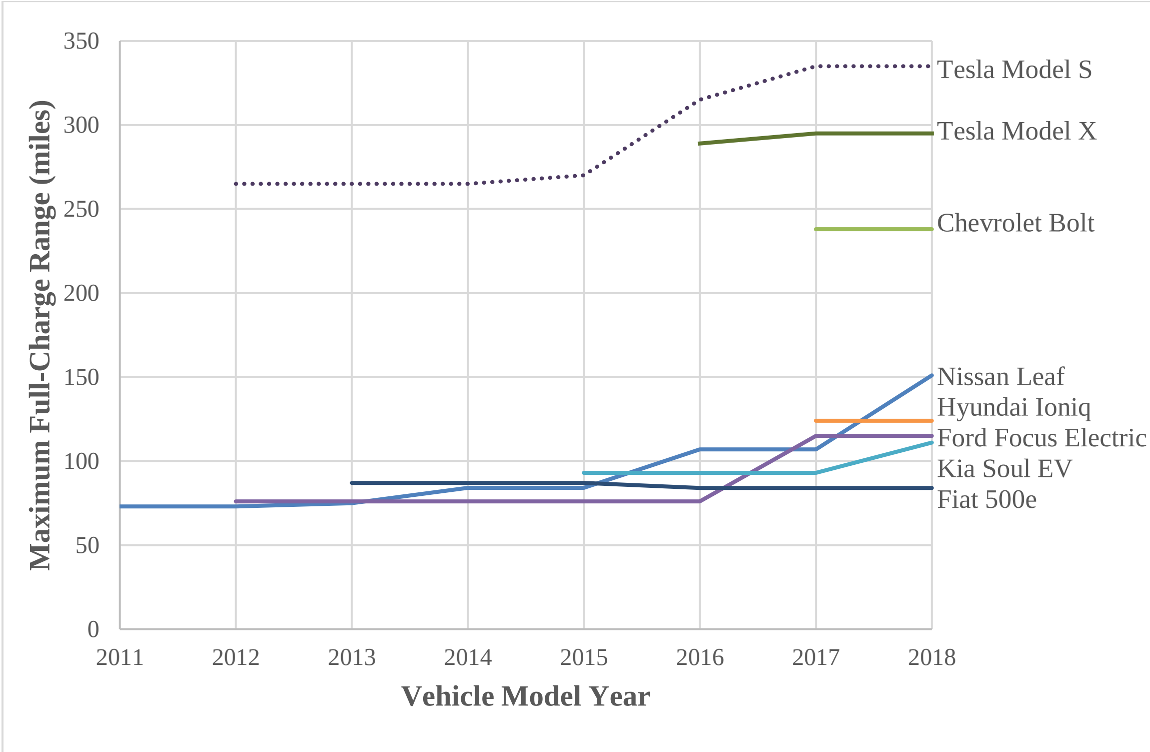

Figure 8: Comparison of nine popular BEV model ranges and EPA average EV range across the 2011-2018 model year range. Data from DoE Fuel Economy website (fueleconomy.gov, 2018).

As the EV market in the United States has grown and diversified, the number of charging station installations has dramatically increased over the past decade, as illustrated in Figure 9. In March 2018, just over 80,000 individual charging ports at 17,600 public charging stations had been installed in the United States (AFDC, 2018).

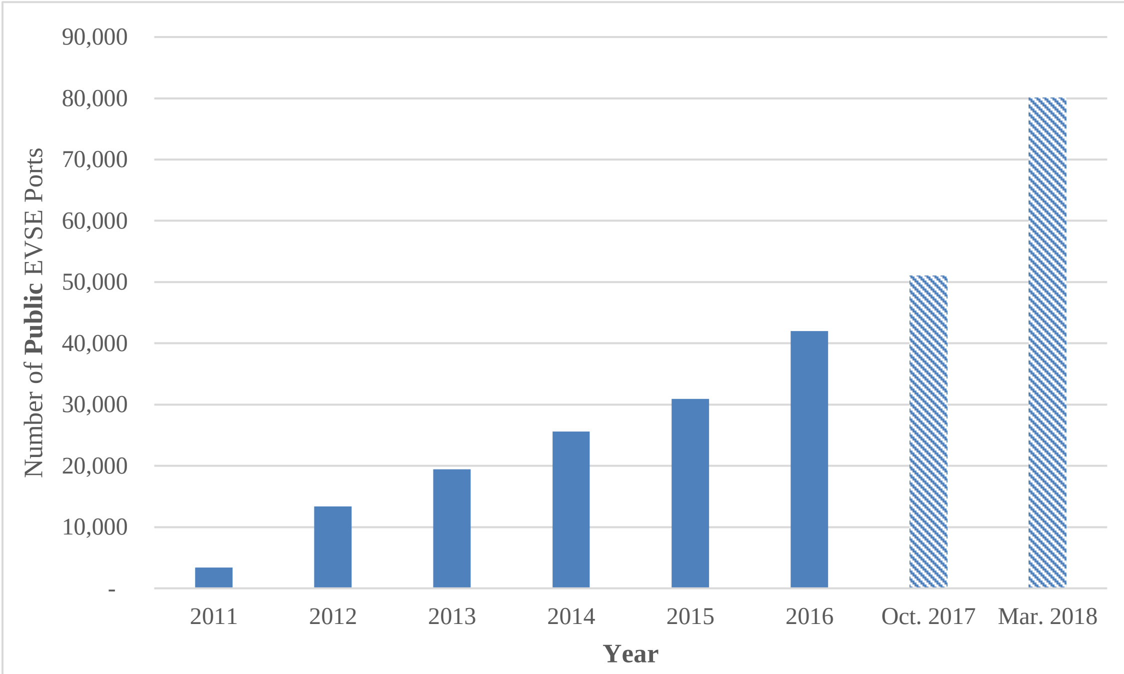

Figure 9. Numbered count of individual charging ports installed in the United States. Counts include public 120V (Legacy/Level 1), 240V (Level 2), and 480V (DC Fast Charge) stations. 2011-2016 data (AFDC, 2016), October 2017 data from AFDC as cited in (EVCA, 2017), March 2018 data (AFDC, 2018).

A recent trend in installations of 480V DC Fast Chargers has made it possible to charge compatible electric vehicles from fully depleted to 80% state-of-charge extremely quickly- in as little as 30 minutes (McDonald, 2016). These DCFC stations typically deliver power rates from 30kW to 150kW, and are well suited to locations along major transportation corridors, enabling long-distance travel due to their power and speed. This is especially important as increasing BEV range may increase demand for fast charging near major transportation corridors, such as freeways or expressways. Meanwhile, the common, lower-power (3.3kW – 6.6kW) Level 2 chargers are less expensive to install but require a longer charge wait time, better suiting them for locations with longer residency times, such as shopping malls or workplaces. When taken in conjunction with increasing average BEV ranges, this improving station geographic coverage has helped to reduce the common issue of "range anxiety": the fear of accidental stranding due to a depleted battery. A survey conducted by the American Automobile Association (2018) notes that the number of respondents concerned about a possible range-related stranding fell from 72% to 58% between 2017 and 2018, a 14% reduction.

In many areas around the United States, stakeholders including city governments, utilities, and vehicle manufacturers are beginning to respond to the increasing popularity of electric vehicles by actively engaging the EV community through ride-and-drive events, offering financial incentives for EV ownership and use, and investing in EVSE infrastructure. Several electrical utilities, including California's Pacific Gas and Electric (PG&E), San Diego Gas and Electric, and Southern California Edison; Hawaiian Electric Industries; and the Rocky Mountains' Xcel Energy, offer specialized EV rates, which are typically less expensive than general rates during off-peak hours. These rates further reduce the effective cost of fueling an electric vehicle, provided the vehicle is charged on a schedule that takes advantage of the lower time-of-use (TOU) rate. Commercial property managers are leveraging the "residence time" inherent to recharging an electric vehicle by installing Level 2 chargers in their parking lots. A study commissioned by a charger manufacturer found that installing Level 2 chargers at one location of a major department store increased average EV driver residence time by 50 minutes (from 20 minutes to 70 minutes), generating approximately $56,000 in additional sales (Chargepoint, 2015). State and local governments around the country offer their own incentives for switching to EVs. As of 2018, the United States federal government offers a tax credit of up to $7,500 with the purchase of qualifying electric vehicles, and several states and utilities offer their own rebates and incentives to add on top of the federal credit (Department of Energy 2017). This credit is typically mathematically determined based on the EV's battery capacity: for each kilowatt-hour (kWh) of battery storage over 5kWh, the credit increases by $417 (IRS, 2017). As of writing, every current model-year BEV is eligible for the full $7,500 tax credit (IRS, 2017). Several state governments, including California, Colorado, and all New England states except Maine offer purchase incentives for the purchase or lease of a BEV (Plug In America, 2018). Hawai‘i, despite its high per-capita uptake of EVs, does not currently offer a state-level incentive for EV purchases.

Electric Vehicles in Tourism

A review of literature examining three EV tourism programs (two existing in Florida and Japan, and one proposed in upstate New York) highlights several important components of a successful EV rental programs. Key among these are: creating incentives for EV rentals, ensuring the program is highly visible and attractive to consumers, providing adequate charging infrastructure, alleviating range anxiety, and the necessity of providing upfront education and driver support, either from the rental car company or a third party.

Charging Infrastructure and Range Anxiety

Given the common concern of finding convenient charging even among seasoned EV drivers, minimizing the hassle of locating and using charging stations may be the single most important element of an EV rental encouragement program. A driver's charging-station experiences play a large role in dictating the overall rental experience.

A Tokyo Electric Power Company (TEPCO) study, as well as a pilot electric-rental program in Okinawa, Japan, illustrate that having too few easily accessible or reliable chargers in an area to provide a sense of geographic coverage can induce range anxiety, which then has a debilitating effect on driving characteristics and driver satisfaction. Providing coverage of a geographic area using DC Fast charging appears to be a keystone component of overcoming range anxiety. The TEPCO study sought to increase the utilization of their in-house EV fleet, which was composed of EVs capable of an 80 kilometer (50 mile) range well above what employees would need to conduct their duties (Anegawa, 2010). They noted that employees who used the EVs for their job-related duties would frequently return with over 50% of the battery power remaining, proceeding to either charge the car at the fleet depot or switching to an internal-combustion vehicle. Employees cited the location of the single available DCFC station at the fleet depot as a major influence on their driving habits. When TEPCO installed a single additional DCFC station at a central location in the area served by the fleet, the average monthly driving distance increased more than sixfold, from 203 kilometers to 1,472 kilometers. However, energy dispensed by the new charger was minimal, even as the average monthly distance significantly increased (Anegawa, 2010). This suggests that the psychological effect of range anxiety on EV drivers was extremely strong, and the “safety net” offered by an easily accessible, rapid-charging station served to dramatically reduce the impacts of range anxiety.

Challenges in the Okinawa EV Rental Service also centered around range anxiety. Okinawa, like the Hawaiian archipelago, is a popular island tourist destination, with an annual average of 5.5 million tourists visiting, and has a similar geographic extent. Three rental car companies on the island provided a total of 200 Nissan Leafs; vehicles with an approximately 100-mile range. The program charged a service fee upfront for unlimited fast charging during the first week of the rental, after which renters were billed a flat fee per station used. The program fell short of expectations, as car utilization failed to reach target levels, the vehicles were unable to be sold at the expected price, and visitors expressed dissatisfaction with vehicle range and fuelling infrastructre. The report specifically cited travel agents’ reluctance to promote the EVs due to their short range and customer concerns about low range and insufficient charging infrastructure, which led them to charge their vehicles more frequently than necessary to alleviate the fear of stranding (Willer & Neely, 2013).

Additional Value and Recouping Upfront Costs

EVs typically require a larger upfront investment over their similarly-sized internal-combustion counterparts. Thus, it is important to determine how best to recoup the incremental cost of procuring electric vehicles; particularly as Lubinsky and Salama (2015) note that manufacturers may be unwilling to offer factory fleet pricing on electric vehicles. There are several methods of covering the increased upfront cost, but two primary methods are mentioned in the literature: simply pass the cost on to consumers, optionally providing "baked-in" auxiliary benefits with the rental of an EV; or attempt to recoup costs through charging infrastructure revenue. The Drive Electric Orlando program offers a combination of these methods. The program has successfully partnered with 28 area hotels and several major attractions to offer premier parking, free charging, expedited airport security, and other benefits to provide added value to the EV rental experience (Combs, 2016).

Additionally, reselling vehicles into the local private market provides excellent opportunity to simultaneously offload a used vehicle; recoup some cost; and improve EV penetration. The Okinawa rental-EV program suffered from a ¥5,000 to ¥10,000 (approximately $500 to $1,000) disparity between the company's minimum vehicle asking price and what people in the secondary market were willing to spend on used cars (Willer & Neely, 2013). The report mentions that the then-limited charging infrastructure likely played a large role, as since-installed infrastructure improved confidence in the ability of EVs to fulfill the needs of drivers on Okinawa and correspondingly increased the value of ex-fleet EVs. Additionally, the local resident's average income was unable to support the purchase of an EV at the price requested by the rental companies (Willer & Neely, 2013).

Visibility, Education and Awareness

An EV rental program can provide renters familiar with EVs with an opportunity to drive the newest models, or to visit a destination with the knowledge that they are minimizing their transportation carbon footprint. However, the primary focus must be on first making visitors aware an EV rental program exists, then providing a convenient, positive rental experience for drivers who may have no prior experience with electric vehicles.

Maximizing the visibility of the program is crucial to meaningful EV rental utilization. Okinawa initially sought to advertise through EV travel-package deals and travel agents, but concerns over charging and the relative infancy of EV technology resulted in a disappointing 20% utilization rate at the end of the three-year trial. Drive Electric Orlando similarly used partnerships with Sabre Holdings and Southwest Airlines to market EV travel packages, but also used partnerships with Orlando-area attractions and lodging to offer highly visible, EV-exclusive benefits to increase the desirability of renting an EV (Combs, 2016). The program is also seeking to work with Florida's State Tourism Office to add the program to high-visibility state marketing efforts (Prochazka, 2015), as well as to conduct outreach to the hundreds of conferences held in the greater Orlando area to foster attendee awareness of the availability of EV rentals (Combs, 2016).

There is high potential to utilize lessons learned from these existing programs to inform the development of an EV rental program within Kauaʻi county. Conducting an comparative analysis of EV-ICE vehicle economics and modeling driver behavior on the island will allow this research to make informed suggestions on how best to implement a potential EV rental car program, with considerations for financial viability and maintaining mutual stakeholder benefits, in order to move the county toward its goal of fully decarbonized transportation by 2045. Encouragingly, a survey of 600 Englishspeaking visitors to Hawai‘i was conducted by the Ulupono Initiative, a Honolulu-based nonprofit, in April 2018. The results showed that 56% of the respondents “probably would have” rented an EV if it was available; with 26% responding that they “definitely would have” (Ulupono Initiative, 2019). This suggests that enough latent demand may exist for a significant portion of visitor vehicle rentals in Hawai’i (estimated earlier in this paper at 3.6 million rental periods annually, this would be just shy of 940,000 rental periods) to be switched from ICE vehicles to EVs.

METHODS

In examining potential motivating factors for rental fleet operators to adopt EVs, three factors typically important to consumer EV adoption were examined during this research. First, an approach was developed to compare the economics of procuring, operating, and maintaining EV and internal-combustion vehicles under a set of assumed normal rental vehicle conditions. Second, a detailed literature review was conducted to examine test cases for policy recommendations and their potential efficacy to incentivize general EV uptake within Kaua‘i County, with the end goal of providing a loose structure for a potential EV rental program. Finally, I used the Plug-In Electric Vehicle Model (or PEVI, developed by the Schatz Energy Research Center) to assess the ability of Kaua‘i County's charging network to support current and future BEV penetrations, as well as to provide insight on where new charging stations are most needed.

Vehicle Procurement, Operation, and Resale

This portion of the analysis projects the service-lifetime economic cost of BEVs as rental cars, and compares BEV service-lifetime costs to those of commonly rented internal-combustion vehicles. "Service lifetime" is defined here as the length of time (or number of miles) for which a car is utilized as part of a vehicle rental operation's fleet before it is retired from the fleet. Microsoft Excel was used to construct a spreadsheet-based calculator using pre-defined vehicle characteristics and a set of user-defined parameters to report estimated costs for comparison purposes. See Appendix A for a complete list of factors included in the model. Many of the variables (e.g. MPG, battery capacity, MSRP) were sourced from manufacturer data; others required calculation or projection to estimate their values. A methodology is presented below for the following calculated variables: annual vehicle-miles traveled (VMT), service lifetime, estimated resale value, estimated per-rental fuel cost, and service-lifetime greenhouse gas emissions (reported in terms of tonnes CO_2e).

The model takes only a small number of inputs: the price of gasoline; the average length of visitor stay; the length of rental service in years; the amount of federal tax credit available to the vehicle; and the price of electricity. The overall vehicle cost-to-operator (VCtO) was calculated using the following general formula:

$$VCtO = (Est. Purchase\ Price - Rebate) + (Annual\ Maintenance\ Costs * Service\ Lifetime) - Resale\ Value \quad (1)$$

Resale value is determined independently for each internal-combustion vehicle model, plotting estimated-value data points across several mileages and all of its model years, finding the equation for the best-fit line, and using that equation to determine the approximate resale of the vehicle, given its age and mileage. Fuel is not included in the VCtO model due to the common practice of rental companies having their clients either return their vehicles fully fueled or pay the rental company to refill it onsite. In both cases, the consumer covers the cost of fuel- and it is assumed that EV rental cars will follow the same model.

Annual, Daily, and Rental-Period Vehicle-Miles Traveled (VMT).

Where required in calculations, the daily VMT value is set to 70 miles, or 20,440 miles per year. This assumes that the vehicles had a utilization rate of 80% in keeping with data from The Hertz Corporation (2017). This means that each vehicle was rented out for 80% of the calendar year, or 292 days in total. I estimated this value by analyzing an inventory of 330 active rental vehicles listed for sale within Kaua‘i County through The Hertz Corporation’s Rent2Buy program. The data for the 330 vehicles, including vehicle years, makes, models, and listed mileage, were recorded on August 29, 2018. Cars were then manually sorted into Hertz rental-car classes based on their characteristics (e.g. number of seats, MPG, size). Daily mileages traveled were determined by dividing the vehicle’s recorded mileage by the vehicle age in years and then multiplied by 292 days to account for the published average utilization rate of 80%. This formula is displayed below as Equation 2.

$$Daily\ Rental\ VMT = \frac{Recorded\ vehicle\ mileage}{Vehicle\ age\ in\ years * (365\ days * 0.8\ utilization\ factor)} \qquad (2)$$

Overall, the daily rental VMT for the listed vehicles averaged 68 miles per day. A condensed summary of annual and estimated daily rental VMTs are shown in Table 2.

Table 2: Condensed summary table of for-sale vehicle (n=330) average quantities, age, annual mileage, and miles-per-day, broken out by vehicle type. Data sourced from (Hertz, 2018)

Vehicle Rental Class	Example Vehicle	Total Number of Vehicles	Average Vehicle Age (years)	Average Miles per Vehicle Year	Average Miles per Day
Midsize Sedan	Toyota Camry	88	1.31	18,400	63.02
Compact	Toyota Corolla	63	1.13	22,600	77.38
Compact Crossover	Nissan Rogue	41	1.32	21,600	73.83
Minivan	Toyota Sienna	37	1.51	17,200	58.97
Midsize Crossover	Ford Escape	24	1.83	18,200	62.32
Extended Fullsize SUV	GMC Yukon XL	21	1	20,300	69.40
Midsize SUV	Ford Explorer	18	2	16,700	57.22
Fullsize SUV	Ford Expedition	14	1	26,200	89.57
Subcompact	Ford Fiesta	11	2	18,500	63.28
Convertible	Ford Mustang	7	2	19,800	67.72
Fullsize Sedan	Chevrolet Impala	5	1.2	19,400	66.48
15-Passenger Van	Chevrolet Express	1	2	10,400	35.51
Full Dataset Averages	**-**	**330**	**1.38**	**19,800**	**67.89** (Weighted Average)

Assuming that the average stay length on the island is 8 days (Hawai'i Tourism Authority, 2018), the typical visitor then drives approximately 540 miles over the duration of their visit.

<u>Service Lifetime.</u>

Due to the proprietary nature of rental car data, it is difficult to confidently determine an industry-wide service lifetime (typically expressed in years). Within the industry, vehicles are sorted into two categories: “program” vehicles, which are purchased with the understanding that the vehicles will be resold to the manufacturer in excellent condition for a pre-negotiated price; and “risk” vehicles, which are purchased at a discount, but places the risks of depreciation and resale with the rental company. Program vehicles typically reside in the fleet for a shorter amount of time; while risk vehicles tend to have longer service lifetimes (Eckhaus Fleet, 2015). However, program vehicles are offered directly from manufacturers and may exclude certain models; whereas risk vehicles typically allow rental companies a much larger selection (Toyota Motor Sales, Inc., 2016). Whether or not a given vehicle would fall under the “program” or “risk” category is unknown; therefore, for the purpose of this analysis, an average service lifetime or holding period was used. Additionally, all vehicles were assumed to be “risk” vehicles in order to reflect one of the desired outcomes of a potential rental EV program: an increase in well-maintained used EV options within Kaua‘i County. Of the major rental companies, the Hertz Corporation (2017) reported an average holding period of 17 months across its United States fleet; Avis-Budget Group (2009) reported a holding period of between four and 16 months across its fleet; and Dollar-Thrifty Automotive Group (2011) reported a holding period of 18 to 22 months on its risk vehicles, and 6-8 months on its program vehicles before the Group was acquired by Hertz in 2012. Enterprise Holdings is privately owned, and so does not report its financial dealings to the same detail as Hertz or Avis. However, associated sites suggest that their average holding time is roughly 8-12 months (Enterprise Holdings, Inc., 2015; 2018). Taken as a whole, this suggests that the industry-wide service lifetime is approximately 15 months. This figure is supported by the data taken from the Hertz Rent2Own program website, which results in an average vehicle age of 1.38 years, or 16.6 months, across 330 vehicles for sale in Kauaʻi County.

Estimated Resale Value.

Resale values for conventional vehicles were modeled based on data from Edmunds' "True Cost to Own" (TCO) tool, set to the Līhuʻe zip code (96766) on July 28, 2018. The Edmunds TCO estimated annual depreciation in US dollars. Finding the estimated resale price of a vehicle was simply done by subtracting the depreciation amount from the previous timestep's vehicle value.

Estimating resale value for EVs was done by graphing a best-fit line through estimated electric vehicle resale values in Līhuʻe, Hawaiʻi. First, makes and models of widely available, contemporary light-duty BEVs were identified, starting in model year (MY) 2011 and continuing through MY2018. Due to their luxury status, Tesla vehicles were excluded from this analysis. Approximate resale values for each unique model (e.g. 2011 Nissan Leaf, 2015 Chevrolet Bolt) were determined by using the Kelly Blue Book website on July 28, 2018, set to the Līhuʻe, HI zip code (96766), and assuming all vehicles conformed to the "good" condition. This condition was selected due to the site automatically assigning a maximum condition of "good" to any vehicle with a rental title, regardless of cosmetic or mechanical condition. In each case, the median trim level for each vehicle was used to reflect an “average” EV. Each vehicle was assumed to be equipped with the standard equipment for the specified model and trim. Private-party resale values were generated for 8 distinct vehicle mileages, which increased in 5,000-mile increments from 5,000 to 20,000 miles, then in 10,000-mile increments from 20,000 to 60,000 miles, for each year that the vehicle was manufactured. This resulted in a matrix for each vehicle, where resale values were retrieved for 8 different mileages for each model year, as shown in Table 3.

Table 3: Sample matrix of Kelly Blue Book private-party resale values across 6 model years and 8 vehicle mileages. Data retrieved on July 28, 2018, for ZIP code 96766 (Līhu‘e, HI).

Nissan Leaf SV	**MY 2011**	**MY 2012**	**MY 2013**	**MY 2014**	**MY 2015**	**MY 2016**	**MY 2017**
5,000 mi	$7,119	$8,196	$8,876	$10,267	$11,978	$15,229	$16,935
10,000 mi	$7,080	$8,140	$8,774	$10,114	$11,782	$14,974	$16,650
15,000 mi	$6,977	$8,025	$8,621	$9,935	$11,576	$14,706	$16,352
20,000 mi	$6,870	$7,904	$8,462	$9,748	$11,360	$14,425	$16,038
30,000 mi	$6,642	$7,648	$8,123	$9,353	$10,898	$13,831	$15,374
40,000 mi	$6,383	$7,355	$7,738	$8,902	$10,383	$13,153	$14,617
50,000 mi	$6,133	$7,067	$7,367	$8,467	$9,881	$12,499	$13,887
60,000 mi	$5,876	$6,785	$6,984	$8,018	$9,362	$11,825	$13,134

Vehicles were then matched with their original manufacturer’s suggested retail price (MSRP) and original EPA-estimated range. Hawai‘i general excise tax (4%) was applied to each of the vehicles’ purchase price to generate a “post-tax” price. As rental agencies appear to be able to claim the federal tax credit under IRS IRC 30D, the full $7,500 was subtracted from each vehicle’s post-tax price to determine the final new-sale cost of each vehicle, which was then adjusted into 2018 dollars using the Consumer Price Index (CPI). The estimated resale value of each vehicle was then divided by the inflation-adjusted MSRP to determine the vehicle's residual value, expressed as a percentage of the adjusted MSRP. This process is illustrated below in Equation 3.

$$Resale\ Proportion\ of\ MSRP = \frac{Estimated\ 2018\ Resale\ Price}{1.04(MSRP) - \$7{,}500 * (CPI\ Adjustment)} \quad (3)$$

These results were then compiled into a single dataset and imported into the R statistical program. The data points were graphed, and a best-fit line was constructed through the data to produce a polynomial equation approximating the average depreciation rate, factoring in both vehicle age and mileage. Finally, the user-defined service lifetime in years (i.e. the vehicle age at time of sale) and the lifetime mileage (i.e. annual mileage times service lifetime in years) are substituted into the generalized equation, the result of which is then subtracted from each vehicle's inflation-adjusted new-sale cost to determine each vehicle's residual value in 2018 dollars.

<u>Estimated Per-Rental Fuel Cost.</u>

Per-rental fuel cost is used to quantify any economic benefit to the consumer in renting an EV over a comparable ICE vehicle. Per-rental fuel cost relies primarily on the user-defined input of the total annual vehicle-miles traveled (VMT). Multiplying the observed average daily rental mileage (approximately 80 miles) by the average number of days in a rental stay results in the mileage driven over each rental period. The rental period mileage is then divided by the vehicle's fuel efficiency, given in either electric mile-per-kWh or gasoline mile-per-gallon (MPG), to determine the number of units of fuel required for each vehicle to travel the average rental period mileage. From there, the total number of fuel units was multiplied by the current retail rate for that fuel- either gasoline or electricity. This general equation is illustrated more concisely in Equation 4.

$$Rental\ period\ fuel\ cost = \frac{\left(\frac{Annual\ VMT}{\left(\frac{365\ days * utilization\ rate}{Average\ stay\ length}\right)}\right)}{Vehicle\ fuel\ efficiency} * Fuel\ cost \qquad (4)$$

Projected Service-Lifetime CO_2e Emissions.

Two distinct methodologies were used to calculate service-life greenhouse gas emissions: one for EVs, and one for conventional ICE vehicles.

Conventional ICE vehicles. The EPA (2018a) estimates that post-2009 gasoline passenger cars emit 0.0173 grams of CH4 per mile; 0.0036 grams of N2O per mile; and 8.78 kilograms of CO2 per gallon of gasoline burned. Calculating ICE vehicle annual CO2e emissions happens in two stages: per-mile emissions and per-gallon emissions. Multiplying the gram-per-mile amounts of N2O and CH4 by the annual vehicle mileage, then converting to tonnes of CO2e using the IPCC's 100-year global warming potential factors results in the amount of CO2e emitted as CH4 and N2O, adapted from the 5th Annual Report (AR5) and shown below in Table 4.

Table 4: Global warming potentials relative to CO_2 for common combustion byproducts (Myhre, 2013).

Compound	**100-year Global Warming Potential relative to CO_2**
CO_2	1
CH_4	28
N_2O	265

Determining the number of gallons of gas required to travel the annual vehicle mileage, then multiplying by 8.78 kg CO_2 per mile (EPA, 2018) results in the amount of

CO_2e emitted as CO_2. From there, adding the two components results in the annual amount of CO_2e; multiplying that by the number of years in the vehicle service lifetime will result in the expected service-lifetime CO_2e emissions. This process is illustrated below in Equations 5-9.

$$Service\ Lifetime\ Mileage = Annual\ mileage * service\ lifetime\ years) \quad (5)$$

$$N_2O\ CO_2e\ = \left(Service\ Lifetime\ Mileage * \left(0.0036\ \frac{\text{grams } \mathrm{N_2O}}{mile} * 265\ \frac{\mathrm{CO_2}}{\mathrm{N_2O}}\right)\right) \quad (6)$$

$$CH_4\ CO_2e\ = \left(Service\ Lifetime\ Mileage * \left(0.0173\ \frac{\text{grams } \mathrm{CH_4}}{mile} * 28\ \frac{\mathrm{CO_2}}{\mathrm{N_2O}}\right)\right) \quad (7)$$

$$CO_2\ emissions = \left(\frac{Service\ Lifetime\ Mileage}{Vehicle\ MPG} * \left(8.68\ \frac{\text{kilograms } \mathrm{CO_2}}{gallon\ gasoline}\right)\right) \quad (8)$$

$$Total\ CO_2e\ emissions\ =\ (CO_2\ emissions\ + CH_4\ CO_2e\ \ +\ N_2O\ CO_2e\ ) \quad (9)$$

Electric vehicles. KIUC falls under the HIMS subregion of the EPA eGRID emissions database. HIMS covers electrical generation on all of the Hawaiian islands other than O‘ahu, which has its own subregion (EPA, 2018a). The eGRID database specifies average CO_2e output emissions rates from electricity generation, divided by fuel type.

Kaua‘i draws power from two petroleum-fired power plants, including one fuel-oil plant in Port Allen and one naphtha/fuel oil plant in Kapaia (EPA eGRID, 2018). Additionally, a biomass-fired plant operates in Līhu‘e. However, according to eGRID (2018), these are the only powerplants that produce CO_2e during generation. The eGRID database estimates that for each MWh of power generated by the fossil fuel plants, 0.7157 tonnes of CO_2e are produced. For each MWh of power generated by the biomass plant, 0.000218 tonnes of CO_2e are produced (EPA eGRID, 2018). For the purpose of this analysis, the renewable energy present on the island (solar and hydropower) will be considered to have zero GHG production associated with their operation, and lifecycle emissions stemming from their production and disposal will be considered out of scope.

Next, the overall percentage of carbon-producing electricity generation present on the Kauaʻi grid needs to be quantified. In 2017, the island generated 276,387 MWh of electricity from fossil fuels, 46,192 MWh from biomass, and 152,292 MWh from hydropower and solar for a total of 473,831 MWh (KIUC, 2018). This represents not only KIUC-operated facilities, but also customer-owned, “behind-the-meter” solar generation. This results in 58.3% of the power mix being sourced from petroleum, with 9.8% sourced from biomass. A graphical representation of the utility’s generation portfolio is shown in Figure 10.

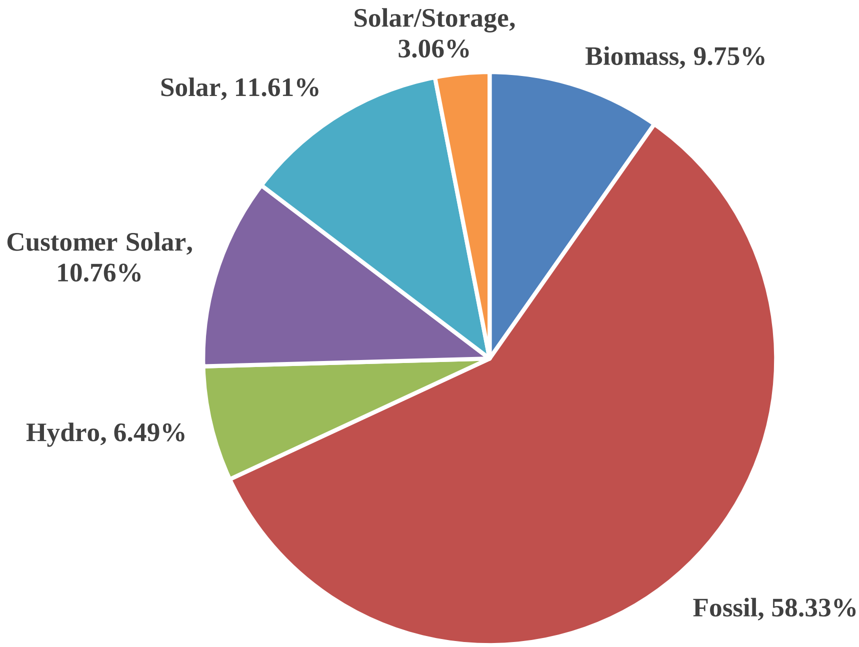

Figure 10: Kaua'i County electricity grid mix for 2017, as reported to the Hawai'i PUC by KIUC. Customer solar is comprised of both behind-the-meter generation and electricity net-metered back into the grid. Data from KIUC (2018).

This analysis assumes that one MWh of electricity is composed of the same grid mix as the overall energy production. To this end, a weighted average emissions factor can be calculated for a blended MWh by multiplying the percentages of biomass and fossil fuel used by their respective carbon intensities. This calculation results in a Kaua‘i-specific average electricity carbon intensity of 0.4175 tonnes CO_2e per MWh of electricity generated, as of February 2018. Average annual EV CO_2e emissions can be estimated by first determining the electricity (in MWh) needed for the vehicles to achieve the annual mileage, then multiplying that value by 0.4175 tonnes CO_2e/MWh generation. Multiple years can be calculated by decreasing the tonnes CO_2e/MWh generation with each passing year. For example, KIUC has committed to a goal of sourcing 70% of its power from renewable sources by 2030 (KIUC, 2018). To reach this goal, at a minimum, the renewable proportion of KIUC's grid mix must increase by 1.97% annually. To find CO_2e emissions over a three-year service life, for example, the non-renewable proportion of energy must decrease by 1.97% with each year to reflect KIUC's minimum progress toward that goal. It should be noted that this methodology does not take into account the source of any power brought online by the increased demand of EV charging, and thus may underestimate the upstream GHG emissions associated with EVs.

Siting EVSE Infrastructure Upgrades and Installations

This portion of the analysis seeks to identify key geographic regions where Kaua'i County's existing charging infrastructure most needs to be expanded, based on modeled tourist behavior and various penetrations of BEVs into the rental car fleet. There are three primary components integral to this process: an estimate of the size of the island's rental car fleet; general models of visitor behavior (e.g. where visitors go; where they stay; and when they embark on trips); and a geo-temporal, agent-based model designed to report out a variety of metrics assessing a given charging network's performance.

Agent-Based Model.

This analysis relies on the Plug-in Electric Vehicle Infrastructure model, or PEVI, developed by Colin Sheppard and Andrew Harris of the Schatz Energy Research Center in Arcata, CA. PEVI takes a given study region, divided into subsections called travel analysis zones (TAZs), then aggregates charging stations based on the TAZs they are located within. In this case, the TAZs were defined by a GIS shapefile dividing the island into 9 distinct zones, illustrated in Figure 11 (U.S. Census Bureau, 2011).

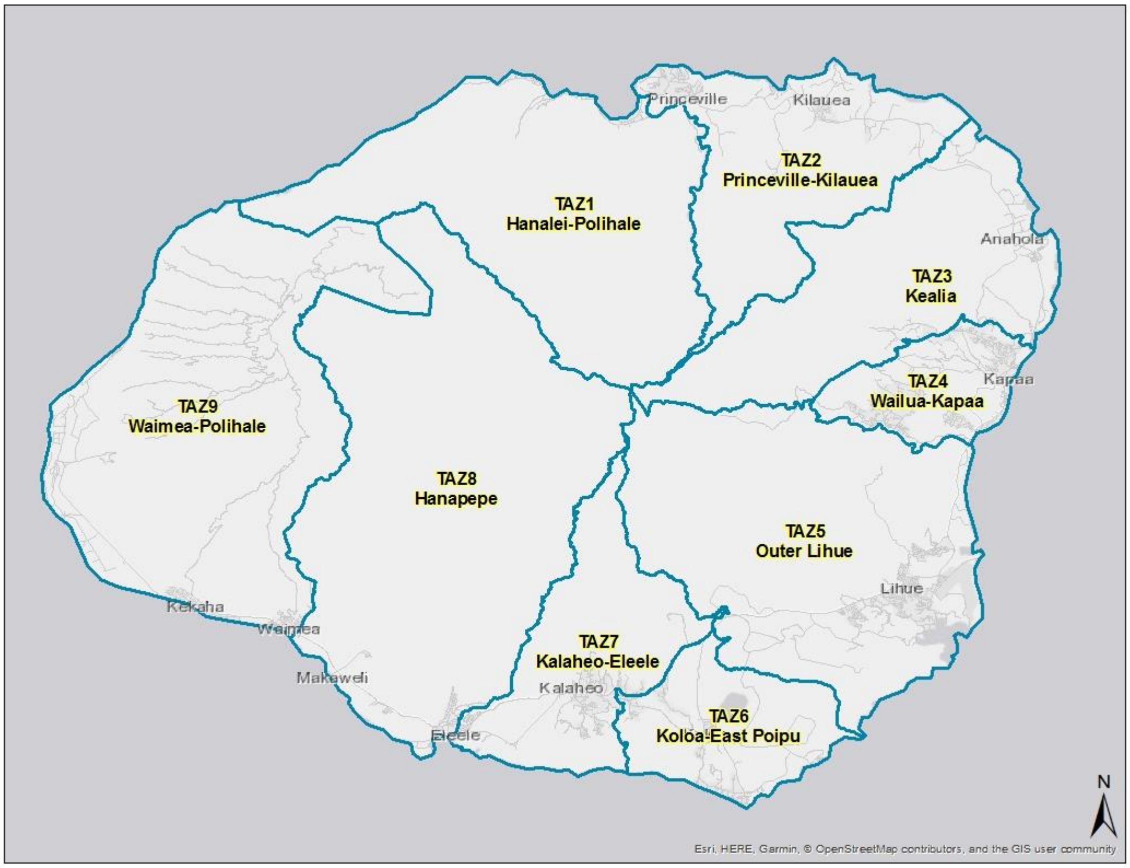

Figure 11: Kaua'i County travel analysis zones (TAZs), numbered consecutively starting at the northernmost TAZ and moving clockwise. Map author's work, TAZs from U.S. Census Bureau (2011).

The shapefile was slightly modified to ensure that the TAZs accurately reflected travel zones within the county, expanding the northeast corner of TAZ 9 to capture a formerly truncated section of Waimea Canyon Road.

Using the TAZs, the model then simulates the interactions between "agent" drivers (a population composed of both the projected numbers of resident and projected visitor EVs) and their vehicles as the drivers move around the island, following a randomly generated itinerary. PEVI allows drivers to monitor the status of their cars, and for any given driver to divert from or stop along their originally assigned route to charge if they believe it is necessary. Drivers are also able to adjust their departure times to account for travel time to an available charger in another TAZ if all chargers in their current location are unavailable. PEVI's outputs are composed of three primary measures: energy (i.e. How much electricity is each individual driver consuming over their day?), travel stages (i.e. Where did each driver end up going, and when?), and driver inconvenience (an abstracted representation of the delays each driver experiences, expressed as units of "pain"). To provide the required inputs to run the model, four inputs needed to be determined: where charging stations were located; what charging speed was offered by each station; what vehicles were used; and the travel time and distance relationships between each pair of TAZs.

Assessing Charging Network Coverage and Power.

The EVSE network within Kauaʻi County was assessed using the PlugShare website, a crowd-sourced dynamic map that allows users to leave comments and/or mark a station as either functional or nonfunctional. Data including station location, accessibility, cost to charge, charging power level, and charging protocol standard (e.g. J1772, Combined Charging Standard) were recorded for each station. If a single physical charging station had multiple plugs to enable simultaneous charging, each plug was counted as a separate station. User-generated comments were reviewed for each station to determine operational status. If a station had comments from within the past 6 months marking it as non-operational and any subsequent comments did not either mark it as operational or specifically note that it had been fixed, the station was marked as inoperative. If a station was marked as existing on Plugshare but had no comments, and a ground-level review through Google Street View or Bing StreetSide revealed no station, its status was marked as indeterminate, and not included in the analysis. From there, a dedicated inventory was built and updated once a month through November 2018. Charging stations were then aggregated by power level (Level 1, Level 2, and Level 3/DCFC) into their respective TAZs. A final table consisting of the number of charging stations of each power within each TAZ was converted to comma-separated value (.csv) format and fed into PEVI as a primary input.

Determining Time and Distance Relationships Between TAZ Pairs.

One of the critical inputs for PEVI is a table illustrating the relationships between each pair of TAZs. Distance, estimated travel time, and TAZs enroute to the destination are specified, as shown in abbreviated form in Table 5.

Table 5: Abbreviated table of traffic analysis zone (TAZ) relationships, showing distance between TAZ road network centroids or distance of TAZ radius, travel time for the same, and the numbers of any enroute TAZs.

From	To	Distance (miles)	Time (in hours)	TAZs Enroute
1	1	4.45	0.10	-
1	2	9.30	0.33	-
1	3	21.4	0.65	2
1	4	27.2	0.83	2, 3
1	5	33.3	1.02	2, 3, 4

Using the existing TAZ GIS shapefile, ESRI ArcMap was used to determine the centroid of the extent of each TAZ’s road network. Due to the large portion of the island that lacks roads, the bounds of each TAZ are significantly larger than the actual road network, as seen earlier in Figure 11. Attempting to calculate travel times between TAZ centroids, as Sheppard (2017, pers. comm) had done, was found to be inappropriate for this analysis, as this method consistently placed the TAZ polygon centroids a large distance away from the actual road network. Road network centroids were used instead, as they represented the center of the extent of the TAZ that was realistically available to be driven. Distances and travel times between road network centroids were calculated using Google Maps, selecting the most direct route if several routes were displayed. Intra-TAZ travel distance and times (i.e. travel from one part of TAZ1 to another part of TAZ1) were calculated by determining the radius of the polygon (Sheppard 2017, pers. comm) and assuming an average speed of 45mph.

Estimating Rental Fleet Size.

This analysis relies on the following assumptions: that each visitor party only requires one vehicle; that the average visitor-unit size on Kaua‘i was 2.2 individual visitors in keeping with the annual state average issued by the Hawai‘i Tourism Authority, or HTA (2018); and that approximately 89% of visitors to Kaua‘i rent a motor vehicle (Steinmetz 2017, pers. comm.). The HTA also reports the monthly visitor-days spent on the island, where a “visitor-day” is defined as total monthly visitor arrivals multiplied by the average stay length during that month. Daily average visitor populations can be calculated by dividing the total visitor-days in a given month by the number of days in that month. Given 2017 statistics for the above variables and assuming an average of 2.2 people per party, this report determined that on average, roughly 10,650 rental vehicles are actively in use on Kaua‘i, with a maximum of approximately 12,600 vehicles occurring in July. This is approximately 16% of the total number of 78,980 registered vehicles within the county (DBEDT, 2018). Since the island is technically a “closed system” with presumably few cars entering or leaving the island, fleet size is assumed to stay constant over the course of a given year, i.e. during periods of low demand, excess rental vehicles are placed in storage until demand rises.

Determining Relative EV Model Penetrations.

EV model penetrations are perhaps the least constrained of any of the variables within this section. Makes and models are only limited by the number of unique vehicles that the modeler decides to specify. This analysis limits the vehicles to sub-$40,000, fully electric vehicles either currently on the market or assigned for release by early 2019: short-range and long-range versions of the Nissan Leaf; the Hyundai Ioniq and Kona EV; the Chevrolet Bolt; the Volkswagen e-Golf; the BMW i3 BEV; the Tesla Model 3; and the Kia Soul EV. Three distinct proportions of vehicles were used to examine how variations in fleet composition affect charging infrastructure adequacy: a mixture of 40% short-range (sub-200 mile) and 60% long-range (over 200 mile) cars; exclusively long-range vehicles; and exclusively short-range vehicles. Model breakouts by vehicle mix are shown below in Table 6.

Table 6: Electric vehicle mixes used in PEVI model iterations.

Vehicle Model *Full Charge Range / Battery Size*	**Short-Range Mix**	**Short/Long Range Mix**	**Long-Range Mix**
2018 Kia Soul EV *111 miles / 30kWh*	20%	-	-
2018 BMW i3 BEV *114 miles / 33kWh*	20%	-	-
2018 Ford Focus Electric *115 miles / 33.5kWh*	20%	-	-
2018 Hyundai Ioniq Electric *124 miles / 28kWh*	-	20%	
2018 Volkswagen e-Golf *125 miles / 35.8kWh*	20%	-	-
2018 Nissan Leaf *151 miles / 40kWh*	20%	20%	-
2019 Nissan Leaf ePlus *225 miles proj. / 60kWh*		20%	25%
2018 Chevrolet Bolt *238 miles / 60kWh*	-	20%	25%
2019 Tesla Model 3 Base *250 miles / 50kWh*	-	-	25%
2018 Hyundai Kona Electric *258 miles / 64kWh*	-	20%	25%

Resident vehicles were also modeled, using EPA data to find the average battery size and range of all EV models available in Hawai'i, across model years 2011-2018. In cases where a model offered multiple battery sizes and ranges in a single year, the mean is taken to represent the model for that year. The combined range and battery averages were taken to represent a "generic" EV driven by all residents.

Modeling Driver Behavior.

The next step in determining the adequacy of the existing charging network is to determine how both visitor and resident EV drivers are likely to use it. The PEVI agent-based model has been used successfully to simulate driver interactions with an EVSE network in Humboldt County, CA (Redwood Coast Energy Authority, 2014) and Delhi, India (Sheppard, Harris, & Gopal, 2016).

Visitor Behavior

Real-world visitor travel data was unavailable for Kaua‘i County, as were other commonly used methods of estimating travel habits of the general population such as transportation surveys and/or studies. To estimate visitor travel volumes, two proxies were used to represent the probabilities of drivers visiting and staying in any given TAZ. First, visitor unit availability data broken out by ZIP code was used as a proxy for visitor likelihood to stay in a given area. The number of available lodging units in ZIP codes falling within a TAZ were summed, giving each TAZ a total “lodging unit count”. Once each TAZ was assigned an aggregated lodging unit count, a “lodging probability” was calculated for each TAZ by simply dividing the lodging count by the total number of units. For example, the data showed 6,262 individual lodging units island-wide (Hawai'i Tourism Authority, 2018). TAZ 6 has 2,265 units in total- or 36.2% of the total advertised vacation lodging. Assuming this is representative of overall visitor likelihood to stay within that zone; this works out to a 36.2% probability that any given visitor party would stay in TAZ 6. A similar process was used to define destination probability: a GIS shapefile comprised of the most popular attractions on the island was sourced from the Federal Highways Administration (2016). TAZs with high concentrations of popular destinations were assumed to be more frequently visited than those with low concentrations. The number of destinations within each TAZ was used as a proxy for visitor likelihood to drive to that TAZ. Attractions were aggregated by TAZ, and then a "visitation probability" was calculated for each TAZ by simply dividing the number of attractions within that TAZ by the total number of attractions. Once visitation and lodging probabilities for each TAZ were calculated, departure times were randomly generated using a flat probability distribution model representing travel volumes, spread across the hours between 8AM and 7PM. These hours were chosen to reflect an assumed 95^{th} percentile of times a driver would likely leave their lodging to start their driving itinerary for the day. In other words, only 5% of drivers would leave earlier than 8AM or later than 7PM.

The number of EV "drivers" then needs to be specified. Each EV driver is first assigned a "home" TAZ from the lodging probability for each TAZ; this is the TAZ where they have their lodging during the duration of their stay. Drivers are assigned vehicles according to an external file dictating the fleet composition (i.e. 60% Vehicle A, 40% Vehicle B) and assigned an initial battery state-of-charge. Drivers are randomly assigned a home departure time between 8AM and 7PM and an overall "time budget" that dictates how much time the driver has available for trips before needing to be back at their lodging. Drivers are assumed to return to their lodging before 10PM the same day they left; thus, the maximum time budget for a driver starting their itinerary at 7PM would be 3 hours, while the maximum time budget for a driver starting at 8AM would be 14 hours. Each driver is then assigned a random number between 1 and 5, based on their time budget: this defines the number of trip "legs" they take, not counting the return trip to their "home" TAZ. Thus, the minimum number of "legs" to a trip is 2 (leave home, arrive at destination 1, and return home); the maximum is 6. Drivers with smaller time budgets (sub-6 hours) are limited to 3 legs; drivers over 6 hours are allowed up to the maximum 6 trip legs to allow enough time to complete the itinerary. Each trip leg for each driver is randomly assigned a destination TAZ, drawing from the destination probability model. The model looks up the travel time between the start and end TAZs, then subtracts the travel time from the overall time budget. From there, the model randomly assigns residence times at each destination that sum to the remaining time budget, effectively generating a randomized itinerary based on the previously constructed probability distribution models for lodging; visitation; and departure times. This generalized process is illustrated in Figure 12.

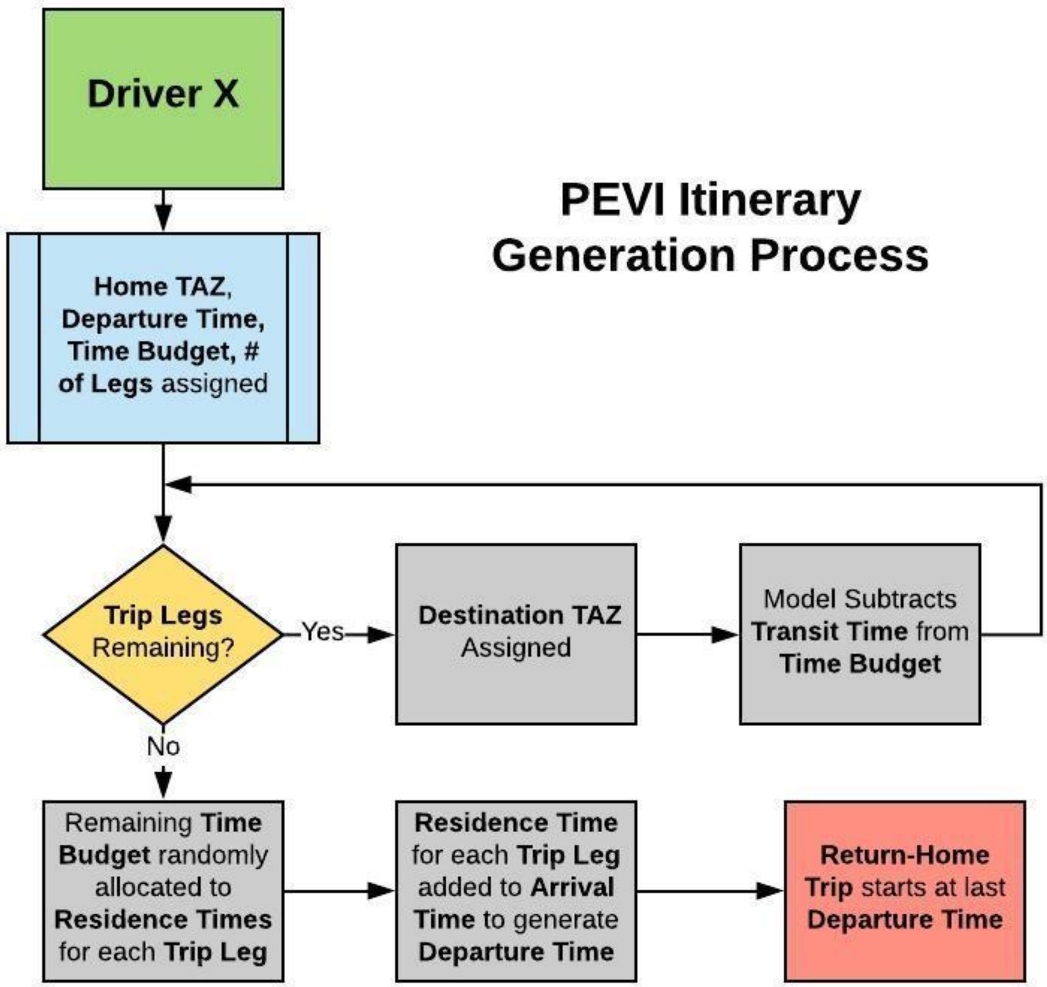

Figure 12: Generalized flowchart of the driver itinerary generation profile for use in the PEVI model. Bolded phrases represent variables.

The itinerary is then converted to the layout and tab-separated text (.TXT) filetype to allow the agent-based model application to read it.

Resident Behavior

Resident itineraries were generated in a nearly identical manner as visitor itineraries, with alterations to the departure time distribution, residence times, home and destination TAZ probabilities, starting charge state, and return-time thresholds.

Instead of adhering to the flat, 8AM-7PM departure time distribution seen with the visitor modeling, this section assumes that 95% of residents will begin their travel days between 7AM and 1PM to adhere to the commonly seen “rush hour” workday peak, as shown below in Figure 13.

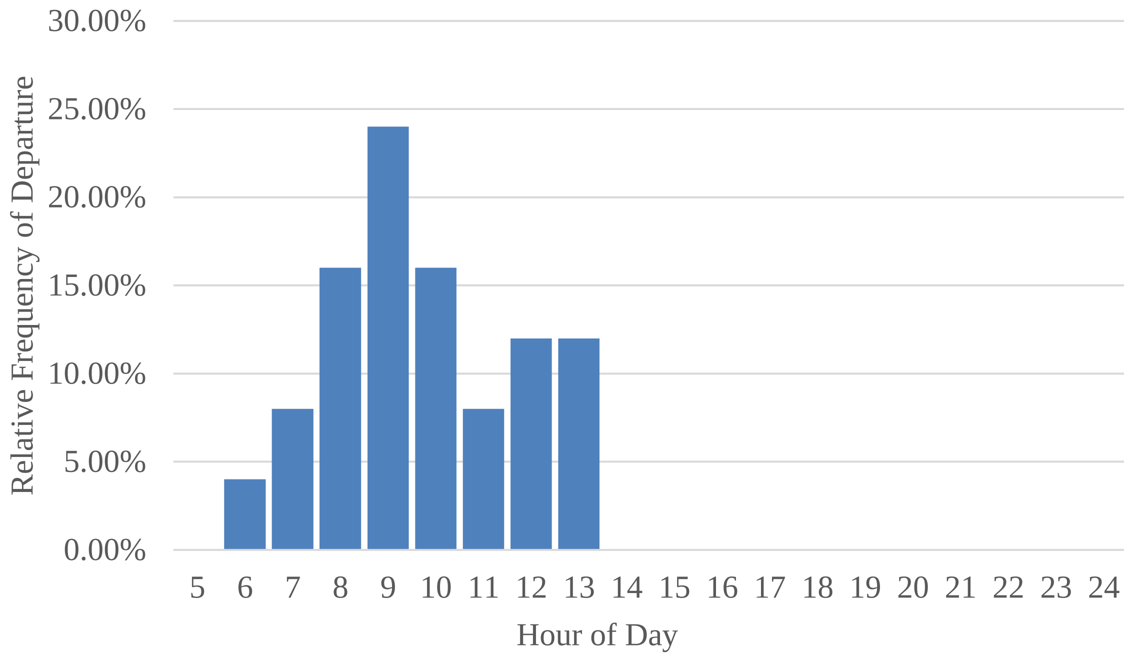

Figure 13: Synthetic resident departure-time probability distribution, with likelihood of departure at a given time expressed as a decimal probability and times expressed in the 24-hour format (i.e. 12 is equal to noon; 23 is equal to 11:00 PM).

Home TAZs are determined by the proportion of EVs registered in each ZIP code, as reported by Coffman, Allen, & Wee (2018). This uses the same method of aggregating

ZIP codes within TAZs as the process to determine the relative proportions of visitor housing units. Thus, a TAZ that holds 20% of total EV registrations has a 20% chance of being selected as a home TAZ for a resident. Destination TAZs were determined by the proportion of jobs within each TAZ, as aggregated by the United States Census Bureau's OnTheMap (2018). Randomized drivers that start their itinerary before 9AM are assigned 8-hour residence times to reflect a full workday. Finally, the analysis assumes that residents will return home and halt their itinerary no later than 11:59PM on the same day they departed.

Model Iterations

The PEVI analysis examines the near-term (~early 2019) ability of the current infrastructure to support both currently registered, resident-owned EVs and a 30-car EV rental pilot program. Following guidance from the U.S. Department of Energy (2017), in cases when the effects of adding new infrastructure was modeled, adding DC Fast charging coverage was prioritized over installing new Level 2 charging. The speed and convenience of DCFC stations make them prime candidates to easily improve charging station geographic coverage, as well as to improve the network's ability to keep up with charging demand. Therefore, new installations were constrained to only DC Fast stations, with any increase in Level 2 chargers reflecting repairs of existing infrastructure. Four infrastructure scenarios were used to compare potential EVSE development routes. First, charging session, inconvenience, and trip data were generated for a single randomized 305-driver PEVI itinerary for a "benchmark" scenario. This used all installed, publicly accessible charging stations functional as of November 2018. Three additional scenarios were examined: an “Existing Infrastructure Only” which focused on repairing all 15 public-access charging ports, including 1 DCFC in TAZ 6 and added 2 charging stations scheduled for installation in TAZ 9 in early 2019; “low DCFC”, which installed one new DCFC station in each of the 3 high-delay areas and repaired 8 critical Level 2 stations to represent a balance between the two technologies; and “high DCFC”, installing 6 new DCFC stations and repairing the TAZ 6 DCFC station, ignoring all other existing infrastructure). These total number of charging stations in each scenario are presented in tabulated form below as Table 7. Due to the relative rarity of battery-electric vehicles on the island and a dearth of functional stations (only 5 of 47 resorts and hotels on the island have charging at all), it is assumed that none of the visitors have reliable access to home charging, while all the resident drivers have the option of charging at home (an assumption in line with other models, including NREL’s EVI-Pro (2018)).

Table 7: Number of Level 2 and DC Fast chargers, including both the currently operational chargers (“base case”) and the three infrastructure cases. Values reported as *number of Level 2 chargers, number of DC Fast chargers*.

Chargers Present in each EVSE Scenario				
Traffic Analysis Zone	**Base Case**	**Existing Only**	**Low DCFC**	**High DCFC**
1: Hāʻena-Kīlauea	0 L2, 0 DC	0 L2, 0 DC	0 L2, 1 DC	0 L2, 1 DC
2: Princeville	0 L2, 0 DC	2 L2, 0 DC	2 L2, 0 DC	0 L2, 1 DC
3: Anahola	0 L2, 0 DC	0 L2, 0 DC	0 L2, 1 DC	0 L2, 1 DC
4: Kapaʻa	1 L2, 0 DC	2 L2, 0 DC	2 L2, 0 DC	1 L2, 1 DC
5: Līhuʻe	13 L2, 0 DC	22 L2, 0 DC	18 L2, 0 DC	13 L2, 0 DC
6: Kōloa	1 L2, 0 DC	3 L2, 1 DC	1 L2, 0 DC	1 L2, 1 DC
7: ʻEleʻele	0 L2, 0 DC	0 L2, 0 DC	0 L2, 0 DC	0 L2, 1 DC
8: Hanapēpē	0 L2, 0 DC	0 L2, 0 DC	0 L2, 1 DC	0 L2, 1 DC
9: Waimea	1 L2, 0 DC	3 L2, 0 DC	3 L2, 0 DC	3 L2, 0 DC
TOTALS	**16 L2, 0 DC**	**32 L2, 1 DC**	**26 L2, 3 DC**	**18 L2, 7 DC**

The drivers consisted of 30 visitor EVs, representing a rental EV pilot program, and the 275 resident EVs currently registered on the island. Three vehicle mixes were used: fully short-range (sub 200-mile) vehicles; a 60-40 mix of, respectively, short-range and long-range (more than 200-mile) vehicles; and fully long-range vehicles to determine the EV fleet composition that minimizes drives' overall delay. PEVI utilizes a random number generator to define certain parameters, with a "seed" option that allows for manual specification of that random number. Two trials using the same input files and the same seed will produce identical results. Five distinct seeds were used to eliminate the random number generator as a source of variation while providing enough model runs to take a representative average. Two components of inconvenience data were used to quantify charging infrastructure adequacy in each TAZ and recommend locations for station installation and/or repair to support near-term EV adoption. The first, inconvenience frequency, reflects how often drivers encounter problems in each TAZ (delays, strandings, unscheduled trips), while inconvenience magnitude reflects the average severity of each problem.

RESULTS

Three vital components for quantifying the feasibility of rental BEVs on Kauaʻi were assessed in this document. Considered were visitor desire for and experience with electric vehicles; the Kauaʻi County-specific economics of EVs compared to ICE vehicles, and the current ability of the island's infrastructure to support both the existing number of EVs and a potential pilot EV rental program. Each one of these factors represents a separate measure for how ready Kauaʻi currently is to begin electrifying its rental fleet: visitor demand and interest; benefits to rental-operator bottom line and perception; and the extent to which the EVSE network will need to expand to provide adequate, reliable levels of charging.

High-Level Assessment of Rental EVs

Public feedback left on five privately owned EVs rented on Kauaʻi through a peer-to-peer carsharing program, Turo, was collected to act as an informal survey for this research. Seventy-one text comments, ranging in date from late 2017 to just before collection in late 2018, were compiled and reviewed for common feedback phrases and sentiments. The results are tabulated below in Table 8.

Table 8: Common feedback phrases taken from 71 text reviews left for 5 EVs rented through the Turo peer-to-peer car rental program on Kaua'i. Data gathered November 2018. Two distinct models (2018 Kia Soul EVs and 2013 Nissan Leafs) were examined.

Feedback	Total Number	Overall Percentage	2018 Kia Soul EV (n=34)	2013 Nissan Leaf (n=37)
Chargers scarce/broken	18	25.35%	4	14
Trips require planning	18	25.35%	10	8
Range anxiety/Needs more range	13	18.31%	1	12
First experience with an EV	8	11.27%	7	1
Long charging times	6	8.45%	4	2
No range concerns	6	8.45%	6	0
Liked environmental aspect	5	7.04%	2	3
Chargers easy to access	4	5.63%	2	2
Driver saved money	4	5.63%	3	1
Driver thinking about buying electric	2	2.82%	2	0

Of 71 text reviews, 18 (25%) mentioned the perceived scarcity of chargers and/or the number of broken chargers on the island, and 18 (25%) explicitly mentioned that EV rentals required planning their itineraries around the chargers. Reviews from 13 (18.3%) total respondents mentioned issues with vehicle range. The reviews suggest that range anxiety issues may be able to be ameliorated by longer-range EVs. Two models were rented on the island: two 2013 Nissan Leafs (84-mile range, 37 reviews), and three 2018

Kia Soul EVs (110-mile range, 34 reviews). Among the reviews for the Nissans, 12 of 37 (32%) text reviews mentioned range anxiety and/or short range as a relevant issue. The reviews for the Soul EVs, which have a 26-mile range (31%) advantage over the Nissans, only mention range anxiety once in 34 reviews (3%). Reviewers who rented the Leafs were much more likely to mention range anxiety: 12 of 34 (35%) reviews explicitly mention this as a problem. Six reviewers of the Kia Soul EV felt that they had no concerns over range; whereas none of the reviews of the Leaf mention "range confidence". Criticisms that trips require careful planning and flexibility to take advantage of chargers are common to both vehicles. Complaints related to the amount of time it took to recharge the battery were slightly more common among Soul EV drivers (12%) versus Leaf drivers (5%). A number of drivers appear to be proactively seeking a novel rental car experience: 8 of the 71 reviews (11%) explicitly state that their rental car was their first time driving an EV.

Vehicle Procurement, Operation, and Resale

The net cost-to-operator for each of the analyzed vehicles was calculated for each year over a maximum 4-year service life. Cost-to-operator was calculated based on purchase price (including rebates and tax), maintenance costs, and projected resale costs. A minimum one-year service life and a maximum four-year service life was used to bound the analysis timeframe. The overall cost trajectories of each of the vehicles as service life increases are symbolized below in Figure 14.

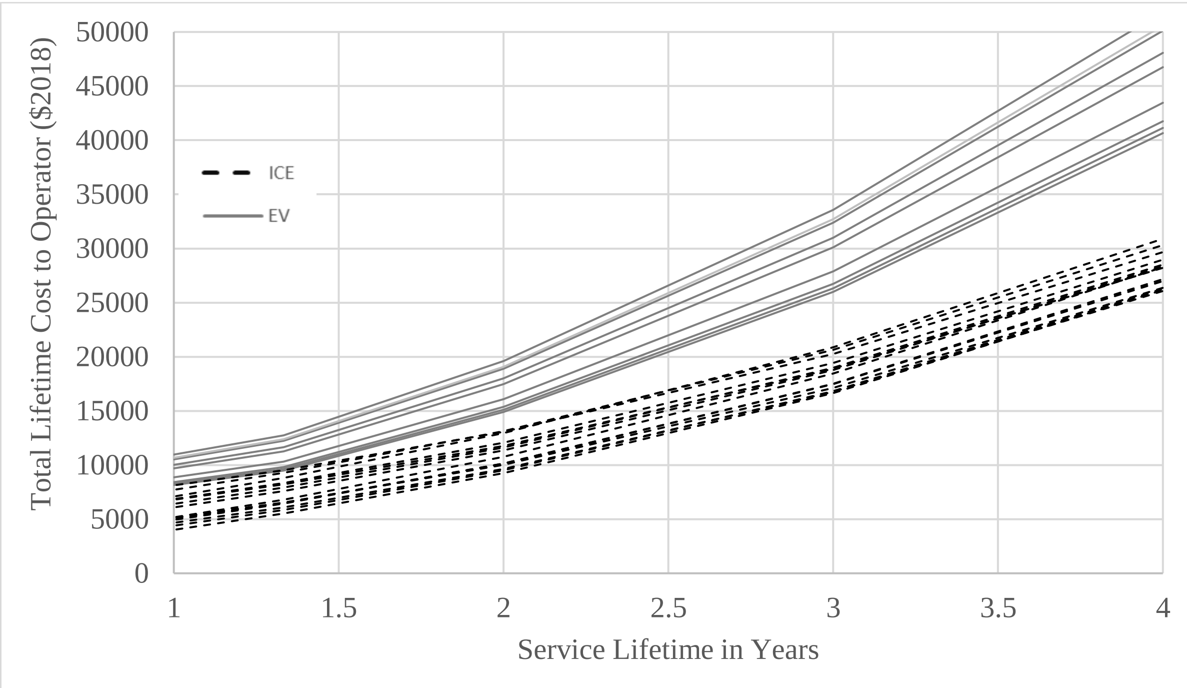

Figure 14: Total cost-to-rental-agency for each individual vehicle, graphed between 1 and 4 years of total service life. EVs are symbolized by solid lines; ICE vehicles by dashed lines.

For the “typical” case, the analysis assumed that rental companies held onto their cars for a total of 16-months, that vehicles averaged 70 miles per rental day (20,440 miles per year, or 27,250 miles in total), and that each vehicle was eligible for the federal $7,500 tax credit. The total service-life costs for each vehicle were graphed, separating vehicles by size classification and fuel type (EV/ICE). These costs are sorted and displayed in descending order in Figure 15.

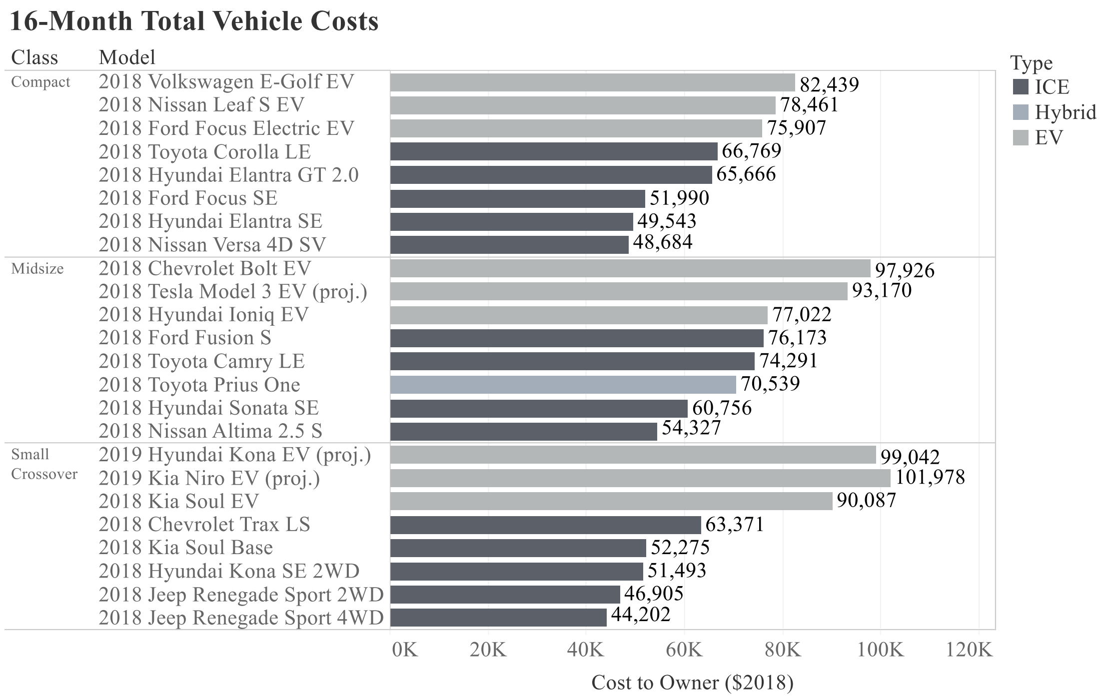

Figure 15: Projected standard (16 month/27,250 mile) service-life costs for 23 vehicles, including costs recouped from private-market resale. EVs symbolized by light gray bars; ICE vehicles by dark gray bars.

Under these assumptions, EVs consistently present a larger total service-life cost to the fleet operator, with average incremental costs of $2,800 for an EV compact; $2,873 for a midsize EV over a midsize ICE; $2,354 for a midsize EV over a midsize hybrid, and $5,673 for a small EV crossover, as presented in Table 9.

Table 9: EV incremental 16-month service life costs (SLCs) above commonly rented, equivalent-class internal combustion (ICE) vehicle average service life costs.

		EV Incremental Costs Above ICE ($2018)				
Vehicle Class	**Average ICE SLC ($2018)**	**EV 1**	**EV 2**	**EV 3**	**EV 4**	**Average EV Incremental Cost**
Compact	$7,066.32	$3,238.57	$2,741.30	$2,422.02	-	$2,800.63
Midsize	$8,298.35	$3,942.42	$1,329.45	$3,347.90	-	$2,873.26
Midsize Hybrid	$8,817.43	$3,423.34	$810.37	$2,828.82	-	$2,354.18
Small Crossover	$6,456.14	$5,924.10	$4,804.77	$6,291.08	-	$5,673.31

Greenhouse gas emissions were also accounted for in a similar manner. Purely internal-combustion vehicles consistently presented an increase in GHG emissions when compared to the average equivalent-class EV, with ICE vehicles emitting an average of 6.08 tonnes more CO_2e over a 16-month rental service life than EVs. These results are illustrated below, in Table 10. Figure 16 breaks emissions out by vehicle class.

Table 10: ICE incremental 16-month service life GHG emissions above equivalent-class electric vehicle emissions.

		ICE GHG Emissions Above EVs (tonnes)					
Vehicle Class	**Avg EV GHG (tonnes)**	**ICE 1**	**ICE 2**	**ICE 3**	**ICE 4**	**ICE 5**	**Average**
Compact	4.240	7.629	6.814	5.782	6.104	3.993	**6.826**
Midsize	3.549	7.505	6.474	6.796	9.266	-	**8.184**
Midsize Hybrid	3.549	2.639	-	-	-	-	**2.639**
Small Crossover	3.956	7.913	7.491	8.367	8.858	-	**6.689**

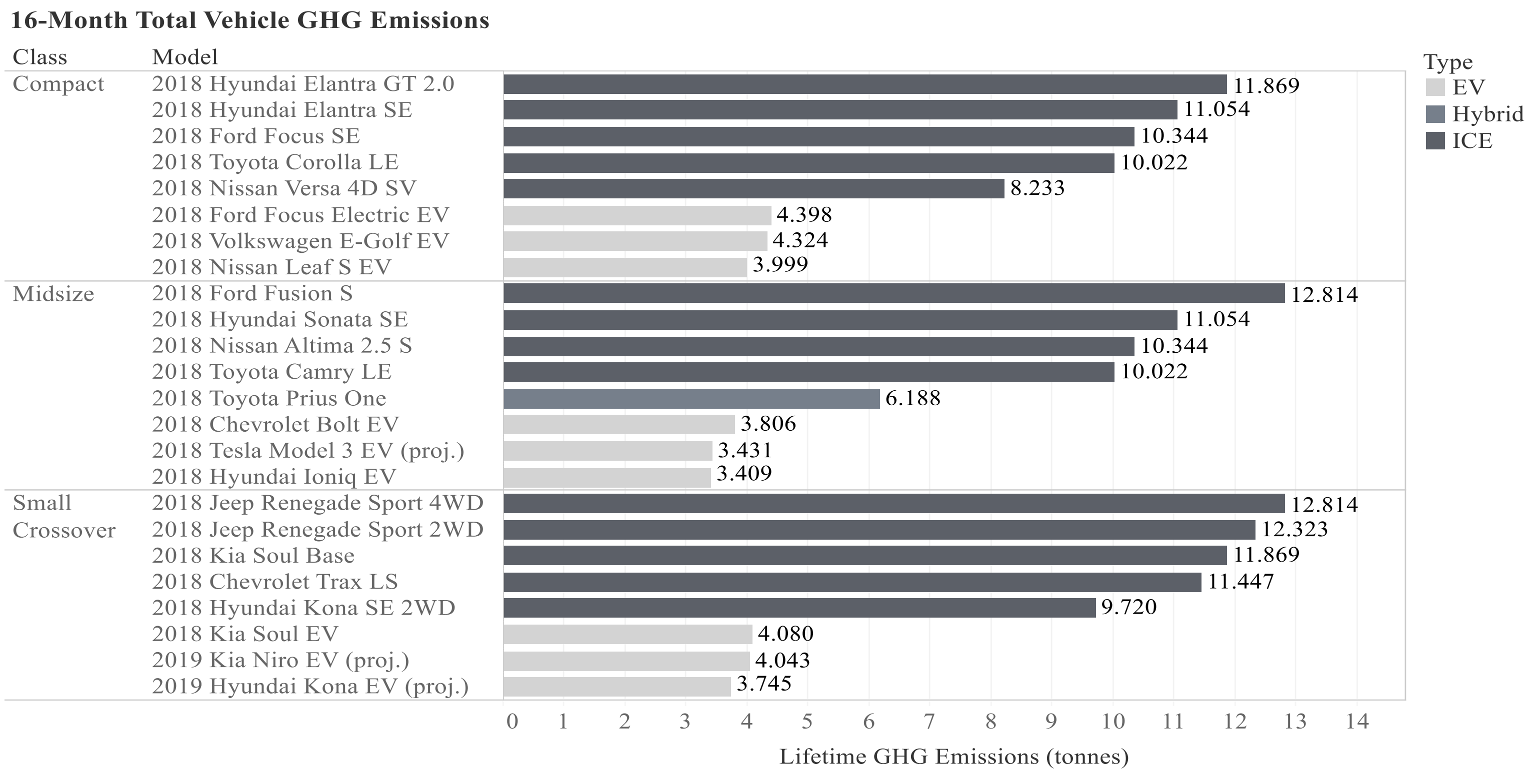

Figure 16: Estimated lifetime GHG emissions, expressed as metric tonnes CO_2e, for each vehicle examined. EVs symbolized in light gray, hybrids in medium, and internal-combustion in dark gray.

Determining EVSE Infrastructure Adequacy

The summarized average "pain" results from fifteen PEVI runs (5 per vehicle mix for three iterations in total) under the current number of operational chargers are shown below, in Table 11 and

Table 12. In the context of the model, "pain" can be thought of as an abstracted representation of the total inconvenience a given driver experiences. Higher values of pain reflect both a longer delay time and the additional distance a driver must travel to find another charger. Each iteration is based on the same 305-driver itinerary and the same "seed" number unique to each run, which constrains the stochasticity of the model. This limits the number of variables, allowing the results of manipulating single individual factors to be expressed.

Table 11:Average total number of inconvenience occurrences (how many individual times in a 24-hour period a driver was delayed within a TAZ) by TAZ and vehicle mix, across 5 PEVI trials under currently existing conditions, or benchmark scenario. (n=305).

"Benchmark" Scenario: Total Delay Occurrences			
Traffic Analysis Zone	**Short Range Mix**	**Short + Long Mix**	**Long Range Mix**
1: Hāʻena-Kīlauea	19.8	20.2	19.6
2: Princeville	8.8	8	7
3: Anahola	9.4	5	4.8
4: Kapaʻa	27	22.4	19
5: Līhuʻe	18.6	13.4	9.6
6: Kōloa	13.4	11.6	11.8
7: ʻEleʻele	2	2.6	2.2
8: Hanapēpē	9.6	8.6	7.6
9: Waimea	4.25	5.5	1
TOTAL	**112.85**	**97.3**	**82.6**
Percentage of Delayed Trips	**11.29%**	**10.10%**	**8.79%**

Table 12: Average total inconvenience magnitude by TAZ and vehicle mix, across 5 PEVI trials under currently existing conditions, or benchmark scenario. (n=305). Magnitude is expressed as an abstracted representation of total delay, consisting of a combination of time delay and additional distance traveled.

"Benchmark" Scenario: Total Delay Magnitudes			
Traffic Analysis Zone	**Short Range Mix**	**Short + Long Mix**	**Long Range Mix**
1: Hāʻena-Kīlauea	93.85	82.52	86.51
2: Princeville	41.00	36.82	28.74
3: Anahola	27.79	17.25	11.18
4: Kapaʻa	55.42	41.38	47.48
5: Līhuʻe	7.08	7.29	3.02
6: Kōloa	19.06	15.74	17.27
7: ʻEleʻele	6.00	6.60	4.50
8: Hanapēpē	36.50	36.27	32.04
9: Waimea	1.12	2.67	0.00
TOTAL	**287.82**	**246.57**	**230.73**

Overall, the “long” rental vehicle mix displayed the smallest number of inconvenience occurrences and the smallest delay magnitudes.

Table 13 illustrates the average magnitude of each single inconvenience for each TAZ and vehicle mix using the currently functional infrastructure.

Table 13: Average individual driver inconvenience magnitude for the currently functional infrastructure, by TAZ and vehicle mix, across 5 PEVI trials (n=305).

“Benchmark” Scenario: Average Magnitude of Single Inconvenience			
Traffic Analysis Zone	**Short Range Mix**	**Short + Long Mix**	**Long Range Mix**
1: Hāʻena-Kīlauea	4.74	4.09	4.41
2: Princeville	4.66	4.60	4.11
3: Anahola	2.96	3.45	2.33
4: Kapaʻa	2.05	1.85	2.50
5: Līhuʻe	0.38	0.54	0.31
6: Kōloa	1.42	1.36	1.46
7: ʻEleʻele	3.00	2.54	2.05
8: Hanapēpē	3.80	4.22	4.22
9: Waimea	4.74	4.09	0.00
AVERAGE	**2.88**	**2.83**	**2.38**

To help make determinations for locations where new Level 2 and DCFC equipment should best be sited to support a near-term, 30-vehicle trial program, a vehicle fleet composed entirely of long-range EVs was selected to minimize overall driver delay

The charger makeup in each EVSE scenario presents a different ratio of drivers to chargers. Smaller ratios are desirable, as they represent lower levels of competition for charging space and time. Due to Level 2 and DC Fast chargers supporting EVs in fundamentally different ways, each charger power is given its own ratio. These are presented below as Table 14.

Table 14: Driver-to-charger ratios in each of the three analyzed EVSE scenarios and under the currently existing scenario, "base case". The number of drivers (n) in each of the analyzed scenarios is 305 (275 residents + a 30-vehicle pilot program), while in the base case, only the 275 existing drivers are used.

Driver-to-Charger Ratios in each EVSE Scenario				
Drivers per Charger	**Benchmark (n=275)**	**Repair Existing Only (n=305)**	**Low DCFC (n=305)**	**High DCFC (n=305)**
# Drivers/L2 Station	17.2	9.5	11.7	16.9
# Drivers /DCFC	-	305	101.7	43.6

The average number of delays, total average inconvenience magnitudes, and individual inconvenience intensities across the 5 PEVI iterations for each scenario are shown below in Tables 15-17.

Table 15: Average total number of inconvenience occurrences (how many individual times in a 24-hour period a driver was delayed within a TAZ) by TAZ and infrastructure scenario, across 5 PEVI trials (n=305).

Total Delay Occurrences across 3 EVSE Scenarios			
Traffic Analysis Zone	**Benchmark**	**Low DCFC** (+3 DCFC, +8 L2)	**High DCFC** (+7 DCFC)
1: Hā‘ena-Kīlauea	14.8	3.6	1.8
2: Princeville	12.6	8.4	3
3: Anahola	3.6	1.4	0.4
4: Kapa‘a	9.2	8.8	3
5: Līhu‘e	6.2	3.4	7.6
6: Kōloa	3.4	9	2.4
7: ‘Ele‘ele	2.4	2	1
8: Hanapēpē	8.8	2	2.4
9: Waimea	0.2	0.2	0.2

Table 16: Average total inconvenience magnitude by TAZ and infrastructure buildout scenario, across 5 PEVI trials (n=305).

Total Inconvenience Magnitudes across 3 EVSE Scenarios			
Traffic Analysis Zone	**Benchmark**	**Low DCFC** (+3 DCFC, +8 L2)	**High DCFC** (+7 DCFC)
1: Hāʻena-Kīlauea	67.92	5.56	1.03
2: Princeville	16.77	15.36	1.65
3: Anahola	9.77	0.45	0.60
4: Kapaʻa	7.30	7.66	0.83
5: Līhuʻe	4.29	0.45	0.15
6: Kōloa	0.35	14.29	0.04
7: ʻEleʻele	5.80	6.00	0.00
8: Hanapēpē	40.80	0.39	1.10
9: Waimea	0.00	0.00	0.00

Table 17: Average individual inconvenience magnitude, by TAZ and infrastructure buildout scenario, across 5 PEVI trials (n=305).

Average Magnitude of Individual Inconvenience			
Traffic Analysis Zone	**Benchmark**	**Low DCFC** (+3 DCFC, +8 L2)	**High DCFC** (+7 DCFC)
1: Hāʻena-Kīlauea	4.59	1.54	0.57
2: Princeville	1.33	1.83	0.55
3: Anahola	2.71	0.32	1.50
4: Kapaʻa	0.79	0.87	0.28
5: Līhuʻe	0.69	0.13	0.02
6: Kōloa	0.10	1.59	0.02
7: ʻEleʻele	2.42	3.00	0.00
8: Hanapēpē	4.64	0.20	0.46
9: Waimea	0.00	0.00	0.00

DISCUSSION

Three components of EV adoption were examined in preceding sections: the ability of current infrastructure to support demand from resident and visitor electric vehicles, the economics and financial justifications for rental agencies to adopt EVs over conventional ICE vehicles, and the existing policy structures that encourage and stymie further electrification efforts.

Determining EVSE Infrastructure Adequacy

At present, there is a high level of dissatisfaction with the current EV infrastructure in the Hawaiian Islands. This has been specifically measured via survey by the Anthology Research Group (2017) on O‘ahu, and echoed by Kaua‘i visitor comments on the Turo car-sharing site. This finding also appears to be consistent with the results from the PEVI model analysis of the EV infrastructure on Kaua‘i.

Examining the results from PEVI under the “currently functional chargers” scenarios, key differences can be seen between each of the unique vehicle mixes. In the “currently functional chargers” scenario, as in the others, there are two groups of drivers, interacting both with themselves and the charging infrastructure. These are classified into “residents” and “visitors”. The key difference between these populations is that residents are assumed have access to home charging and follow a specific itinerary pattern. Given the low availability of reliable chargers at resorts and other rental lodging sites, visitors are assumed to not have access to home charging.

Due to their smaller batteries, shorter-range EVs require more frequent charging, which increases the likelihood of drivers encountering an unavailable charger, or requiring one where none are available. Drivers in the short-range EV scenario experienced a 30% increase in mean inconvenience, and a 2.5-point increase in the percentage of trips experiencing delays over the figures seen in the long-range EV scenario. Long-range EVs require more charging time, but their larger batteries allow them to take advantage of a wider geographic range of chargers enroute to their destination. Overall, the long-range EVs display the least amount of delay occurrences (1.3% lower than the mixed-range scenario) and smallest mean delay magnitude (16% lower than the mixed-range scenario), considering the currently functional chargers. This finding is supported by conclusions from the National Renewable Energy Laboratory (2017), which found that long-range (~250 mile) BEVs required far fewer public charging ports than lower-range vehicles in a national assessment of EV infrastructure. Under the long-range EV mix, three TAZs exhibit disproportionately high delays: Hāʻena-Kīlauea (TAZ 1), Hanapēpē (TAZ 8), and Princeville (TAZ 2), all of which delay drivers for an average pain magnitude more than 40% higher than the 24-hour mean. Līhuʻe (TAZ 5) and Waimea (TAZ 9) are the lowest, with delays in TAZ 5 87% below mean, and no measurable delay in TAZ 9.

Next, examining the results from the three near-term infrastructure buildout scenarios illustrates the importance of thorough DC Fast Charger geographic coverage. Three TAZs, Hāʻena-Kīlauea (TAZ 1), Princeville (TAZ 2) and Hanapēpē (TAZ 8), exhibited high delays under the “current” scenario. The Hāʻena-Kīlauea and Princeville TAZs are both situated at the extreme northwestern terminus of the arterial highway, while the Hanapēpē TAZ is adjacent to its extreme southwestern end. Under the Low DCFC scenario, installing a single DC Fast Charger in each of the three high-delay TAZs (1, 2, and 8) nearly eliminated delays within those zones, but had negligible impact on delays in neighboring TAZs. Implementing seven functional DC Fast chargers around the island dramatically reduced delays for most TAZs, but saw an increase in delays within TAZs not selected for DCFC installation. These delays were particularly noticeable in the heavily urbanized core of Līhuʻe, which has a high concentration of Level 2 chargers but no DC Fast Chargers. This heavy-DCFC scenario did not involve repairs for the existing Level 2 infrastructure, so several crucial Level 2 chargers in Līhuʻe remained offline. Increasing the number of DC Fast Chargers allowed vehicles to travel to the further reaches of the island’s road network without being stranded. Paradoxically, this allowed more vehicles to complete their trips to the extremes of the road network and return to their home bases. Given the simple road network, all traffic passing between the Kōloa region on the south shore and Kapaʻa on the east side must pass through Līhuʻe. In the context of the model, this meant more competition for the limited number of slower Level 2 chargers in Līhuʻe, leading to a marked increase in delays within that TAZ. This suggests that though a heavy implementation of DC Fast chargers is highly desirable, DCFCs work best in close conjunction with Level 2 infrastructure, which can be sited to take advantage of drivers' natural residence time at locations such as shopping malls, state parks, and other attractions. This conclusion supports previous findings from Allen (2016) and NREL (2018), which noted that while DCFC installations can function as both vital to bolstering a charging network's overall geographic coverage and corridor-travel demand, the ability of Level 2 chargers to provide relatively inexpensive, reliable coverage within communities is critical to meeting the requirements of BEV charging.

Compliant charger siting opportunities

Seeing heavy delays in the Hāʻena, Hanapēpē, and Princeville traffic analysis zones is not unexpected. Hāʻena and Princeville are heavily trafficked, with many of the installed chargers in Princeville nonoperational or not publicly accessible. Both Hāʻena and Hanapēpē lack chargers altogether. Within these communities, there are several potential options for DC Fast Charger installation to bolster both coverage and site compliance with Act 89, which mandated sites with more than 100 spaces in a parking lot to install EVSE infrastructure. In the Princeville TAZ, the newly constructed Anaina Hou community park represents a popular location immediately adjacent to the Kūhiō Highway arterial, and would be able to easily serve EVs traveling toward Princeville and the rural Hāʻena coast, though it does not require chargers under Act 89. Within the Hāʻena TAZ, the Ching Young Village and Hanalei Commercial shopping centers both appear to be logistically well-suited for chargers, as the sites are located immediately off the Kūhiō Highway, represent an opportunity to improve visitor-business engagement, and appear to require them under Act 89. However, there is a flood hazard present at both sites due to a nearby river and close proximity to the coast, requiring additional preparations and permitting considerations. An alternative or supplemental charger may be appropriate at the Hāʻena State Park lot at the end of the Kūhiō Highway. However, electrical infrastructure limitations may make this site economically unfeasible. Within the Hanapēpē TAZ, there are few obvious opportunities for convenient charger siting. The town of Hanapēpē would logistically make the most sense within its small commercial district, but the town's compact parking lots may prove a hindrance if businesses do not wish to designate a specific stall for EVs only. Implementing chargers in the immediately-adjacent ʻEleʻele Shopping Center may be a simpler alternative, as it would bring the parcel into Act 89 compliance and its commercial diversity appears to be make it an attractive location for Level 2 charging.

Vehicle Procurement, Operation, and Resale

For the baseline case of a 16-month service lifetime at 70 daily miles, the examined EVs consistently had higher total service-life costs than their commonly-rented ICE counterparts, even after factoring in the full $7,500 federal tax credit on each EV vehicle. Passenger cars displayed service-life costs 28%-34% higher than those of conventional vehicles, while small crossovers more than doubled the overall service-life cost at 111%. The incremental cost increases with vehicle size, with compact cars displaying the lowest additional cost and small crossovers displaying the highest. Much of this may be able to be attributed to the rapid projected depreciation of electric vehicles: in a market where the average value retention is 35.1% after five years, Kelly Blue Book expects the Chevrolet Bolt to retain a best-among-EVs 15.5% of its MSRP after the same timeframe (Gorzelany, 2018). Despite the higher MSRP of EVs, after two years, projected depreciation sharply reduces their resale values to roughly that of their less-expensive ICE counterparts, decreasing the percentage of the sale value recouped by private sales.

In the base case, using a 16-month service lifetime and assuming 20,400 miles per year (27,250 over the vehicle life), EVs were consistently more expensive for fleet owners to operate than their internal-combustion counterparts, though EVs occasionally reached parity in some cases, such as a highly abbreviated 12-month service life. It is important to note that neither EVs nor gasoline vehicles include fuel/charging costs. Rental contracts typically require the renter to either return the vehicle fully fueled or pay a charge for the fleet owner to refuel; this analysis adhered to the assumption that fuel costs are not borne by the operator. In the midsize segment, the Hyundai Ioniq EV is only slightly more expensive to operate than either the Toyota Camry ($341 more over an equal vehicle service lifetime) or the Ford Fusion ($106 more). The Ford Focus EV is relatively close in total cost to the Corolla LE, with a $1,140 premium over the internal combustion vehicle over an equal 16-month service lifetime. However, each of these models represents a moderate-range EV, with the Leaf advertising the longest EPA-rated range in this segment at 151 miles. Each of the vehicles offering more than 200 miles on a single charge costs significantly more to operate than the internal combustion vehicles in the same vehicle class. Portions of this cost can be recouped by simply pricing EV rentals higher than an equivalent-class internal combustion vehicle; Figure 17 illustrates how that amount changes for each vehicle as its service lifetime increases.

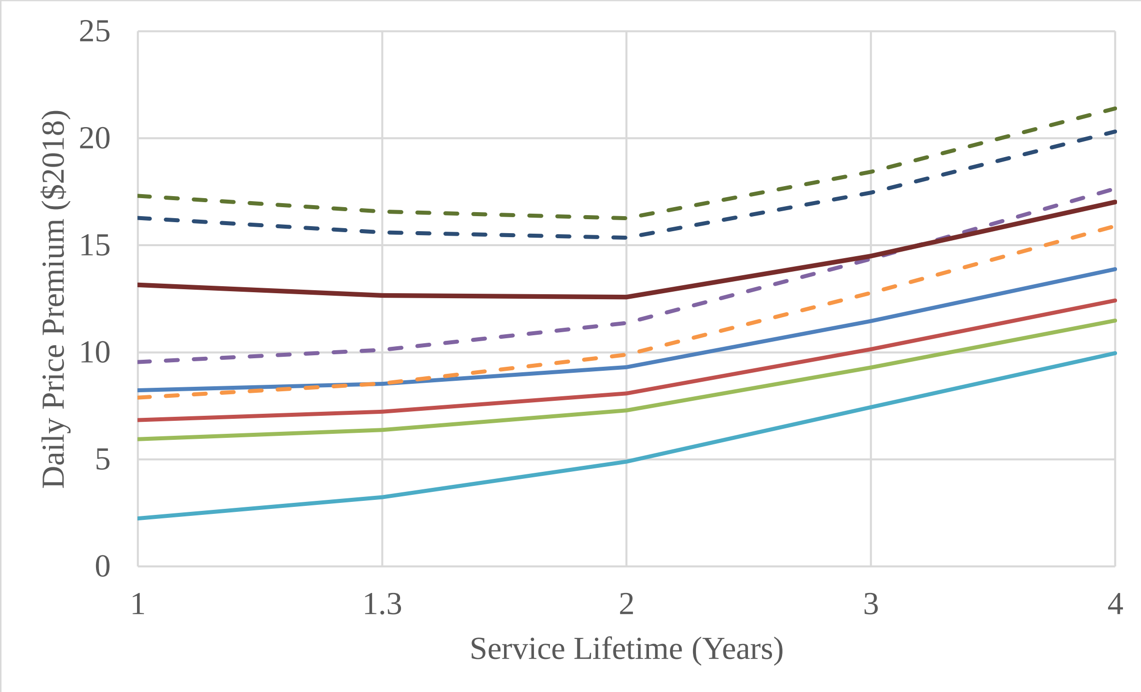

Figure 17: Required daily rental price premium to cover the incremental cost of purchasing and operating an EV over an average internal-combustion rental car, assuming a utilization rate of 80% (292 days). Long-range EVs are symbolized by a dashed line.

The longer an EV rental is in service, the more it is subject to the accelerated depreciation that has characterized used EV sales over the past 7 years. The increase in required price premiums seen in EVs at the 2-year mark is due to this depreciation. The data used to model EV resale values reflects a dramatic decrease in resale value starting in year 2 and continuing in years 3 and 4 (Kelly Blue Book, 2018). Examining data for internal combustion vehicles shows that the vehicles examined in this analysis depreciate at a much slower rate, thus holding their resale value much better. However, it is possible to mitigate this if a fleet operator knows how long they plan to operate a given BEV for.

At a 1-year service lifetime, the most expensive EV requires an $18-per-day premium over a similar ICE vehicle in its class (subcompact SUV) to achieve cost parity to the operator, assuming an 80% utilization rate (292 days). This is equivalent to a roughly 35% increase in price. Over a 4-year lifetime, the same vehicle's breakeven price premium increases only slightly, to $22 per day. However, this assumes that the vehicle is able to consistently be rented for 292 days per year, and that the higher rate is charged from the very beginning of operation. Smaller EV price premiums make electric vehicles more attractive to consumers, but providing additional external benefits with the rental (such as free parking, coupons to local businesses, etc.) may allow rental companies to slightly raise the price of electric vehicles to make a profit. Overall, it appears that adhering to a service life between 16 and 24 months would strike a balance between keeping rental premiums mild, maximizing fuel savings, and introducing used EVs to the local vehicle market at a reasonable price. Additionally, keeping the service life to the previously estimated 16-months limits the necessary price premium to approximately $10. Research from the Ulupono Initiative indicates that at this price point, there is strong interest in EV rentals: more than 80% of the visitors interested in renting an EV responded that they would be willing to pay an additional $10 per day to rent an EV (Ulupono Initiative, 2019).

An additional consideration is the ability of a state- or local-level rebate to improve the attractiveness of electric vehicles. Rebates programs in other states range from \$1000-\$5000 and are offered in the form of cash rebates and/or tax credits; some utilities offer between \$50-\$1000. Currently, EV buyers in Hawai‘i are only able to access the \$7500 federal tax credit on electric vehicles. Additional rebates have been available in the past through KIUC, but only on specific models. Figure 21 illustrates the effect on total cost-to-operator as time-of-purchase rebates increase.

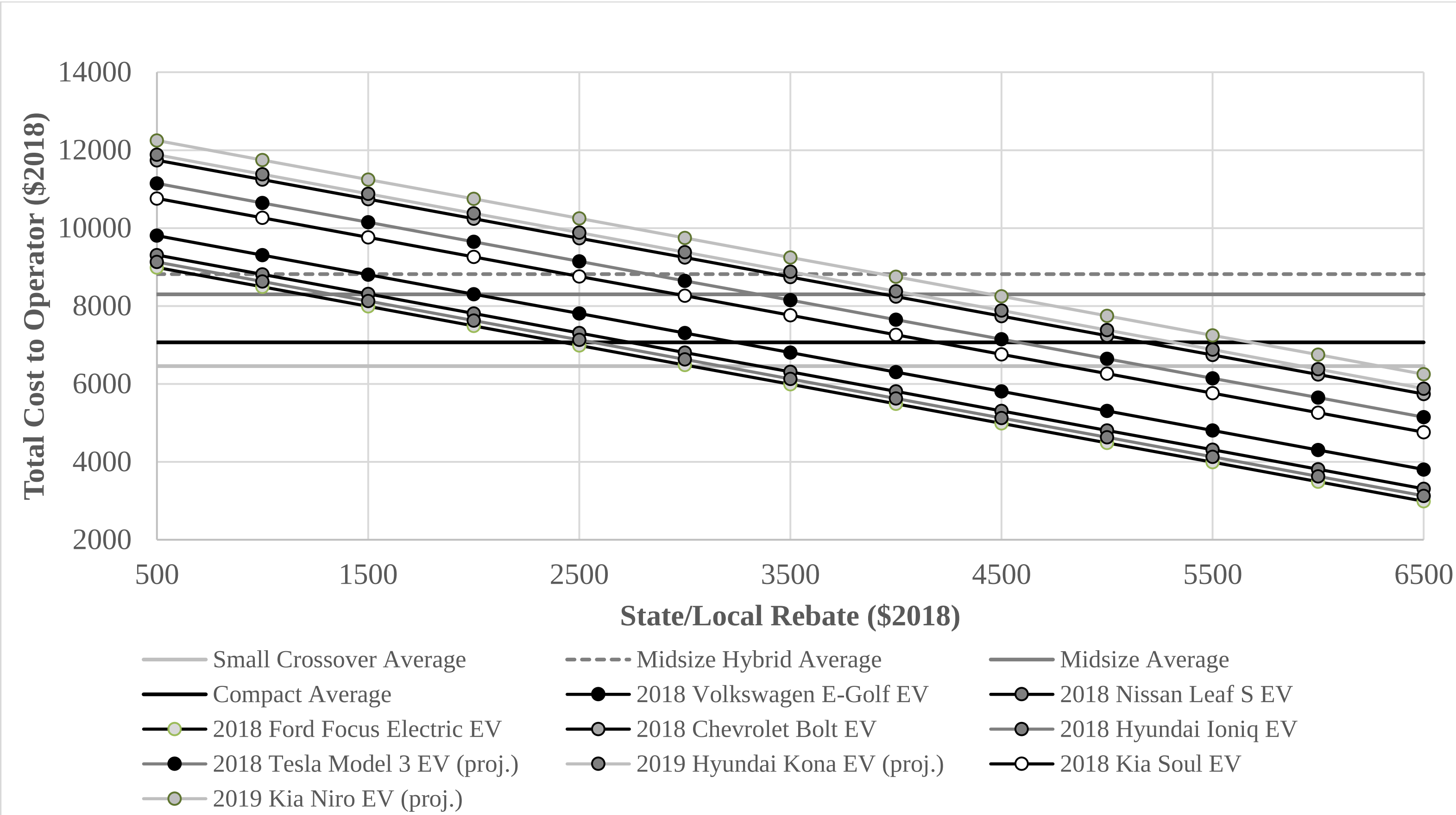

Figure 18: Effect of increasing local- and/or utility-level rebates on the total overall cost to operator for a 16-month service lifetime. Averages are for ICE vehicles.

The average internal combustion cost-to-operator for each class was calculated and used as the point of reference, and was compared to the EVs in their respective classes. Each vehicle class reaches cost parity at a different level of rebate: compacts reach parity between $2,500 to $3,500 in additional rebates; midsize between $1,500 and $4,000; and small crossovers between $2,500 and $3,500.

The state of Hawai‘i currently does not price carbon emissions or offer financial incentives for vehicle electrification, as California does. This moderates the economic attractiveness of the greenhouse gas savings that EVs offer. However, the vehicles do provide the potential for significant GHG savings. For example, the average midsize EV drawing power from the Kaua‘i grid produces 69% fewer GHG emissions over its lifetime than a comparably-sized ICE vehicle in the same class. Compact EVs using the Kaua‘i power mix produce on average 60% fewer GHG emission than a comparably-sized ICE vehicle. In August 2018, midsize sedans and compact cars made up 46% of the 330 vehicles for sale on the island through the Hertz rental agency. Assuming this ratio is representative of the overall fleet composition, there is high potential to significantly reduce fleet GHG emissions by replacing ICE vehicles with EVs. These two EV market segments are already well-developed, with a multitude of electrified options already available.

Overall, the lower purchase price, smaller batteries, and wider selection of compact and midsize-class EVs appears to better suit these classes of rental car to electrification. Vehicles in these categories typically have moderate prices, high fuel efficiency, and quick-charging capabilities: factors that give these models the potential to easily replace ICE vehicles within a fleet. The total cost-to-operator for EVs in these segments, though still higher than ICE vehicles, is extremely close. The cost difference may be able to be bridged through near-term policy and structural changes at the utility and state levels. However, as manufacturers including Tesla, Nissan, and Chevrolet approach the 200,000-vehicle mark that would trigger the beginning of the phase-out of their share of the tax credit, this gap will begin to grow unless the tax credit is extended.

Policy Recommendations

Transitioning the entire rental car fleet to run on renewable power by 2045 will require navigation of many of the roadblocks and obstacles mentioned in the Orlando, New York, and Okinawa case studies. Developing a rental EV program in Kauaʻi County is further complicated by a lack of state-level financial incentives, high utility demand charges, and frequent station outages. However, growing consumer interest in electric vehicles amidst a rapidly diversifying marketplace suggests that a well-implemented EV rental program may have benefits far beyond sating consumer curiosity and meeting Hawaiʻi's ambitious 2045 goals. The Drive Electric Orlando program appeared to improve renters' opinions of electric vehicles, increasing the percentage of participants who were either "very likely" or "likely" to purchase/lease an electric vehicle from just over 50% to nearly 70% (Prochazka, 2015). Gradually increasing the number of EVs on Kaua‘i County’s roads would slowly increase demand for charging stations, making installation more appealing to potential site hosts and improving accessibility for the entire island. A rental EV program would be able to feed reasonably-priced used vehicles into the local market, which would further increase the market presence of EVs. To achieve this, there are certain overarching program-, county-, and state-level policies that, while not strictly necessary, can help to catalyze the successful implementation of such a program.

EV Rental Program Development

As previously discussed, there is evidence of growing interest in electric vehicle rentals. Over half (56%) of 600 visitors surveyed at Honolulu’s Daniel K. Inouye International airport stated that they “probably” would have rented an EV if one was available, with strong interest even with rentals priced at $10 more per day. An EV rental program building upon the lessons learned from previous iterations around the world has high potential to both move Kaua‘i toward achieving its ground transportation decarbonization goals and set a strong example for the rest of the state to follow.

Structuring a potential program.

A comprehensive program will provide methods of expanding and improving the utility of the existing charging infrastructure; offer benefits to visitors beyond that of simply driving electric; improve charger-associated local business traffic; and showcase

Kauaʻi as a proactive county intent on rapidly making its roads much more hospitable to clean-fuel vehicles. Through creative structuring and the leveraging of public and private partnerships, such a program has the potential to benefit all of its stakeholders, offering an attractive rental prospect to tourists; a competitive alternative to ICE vehicles for rental companies; a source of well-maintained, inexpensive vehicles for Kauaʻi residents; and a step toward energy independence for the Kauaʻi County government.

Under the shortest, 12-month scenario, most EVs appeared to never reach cost parity with internal combustion vehicles. This means that even at an abbreviated service lifetime, when pricing EVs at the same rental rate as ICE vehicles, there currently does not appear to be a financial incentive for rental companies to incorporate EVs into their rental fleets. As previously discussed, there are several avenues by which a rental company can make up this difference. One method is to set EV rental rates to cover the entire amount of the difference in cost between the EV and an equivalent ICE vehicle, optionally collaborating with external partners to offer EV-exclusive benefits to add value and increase the appeal of the added premium. An additional option might be to partner with sites that are interested in installing charging stations, sharing in both the installation costs and the revenue from their usage.

Developing working relationships.

Stakeholder partnerships are integral in developing a cohesive, functional EV rental ecosystem. Drive Electric Orlando's model relies heavily on the appeal added by free charging at area hotels, preferred parking at theme parks, and other attractive benefits. Kaua‘i County, as a major tourism destination, has a wide range of opportunities that could be pursued. Offering EV drivers small discounts at restaurants; preferred parking at the island’s popular commercial destinations; and free low-cost upgrades during guided outdoor recreation are all potential avenues for local businesses to both showcase their support for EV adoption and to potentially attract new customers. For businesses interested in hosting charging sites, an EV rental program could provide an influx of customers waiting for their vehicles to charge. These customers may be likely to return multiple times due to the presence of a reliable, easily accessible charging station.

Resorts and hotels will be vital stakeholders, as their facilities host a significant portion of the lodging accommodations on the island and will inevitably serve as EV congregation points in the future as Kaua‘i moves toward fully electrifying its vehicles. Installing charging stations on resort and hotel properties has the potential to offer a unique and desirable amenity to both visitors and tourists. Offering additional discounts and/or other incentives (such as preferred parking) to drivers of EVs may further position electric vehicles as a desirable option even for visitors not specifically interested in electrified transportation (Prochazka, 2015).

Local and state governments additionally play integral roles in organizing, developing, and incentivizing electric vehicle charging infrastructure and education in locales around the nation. California’s prolific state-level funding opportunities for infrastructure buildout and awareness development are extremely popular measures. A recent funding release offering to fund large portions of DC Fast Chargers and Level 2 chargers in the Sacramento metropolitan area saw rapid adoption, with more than 70% of DC Fast Charger funds reserved within the first two weeks of the program's availability (CALeVIP, 2019). The San Diego Association of Governments developed an EV Readiness "blueprint" aimed at bringing stakeholders, planners, and residents together to map out specific timeframes and actions that would accelerate both the adoption of EVs and the buildout of EV infrastructure in the San Diego region (SANDAG, 2014). Kaua'i County would strongly benefit from a similar document, with local government serving as an organizer to bring community stakeholders, vehicle manufacturers, and technical experts together to develop a set of EV implementation goals, commitments, and actions.

Charging Infrastructure and Range Anxiety.

One of the most important steps in a rental program is procuring and installing DC Fast charging stations. Though the island has a number of functional Level 2 stations, due to their low charging speed they are best used at locations where residents have a long residence time, rather than primary on-the-go charging options- particularly when considering the increasing size of EV batteries. DC Fast chargers can act to reduce range anxiety, meet a high level of demand, and have the ability to approximate the conventional "pit stop" method that gasoline vehicle drivers are accustomed to. Though KIUC does implement demand charges on heavy consumers of electricity, there are several methods of working around this. The first is to actively throttle a conventional DC Fast charger down from 50kW to approximately 25kW as appropriate. This is something that can be achieved through the onboard software loaded onto the charger itself (ChargePoint, 2019). Though this will extend charging time, a throttled DC Fast charger would still have the ability to replenish roughly 90 miles of range in an hour, which is 3.75 times faster than a typical 6.6kW Level 2 charger. A throttled DC fast charger, however, would still require the high upfront cost of installation. Installation itself can range from as low as $4,000 up to $50,000 per charger (U.S. Department of Energy, 2015), with the price of the charger an additional expense. Another option is utilizing a battery-storage charger, which charges off the grid at the common 6.6kW Level 2 rate, but has the ability to discharge at a full 50kW for a limited number of fast charging sessions in between recharging the stationary battery. Additionally, some of these chargers are mobile, and can actively move from spot to spot to charge vehicles as necessary. Charger mobility allows for two ancillary benefits. First, since the charger is not passing high-voltage current directly from the grid, it is not subject to the same high installation costs (trenching, transformer installation) as a conventional DC Fast charger. Instead, it can charge its battery from a 240V outlet, which is commonly used as a connection point for household appliances (such as dryers) and thus can be installed by most electricians. Second, its mobility eliminates the need to designate a particular parking stall as “EV only”. Instead, visitors to a site can mark their location within a mobile phone app, which signals to the charger operator that someone is waiting to charge. The charger is moved to the appropriate location, allowing charging to take place anywhere within a parking lot. However, due to their design, mobile chargers may not be suitable for areas of extremely high demand, as once its battery is exhausted, mobile chargers can only pass current from the grid at the 6.6kW rate.

Equally important to supplying charging stations is ensuring that drivers always know where those charging stations are located. Online crowd-sourced maps, such as Plugshare, are an option that can easily be accessed from a renter’s smartphone and can reflect real-time charger occupancy and status. Additionally, paper maps displaying charger locations could be included with rental packets. Many EVs offer optional infotainment systems capable of navigating to nearby charging stations. Ensuring that all rental EVs are equipped with this option would provide an additional method of easily locating charging. Highly visible road signs should be installed on major thoroughfares to serve as visual aids to drivers seeking charging stations. Retailers and town centers provide a natural complement to charging stations. Drivers visiting these locations are highly likely to utilize charging stations if available, as they can leverage the time spent away from the vehicle (often patronizing businesses nearby) to charge. In addition to drawing in EV-driving customers, there is also an inherent advertising advantage from the increased visibility offered by installing charging stations, as the stations are prominently featured on EV in-car navigation and popular station locating websites such as Plugshare.com. Some brick-and-mortar retailers have begun partnering with charger and vehicle manufacturers to offer charging stations at their sites. As one example, Target plans to have sites in 20 states operational by the end of 2019; as another, Whole Foods has operational charging at nearly a quarter of its 479 locations (Target Corporation, 2018; Browne, 2018).

Education and Support.

Familiarizing drivers with the differences between driving an EV versus an ICE vehicle is a necessary step in the rental process, setting expectations and answering any upfront questions about the vehicles. As a visitor's first physical point of contact with the rental vehicle, rental agencies must have staff on hand able to familiarize EV renters with crucial information, including vehicle range expectations; charging procedures; and charging station locations. Drive Electric Orlando prioritized working with rental agencies to provide training and educational collateral to employees at locations where EVs would be available for rental. Encountering problems with travel agents who were unable to address common concerns among EV renters, Okinawa chose to propose a different solution to this problem: providing a 24/7 third-party support line for the program that drivers could call with questions or issues. Establishing a dedicated call center could overcome any potential problems with employee turnover at rental car agencies, as well as providing a direct point of contact for issues that arise outside of normal rental agency business hours.

Drivers unaccustomed to driving and charging an electric vehicle will need to be able to quickly identify the appropriate charging standard and speed for their vehicle. Adopting an intuitive set of charging symbols, such as the recently developed Chargeway language (Figure 19), would provide a graphical representation of the distinct charger types and speeds a vehicle can accept. Appropriate symbols could be included in a prominent place on every electric vehicle, and charging stations could be clearly labeled with this language's set of symbols to ease the task of matching a station's charging protocol with that of the vehicle. Additionally, to adhere to the traditional experience of returning a rental car, it may be advisable to alter the "bring it back full" policy typically enforced by rental car agencies. The process of refueling an EV is significantly more time-intensive and less convenient than refueling a gasoline-powered vehicle, and may cause unexpected issues with drivers who are not used to the time it takes to refuel an EV, such as not allocating enough time to both refuel the EV and drive to the airport in time to board a flight. Given electricity's lower fuel cost, implementing a "bring it back *mostly* full" policy (returning a vehicle with charge above 70% to 80%) may closer approximate the experience of returning a gas rental car, or even provide a small incentive to rent an EV over an ICE vehicle.

Figure 19: This image shows the proposed Chargeway design language, which codes according to color (charging standard) and number (charger power). (Chargeway, 2018)

<u>Charging Management Entity.</u>

Maui County was able to successfully launch their DC Fast charging network by creating a nonprofit group dedicated to the installation and maintenance of charging stations during the network's infancy. This group brought stakeholders together and formed working groups dedicated to develop plans to prepare the County for EVs in five primary areas of concern. These were: EV charging infrastructure, policy and legislation, the visitor industry, residents and local businesses, and outreach and education (Ku et al., 2013). Over the course of the group's life, it served as a valuable force that fostered awareness and support for EVs and EV infrastructure among residents, visitors, government entities, and utilities. Kaua'i County's infrastructure could benefit from a similar organization. Ideally, a nonprofit dedicated to improving EV penetration within the county would take on the responsibility of securing external funding for charger installation and maintenance, manage and reinvest any charger revenue into maintaining the charging network, and work with local agencies to bolster local awareness and alternative-fuel vehicle education. Such an agency would also be the face of advocacy for change, both at the local level and the state level.

Large-Scale Changes

Hawaiʻi has set two of the most ambitious decarbonization goals in the world, yet the state itself offers no incentive to purchase an electric vehicle over a conventionally powered one. This becomes even more crucial as manufacturers begin to meet the national sales cap of 200,000 vehicles eligible to receive the full $7,500 tax credit, as Tesla did in July 2018. All Tesla models delivered between January and May 2019 will only be eligible for 50% of the tax credit. Between June and December, that will decrease to 25% before expiring completely on December 31 (Lambert, 2018). As more manufacturers begin to reach the point where their tax credits sunset, state-level subsidies will become increasingly important in keeping EVs affordable in places they have not yet achieved adequate penetration.

Assigning a statewide price to carbon emissions will also play an important role in EV adoption within Hawaiʻi. Currently, the primary economic attractions for an EV over an ICE vehicle are the lower prices of fuel and maintenance. However, within

Hawai‘i, these factors alone are not enough to economically compensate for the higher upfront cost of an EV. This could be altered by assigning a monetary value to each tonne of avoided carbon emissions, as each ICE vehicle emits a significantly higher amount of GHGs than an equivalent-size EV, and issuing rebates based on the amount of abated GHGs.

KIUC’s implementation of a demand charge is common among electrical utilities of all sizes. However, Hawaiian Electric Industries waives the demand charge for EV charging, instead placing EV charging on its own time-of-use rate to improve the attractiveness of high-power charging. While KIUC acknowledges that electrified vehicles will eventually need to make up a large portion of the vehicle mix on the island, their internal timeline for mass acceptance of EVs puts widespread EV adoption on Kaua‘i after EVs achieve a higher penetration on the mainland (Tokioka 2018, pers. comm). If KIUC were to offer either a dedicated EV charging rate or selectively waive the demand charge for DC Fast chargers, it would make charging significantly more economically viable, potentially incentivizing potential site hosts to make the leap to installing high-power stations.

One final alteration that may improve EV adoption throughout the state may be joining the ZEV Coalition. This is a working group of nine states committed to improving EV penetration by mandating manufacturers to sell a certain number of EVs to residents of states within the coalition, based on their total sales within each state.

Manufacturers that are offering relatively inexpensive, long-range BEVs typically have no plans to bring these vehicles to Hawai‘i at launch, focusing their efforts on the “ZEV states” forming this coalition. Currently, Hawaiian consumers who desire one of these vehicles will need to special-order the car from a dealer, import one from the mainland, or wait for the manufacturer to begin sales on the islands. Joining the ZEV Coalition would provide Hawai‘i with the ability to collaborate with states on both coasts, increase the likelihood of the newest EVs being available at local dealers, and reaffirm the state’s commitment to clean transportation.

Study Limitations and Shortcomings

While the analysis presented here benefitted from access to considerable amounts of useful information, it suffered from data limitations in three main areas: predicted EV resale values, tourist travel patterns, and tourist VMT.

EV Resale Values

In the 7 years since the first modern mass-market EVs entered the market, battery capacities have soared while vehicle costs have largely stayed the same. An unusual aspect of the EV industry is the presence of a rapid technological progression typically not seen in the automotive world. Older vehicles are quickly made obsolete as the newer vehicles debut with more range, more space, and more power. Currently, most of the data available for vehicle depreciation is either for the nearly obsolete short-range EVs (Fiat

500e, Nissan Leaf, Ford Focus Electric) or for boutique, highly sought-after vehicles (Tesla models). As mass-market 200-mile EVs debuted in 2017, there is very little data that represents their likely rates of depreciation. The generalized linear model fitted to the resale values of the analyzed vehicles therefore may be weighted heavily toward the short-range vehicles, which tended to drop off sharply in value as their newer versions were released. This may result in artificially low resale value predictions for the newest generation of BEVs.

Tourist Travel Habits

Ideally, the PEVI model I used to estimate suitability of the charging network would be based on itinerary files generated from real driving data, gleaned from a combination of existing travel surveys, traffic studies, and other extant data. None of these data were publicly available for Kauaʻi County. The closest available approximation was to attempt to set up estimated probability values for locations where visitors were most likely to stay, as well as where they were most likely to visit. Mechanisms to better approximate real-life tourist decisions, such as visiting the south side of the island on one day and the north side of the island at a later time, were not built into the itinerary generation model due to time limitations and the complexity of reliably implementing such mechanisms. As such, tourist itineraries may not follow a logical pattern, which may contribute to an inflated estimation of daily VMT, which then is extrapolated to find annual VMT. Additionally, without ground-truthed tourism data, determining travel departure times was impossible with the available data. The tourist departure-time distribution was extremely generalized (essentially a flat distribution across 12 hours of the day), but it is highly probable that real traffic peaks do not correspond with the generalized model used in this analysis.

Next Steps

Future research would benefit hugely from grounding as many of the hypotheticals (e.g. miles driven, vehicles present on the island, most popular vehicles) in reality to the degree possible. Metrics such as visitor and resident average daily mileages driven, locations visited, departure times, and trip legs should be assessed by working with local data companies to interview visitors and conduct travel surveys. At a county level, opening dialogues with local businesses and the resort community to assess how many sites would be amenable to hosting charging stations would provide some context on where stations could realistically be located. Determining how much money the County is willing to spend annually on developing EVSE infrastructure will inform how many, and what type of, chargers can be installed each year. Talking with rental companies to determine how long rental vehicles are typically kept in service in general and/or how long an EV rental, in particular, would be kept in service will inform how much value a given EV will have at the end of its rental life. It will also be important to chart resale values for the newest crop of EVs with more than 200 miles to a full charge, and whether they depreciate at the same rate as older EVs with smaller batteries and shorter ranges. Additionally, finding a way to reconcile the County's goal of completely decarbonizing the island's ground transportation with KIUC's goal of providing reliable, clean power to the island's residents will be instrumental in moving toward a more amenable environment for high-powered charging stations.

CONCLUSIONS AND RECOMMENDATIONS

Kaua‘i County and the state of Hawai‘i have made a bold commitment to decarbonize their entire ground transportation system by 2045. As the electric grid moves toward its own decarbonization, this represents an incredible opportunity to power the entire island’s commute with locally produced, renewable energy. To meet the decarbonization goal, 3,000 EVs must be registered on Kaua‘i roads within the next 7 years. This is 10 times as many as currently exist.

The island’s charging infrastructure must be improved in order to support those EVs as well as the estimated 105,000 that will be present on the island by 2045. Installed stations must be future-proofed in order to accommodate future advances in EV battery capacity and technology. This undoubtedly means installing a significant number of grid-tied DC Fast charging stations on the main arterials, the Kūhiō and Kaumuali‘i Highways, as well as increasing the Level 2 station density within urban cores, particularly at many of the shopping malls, hotels, resorts, retail stores, and state parks where visitors and residents alike tend to spend time.

Even given their reduced maintenance costs, decreased greenhouse gas emissions, and ability to use clean power, EVs on Kaua‘i remain more expensive than their ICE counterparts at a 16-month service lifetime, which adheres to observed fleet turnover within the Hertz rental car company. This is due primarily to the higher upfront purchase cost of an EV, coupled with the precipitous depreciation associated with electric vehicles. Cost parity is close for the compact and midsize segments. Cost parity for compact and midsize EVs can be achieved through a state- or local-level incentive of as little as $3,000. Small ICE crossovers appear to depreciate much more slowly than compact and midsize ICE vehicles and present a larger gap to overcome to reach parity: approximately $6,500. It is possible that the newest generation of EVs will depreciate more slowly than their predecessors due to the longer range that post-2018 EVs typically exhibit, which will significantly alter the results of this analysis and may present a case for parity.

Implementing an organization specifically dedicated to EV charger maintenance and repair, advocacy, and public engagement could be valuable, as many of the managers of existing charger locations are reluctant to conduct repairs due to a perceived lack of demand. A similar effort on Maui resulted in the eventual buy-out of the charging infrastructure by Maui Electric, who now controls, maintains, and operates the entire charging network, bolstering reliability and placing the energy service under a familiar name and logo. Such a group could additionally provide visitors and residents with an easily accessible customer-service resource to help them navigate charging processes, troubleshoot vehicles, and get roadside assistance if they are stranded.

Though major advancements have been made in terms of electric powertrain efficiency, battery chemistry, and range, EVs still command a sizeable cost premium over internal-combustion vehicles, with estimates of natural parity occurring sometime between the mid-2020s and the early 2030s. To encourage resident and visitor adoption, that premium must be lessened, either by offering a state-level financial rebate or by offering countywide benefits to EV drivers that are worth the increased price. These incentives need not be permanent. As EVs reach cost parity, those incentives can be phased out, but they are vital in spurring early adoption. For rental agencies, this cost can be recouped by increasing the daily rental fee for an EV over that of a comparable internal-combustion rental. Additionally, offering additional auxiliary benefits (e.g. a coupon book good for discounts at local businesses) exclusive to EVs rented through the program may provide further incentive to switch away from a conventional vehicle.

An EV rental program on Kauaʻi will need to be made a reality at some point in the future. Rental EVs should initially be exclusively long-range to decrease the perception of range anxiety, particularly with the current lack of DC Fast chargers. More inexpensive, shorter-range vehicles should be introduced as charging station coverage improves. A successful program will require collaboration with a number of crucial stakeholders, for whom the rental program should represent a mutual benefit. Manufacturers that offer their BEVs as rental vehicles can benefit from increased exposure and familiarity, which Prochazka (2015) suggests may translate to an inherent marketing advantage over non-program EVs. Local businesses and lodging sites willing to offer EV discounts or act as charging hosts may benefit from increased business opportunities with drivers seeking those amenities, as seen in Chargepoint (2015). A rental program has the potential to catalyze the local EV resale market by providing a reliable source of well-maintained, inexpensive BEVs within Kauaʻi County. This would represent a significant improvement over needing to have desired vehicles imported from neighbor islands or the mainland.

When the program is designed, it will be important to make it as streamlined and familiar as possible. Licensing and implementing the Chargeway design language to simplify the identification of whether a charging plug is compatible with a given vehicle may prove intuitive enough to replicate the experience of selecting the correct grade of gasoline. Charging stations will need to be clearly marked and signed, with fines swiftly implemented if an internal combustion vehicle appropriates a spot designated for charging at a non-mobile station. Rental agents may need to be trained to give concise, intuitive instructions on how to maximize range and manage expectations for the EVs. Alternatively, diagrams may be posted within the vehicle itself to facilitate intuitive operation.

With careful consideration, appropriate planning, and immediate action, Kauaʻi county may be able to blaze a trail for the rest of the world to follow by cutting one of its major ties to imported petroleum in favor of transportation fueled by local, renewable power.

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APPENDIX A

Appendix A: Complete list of factors included in the EV- ICE vehicle cost comparison spreadsheet.

Table 1A: Complete list of factors included in the EV- ICE vehicle cost comparison spreadsheet.

Factor	**Notes**	**Source**
Vehicle Type	Example: EV Compact 5-Door	Manufacturer Website
MSRP	Does not include tax, does include delivery fees	Manufacturer Website
Price After Tax	Uses Hawai‘i State Excise Tax (4%)	Calculated
Federal Incentives	Typically $7,500; assumes all vehicles eligible for the tax credit	Federal legislation
Other Incentives	Unused by default; a place for state- or local-level incentives	-
MPG (combined)	Gasoline vehicles only	Fueleconomy.gov
Maximum Estimated Range	Either given by EPA (EV), or miles per gallon multiplied by fuel tank size (ICE).	EPA, Calculated
Max Charge Rate (kW)	EV only; notes how quickly cars can accept rate. Used to calculate charging times.	Manufacturer Website
Battery Size (kWh)	EV only.	Manufacturer Website
Tank Size (Gallons)	ICE only.	Manufacturer Website
Miles per kWh	EV only. Derived by dividing EPA-estimated maximum range by battery size.	Calculated
Service Lifetime	Set to 1.33 years by default	Derived from public rental car financial records

Factor	Notes	Source
Estimated Annual Maintenance Costs	Used to quantify avoided maintenance costs between EVs and ICE vehicles.	Mitropoulos et al. (2017)
Service Lifetime Maintenance Costs	Annual maintenance costs multiplied by service lifetime	Calculated
Estimated Resale Value	EVs used a single generalized equation due to a lack of reliable data; ICE vehicles used much more solid data from Edmunds.	Calculated using Edmunds True-Cost-to-Own data (ICE), modeled from Kelly Blue Book depreciation data (EVs)
Miles driven annually		Calculated
Lifetime mileage	Annual miles multiplied by service lifetime	Calculated
Initial Proportion of Renewable Energy	Used to help determine incremental increases in renewable energy on Kauaʻi grid	KIUC/PUC filings
GHG Emission Factors and Emission Rates for Mobile Sources (CO_2, CH_4, N_2O)	Used to determine GHG emissions from mobile sources and convert to CO_2 equivalance.	IPCC AR5