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Overview of the Electrification of Transportation in Hawaii

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ABSTRACT

This document is a summary of electric vehicle (EV) experiences in Hawaii. It is meant to be informative but does not present any new technical analysis except for the development of key lessons learned that could be applied in similar contexts.

The electrification of transportation is essential for Hawaii's energy goal. An electrification of transportation strategy complements other energy policy goals, increases clean energy impacts, and provides customer value. By the end of 2020, there were over 12,000 EVs registered in Hawaii (about 1 percent of all cars). That number is expected to grow, based on the results from recent surveys and studies in Hawaii. Surveys pointed out the need for more charging stations, especially in places where people do business or park for long periods of the day. Participation in controlled charging programs should have attractive incentives since a majority of EV owners would not be willing to interrupt their EV charging for demand response.

Various studies have confirmed the EV potential in Hawaii. For example, the JUMPSmart Maui demonstration project, a public-private partnership with Japan, helped to establish the EV charging station infrastructure in Maui and provided important information about charging behaviors. A critical backbone study commissioned by the utility recommended that 3,600 public chargers be installed by 2030 on the five islands, which confirms the need for infrastructure improvements expressed in earlier surveys.

The process that emerged in Hawaii can be an example to other locations, which could heed the lessons from Hawaii's EV experiences: The importance of an overarching energy goal/objective based on a shared vision; planning and pilot projects; a strategic plan (roadmap) leveraging on initial experiences; evaluation of the effectiveness/success of actions; fine-tuning as needed; close regulatory oversight and stakeholder participation.

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EXECUTIVE SUMMARY

This document is the result of a literature survey to understand the technical, economic, and regulatory impacts of electric vehicle (EV) integration in Hawaii. It is meant to be informative, but does not present any new technical analysis except for the development of key lessons learned that could be applied in similar contexts. The specific objectives of this report are:

1. Inform existing and future Sandia EV projects about the lessons learned in Hawaii – a location where EV has a significant presence, with a holistic energy policy framework; well-laid out plans; supportive government, laws and regulations; and active stakeholders.
2. Provide a possible model for EV plans in other islands and remote locations.
3. Develop a tool for Sandia to engage and start a conversation with possible collaborators

Even though there are a significant number of laws and initiatives in support of EVs in Hawaii, compared to progress in the electricity sector, the transition of transportation to cleaner technologies and fuels is lagging. By November 2020, there were over 12,000 EVs registered in Hawaii (about 1 percent of all cars). That number is expected to grow, based on the results from recent surveys and studies in Hawaii.

Results from an investment firm's survey in 2016 showed that Hawaii EV drivers were generally dissatisfied with the Hawaiian Islands' existing charging network. The most common criticism was limited access to charging stations throughout the state, which further validates that demand is outpacing supply. Survey results also showed that 71% of drivers preferred parking in structures with access to charging stations. Additionally, 73% stated that the availability of charging stations affected how likely they were to frequent establishments or businesses. Since 85% of EV drivers reported utilizing public charging stations, businesses without charging infrastructure nearby could be negatively impacted.

An online survey was commissioned by the utility (Hawaiian Electric Companies) in 2017 of residential customers from Oahu, Maui, and Hawaii. The main barriers mentioned for EV adoption were financial considerations, charging station availability, and driving range. Among EV owners, 85% primarily charge at home, with 58% owning a Level 2 Charger at home. The lack of charging stations and constantly occupied stations are the top reasons that discourage charging away from home. Similar to the 2016 survey, 78% were more likely to visit a business that has a charging station. The majority of EV owners (57%) were not willing to have their EV charging interrupted to support utility efforts to manage demand, which evidences the need to better inform EV users of the incentives available through controlled charging.

Various studies have confirmed the EV potential in Hawaii. For example, the JUMPSmart Maui demonstration project incorporating EVs, smart grid, and high penetrations of renewable energy in a public-private partnership with Japan. Energy data from EV owners was collected and evaluated then smart system controls were developed and installed. The utility managed EV charging to balance power demand with distributed photovoltaics (PV) and wind energy generation. The project helped to establish the EV charging station infrastructure in Maui. It also provided important information about the charging behavior of EV owners that will inform future operations and growth.

Hawaiian Electric Companies is a key EV stakeholder, and with guidance from the Public Utilities Commission (PUC), the utility is leveraging its experience and knowledge of the electric system to achieve an EV strategy that is integrated within the broader state energy context. The PUC approved three EV pilot rates in 2010, which gives Hawaiian Electric 10 years of experience with EV rates. In

2016 the PUC mandated Hawaiian Electric to create an Electrification of Transportation (EoT) strategy, followed by the creation of an Electrification of Transportation Department in 2017, and an extension to the EV pilot program to June 2023. Hawaiian Electric produced an EoT Roadmap in 2018, complying with a PUC order, with ten key initiatives that established the need to identify the critical charging infrastructure required to support the growth of EVs. The utility commissioned a Critical Backbone Study in 2019 which recommended that 3,600 public charging stations be installed by 2030 on the five islands in addition to the 47,000 private chargers in homes and workplaces. Thus, the study supports the expansion of the public charging network. Also in 2019, an EoT Workplan ordered by the PUC was published, with an 18-month timeline to implement the actions in the EoT Roadmap.

The EV process that emerged in Hawaii can be an example to other locations. The following guidelines are based on Hawaii's EV experience:

1. Start with an overarching energy goal/objective based on a vision built with support of a broad base of stakeholders.
2. Turn that objective into law and policy, with clear expectations and roles for key stakeholders.
3. Develop planning and pilot projects with close regulatory oversight and stakeholder participation.
4. Develop a strategic plan (roadmap) leveraging initial experiences.
5. Create more refined planning to further develop a roadmap.
6. Perform needed studies.
7. Implement the roadmap's actions.
8. Evaluate effectiveness/success of actions; fine-tune or make changes as needed.
9. Maintain close regulatory oversight and stakeholder participation.
10. Go back to previous steps as circumstances require or to fine-tune.

ACRONYMS AND DEFINITIONS

Abbreviation	Definition
DCFC	direct current fast charging
DOE	Department of Energy
EoT	Electrification of Transportation
EV	electric vehicle
GE	General Electric
HAVEN	Hawaii Advanced Visualization Environment
HCEI	Hawaii Clean Energy Initiative
HECO	Hawaiian Electric Company
HEVI	Hawaii Energy Visualization Imitative
HNEI	Hawaii Natural Energy Institute
HOV	high occupancy vehicles
HSEO	Hawaii State Energy Office
ICCT	International Council on Clean Transportation
MECO	Maui Electric Company
MEDB	Maui Economic Development Board
MPGe	miles per gallon equivalent
MUDs	multi-unit dwellings
NEDO	New Energy and Industrial Technology Development Organization
NREL	National Renewable Energy Laboratory
O&M	operation and maintenance
PUC	Public Utilities Commission
PV	photovoltaic
RPS	renewable portfolio standard
STCH	Sustainable Transportation Coalition of Hawaii
TOU	Time-of-Use

1. INTRODUCTION

The Hawaii Clean Energy Initiative (HCEI) established a goal of meeting 70 percent of the state's energy needs through energy efficiency and renewable energy by 2030. Act 155-2009 increased the renewable portfolio standard (RPS) to 40 percent by 2030 and set an energy efficiency goal of 4,300 GWh reduction in electricity by 2030. In 2015 the clean energy goal was increased to 100 percent.

HCEI provided a comprehensive framework to plan and build a clean energy future through a strong federal-state partnership [1]. It also brought together business leaders, policy makers, and concerned citizens committed to leading Hawaii to energy independence [2]. Grassroots organizations, community members and subject matter experts worked in four main groups: electricity (generation and delivery), end-use efficiency, transportation, and fuels [1]. The groups developed a roadmap that integrated policy and regulatory change, community education and outreach, project development, and planning and management [1]. The working groups inspired public and private sector partnerships that are furthering the roadmap through clean energy policy development and energy technology innovation activities [1]. In one of those efforts, the Hawaii State Energy Office (HSEO) commissioned the development of the HCEI's energy plan for transportation to the International Council on Clean Transportation (ICCT). Stakeholder consultations were held regarding new transportation options and recommendations were made to reduce petroleum use in the transportation sector. One of the key recommendations was to accelerate the deployment of electric vehicles (EVs) [3].

The following is a sample of state laws in support of increasing the number of EVs in Hawaii:

- 2010: Act 186 allows the installation of an EV charger on or near the parking space of any multi-family residential dwelling or townhouse that the person owns.
- 2012: Act 89 requires parking areas with 100 or more spaces to have at least one space exclusively for EVs and a charging system.

  Act 168 provides incentives for the registration, licensing, and operation of EVs. It also provides free parking at state and county facilities, including meters and use of high occupancy vehicle (HOV) lanes.
- 2015: Act 38 supports the elimination of fossil fuels for ground transportation [4].
- 2019: Act 142 provides a rebate for installation of new or upgraded multi-user EV charging systems.

  Act 144 allows "energy performance contracts" to include avoided vehicle maintenance or fuel costs from the installation of charging infrastructure.

Furthermore, all Hawaii mayors committed to 100 percent renewable-powered transportation by 2045 [5].

However, compared to progress in the electricity sector, the transition of transportation to cleaner technologies and fuels is lagging [6]. Some policies have proven difficult to implement, such as the installation of EV charging stations in apartment buildings and reserving space for EV charging stations in large public parking lots. Furthermore, as EVs increase their market share in the coming decade, states strive to recover some of the taxes that gas vehicles provided for road and bridge programs [7]. Hawaii is no exception, establishing an annual registration fee for EVs and alternative fuel vehicles of $50 (Act 280-2019). EV advocates see these fees as a penalty for switching from conventional vehicles. Supporters claim that the fees are necessary to make EV owners share the

cost for the maintenance and construction of transportation infrastructure [7]. By November 2020, there were over 12,000 EVs registered in Hawaii (about 1 percent of all cars).

Table 1: Registered EVs in Hawaii [8]

County	Number of EVs
O'ahu	9,960
Maui	1,521
Hawai'i	862
Kau'i	373
Total	12,716

1.1. Purpose of this Report

This document is the result of a literature survey to understand the technical, economic, and regulatory impacts of EV integration in Hawaii. It is meant to be informative, but does not present any new technical analysis except for the development of key lessons learned that could be applied in similar contexts. The specific objectives of this report are:

1. Inform existing and future Sandia EV projects about the lessons learned in Hawaii – a location where EV has a significant presence, with a holistic energy policy framework; well-laid out plans; supportive government, laws and regulations; and active stakeholders.
2. Provide a possible model for EV plans in other islands and remote locations.
3. Develop a tool for Sandia to engage and start a conversation with possible collaborators

The rest of this document focuses on the electrification of ground transportation in the Hawaiian Islands: its stakeholders, a sample of plans, utility actions, and an appendix with examples of specific research studies.

2. EV STAKEHOLDERS

HSEO convened a broad spectrum of stakeholders in discussion sessions facilitated by experts, and with participation of national and international energy leaders [1]. Regarding the electrification of transportation (EoT), HSEO identifies the following key EV stakeholders [2]:

- Counties' leadership from City and County of Honolulu, Maui County, Hawaii County, and Kauai County. All Counties have a 100 percent renewable goal by 2045 for public and private ground transportation.
- Drive Electric Hawaii is a coalition of public, private, and nonprofit organizations that includes the State Government, the Hawaiian Electric Companies, Kauai Island Utility Cooperative, Ulupono Initiative, Blue Planet Foundation, and Rocky Mountain Institute among others. It promotes the use of EVs and the reduction of fossil-fuels in transportation through collaboration on education, advocacy, and infrastructure development.
- Elemental Excelerator finds and funds entrepreneurs that can help redesign systems in energy, agriculture, water, and mobility [2].
- Hawaiian Electric Companies provide rates to encourage EV charging that aligns with the electric system operation. They own and operate public DC Fast Chargers (DCFCs) in Oahu, Maui County, and Hawaii Island with oversight from the Hawaii Public Utilities Commission (PUC) [2].
- Hawaii Energy is a ratepayer-funded energy conservation and efficiency program under contract with the Hawaii PUC that serves the islands of Hawaii, Lanai, Maui, Molokai, and Oahu [2].
- The Hawaii Automobile Dealers Association helps auto dealers comply with the laws to facilitate car buying by the public.
- The Sustainable Transportation Coalition of Hawaii (STCH) is a program coordinated by Blue Planet Foundation (a non-profit clean energy organization in Hawaii). STCH supports efforts to reduce petroleum use in transportation by providing information and technical assistance on the benefits of alternative fuels and alternative fuel vehicles [2].

Besides HSEO, other state government entities such as the Hawaii Department of Transportation and the Division of Consumer Advocacy support the growth of EVs.

Two partnerships that have supported HCEI are the Hawaii Advanced Visualization Environment Nexus (HAVEN) and the Hawaii Energy Visualization Initiative (HEVI). HAVEN provided HSEO access to advanced computing infrastructure and state-of-the-art visualization cyber-infrastructure through a Department of Energy (DOE) State Energy Program grant establishing a partnership among HSEO, the University of Hawaii at Manoa's Laboratory for Advanced Visualization & Applications, the Hawaiian Electric Companies, and key external stakeholders [1]. HEVI is a collaboration of HSEO, DOE, and National Renewable Energy Laboratory (NREL) to generate the data necessary for visualizations from future scenarios incorporating new energy efficiency targets and EV adoption [1].

Even though there is ample support for the 100 percent clean energy goals, the road to achieve those goals is not without controversies. The Hawaiian Legislature approved a portfolio of laws, and more are in the legislative pipeline. In particular, a proposed $2,500 EV incentive has created a heated debate between auto dealers and green energy advocates [5].

Although EVs are cheaper to operate and maintain, their cost is typically a little higher than an equivalent gas-powered car [5]. The Blue Planet Foundation supports ways to lower the upfront cost of EVs and make them price-competitive with conventional gas cars. For example, a state tax credit. However, the Hawaii Auto Dealers Association describes tax credits as "very disruptive" to the industry. They present Georgia as an example, where EV sales plummeted once a $5,000 EV state tax credit was repealed [5]. Based on current sales data, they claim that over $20,000 per EV would be needed in tax credits. Blue Planet believes the number is much lower [5]. Some lawmakers want to go beyond financial incentives for EVs and target the supply of conventional internal combustion cars. Multiple bills call for a ban on the sale of all new gas vehicles [5]. Proposed start dates for this ban range from 2025 to 2045. The car sales industry says this would have disastrous economic consequences. Industry representatives suggest that a ban on new sales starting in 2050 would be more reasonable and would match the expected EV growth that is expected after 2040 [5].

Another example of stakeholders' disagreements is a bill that would require multi-housing owners to install EV chargers. Over 30 percent of people in Hawaii live in multi-housing complexes, thus their access to EV chargers at home is limited. However, property-owners claim the cost of such mandate would be too high. Builders protest because their construction costs would increase and therefore the cost to customers would also increase (median housing costs in Hawaii are already among the top in the U.S.). The bill was tabled on March 2020.

3. PERSPECTIVES FROM STAKEHOLDERS

3.1. Ulupono Surveys (2016)

Ulupono Initiative, a Hawaii-focused impact investment firm, commissioned market research and collected data about EVs, infrastructure, rates, environmental impact, fees, taxes, and policies. Their report presents the results from surveys conducted in Hawaii [9].

Ulupono's initial survey was conducted in 2016 by Honolulu-based Anthology Marketing Group. Survey questions gauged EV owners' access to charging ports and locations, average days of the week and distance each commuted, whether EVs were their primary means of transportation, and their responses to a variety of other queries. Results showed that Hawaii EV drivers are generally dissatisfied with the Hawaiian Islands' existing charging network, rating it an average score of 4.26 out of 10. The most common criticism was limited access to charging stations throughout the state, which further validates that demand is outpacing supply [9].

Information captured also showed that 71% of drivers preferred parking in structures with access to charging stations. Additionally, 73% stated that the availability of charging stations affected how likely they were to frequent establishments or businesses. The survey also illustrated that a majority of local EV owners (80%) charged at home and, if access were available, 92% would charge their vehicles at work [9]. Additional findings indicated that just over half of EV drivers tend to avoid traveling long distances due to lack of available charging stations. Since 85% of EV drivers reported utilizing public charging stations, businesses without charging infrastructure nearby could be negatively impacted [9]. Another notable finding was that 68% of EV owners were receptive to paying a fee for charger usage. Acceptance of a usage fee tended to be higher (81%) for EV owners on some of the islands [9].

Based on the survey results, the report recommends faster actions to accelerate the economic, environmental, health, and energy benefits. Key actions include increasing drivers' confidence when buying EVs (affordability of EVs and availability of charging stations). Requiring new facilities to be EV-ready adds less than 1 percent to the cost of development, while installing EV infrastructure post-construction costs three times more. Upfront investments are cost-effective, smart, and essential future proofing [9]. Thus, postponing investments is unlikely to generate cost savings.

Local stakeholders are actively involved in the electrification of transportation. In 2016, a group of industry stakeholders formed Drive Electric Hawaii (described in Section 2), while individual groups, including community-based associations, are also advocating and convening to raise awareness. One of these, the Big Island EV Association, is comprised of over 200 EV owners from the County of Hawaii [9].

The report also mentions an environmental concern related to batteries. EV batteries typically retain 70 to 80 percent of their capacity after seven to 10 years on the road [9]. Below that threshold batteries should be replaced and used in other applications. For example, Nissan is recycling old batteries to power streetlights in Japan. A company in Germany has developed its own recycling system for lithium-ion batteries, which it claims is eco-friendly. There are also efforts to establish a system and regulatory framework to recycle EV batteries [9]. As the worldwide EV market develops and matures, technologies are expected to improve and to include recycling solutions.

3.2. Electric Vehicle Market Survey (2017)

An online survey was conducted between July and November of 2017 of residential customers from Oahu, Maui, and Hawaii. A total of 2,247 responses were received from 5,651 random invitations. There were 1,905 non-EV customers, 200 hybrid owners and 142 EV owners [10].

The responses from the non-EV customers provided an understanding of their EV knowledge, future purchasing likelihood, and purchasing influences/concerns. Some of the key findings from the non-EV customers were:

- More education is necessary to support EV adoption.
- Largest knowledge gaps exist for benefits and cost of ownership.
- Over 80% of respondents have not driven an EV, but 75% would consider an EV in the future.
- Financial considerations, charging station availability, and driving range are among the top concerns for EV adoption.

For the EV owners, the survey focused on charging habits and preferences. Most responders owned either a Nissan Leaf (54%) or a Tesla Model S (11%), which follows Hawaii's overall EV ownership [10]. Some of the key findings were:

- 85% of EV drivers primarily charge at home, with 58% owning a Level 2 Charger at Home.
- Lack of charging stations and constantly occupied stations are the top reasons that discourage charging away from home.
- Availability and charging speed scored highest in importance for public charges.
- Among the location-based attributes, remote siting rated highest in importance.
- 78% were more likely to visit a business that has a charging station.
- 69% were more likely to travel to a destination if there is a charging station along the way.
- 52% do not drive long distances because of fear of not being able to access a charging station.
- 49% think that using a DCFC (Level 3) decreases the life of the EV's battery.
- Two-thirds charge their battery to 100% always or most of the time.

Another group worth mentioning were drivers who have and have not used a DCFC (207 and 164 respectively) [10]. A DCFC profile could be deduced from the results of this group:

- A quarter of the DCFC users always charge away from home.
- About a third of the DCFC users primarily charge away from home.
- Two out of five DCFC users would most prefer to charge at work or a public location.
- Availability and charging speed of public charging stations scored high.
- Weekly charging frequency is relatively the same between DCFC users and non-users.
- Fully charging a battery occurs more often than partial charges.
- 57% would not be willing to be interrupted to support utility efforts to manage demand (also referred to as providing demand response).
- DCFC users tend to drive a shorter commute for work.
- DCFC users are made up more of urban and suburban residences compared with non-users.
- DCFC users are less likely to have a Level 2 charger installed at home.

- DCFC users are less likely to have home solar.

4. THE STATE OF ELECTRIC VEHICLES IN HAWAII

The Hawaii Natural Energy Institute (HNEI) published "The State of Electric Vehicles in Hawaii" reports in 2015 and 2016. These reports affirm that leadership from state and federal government agencies along with the private sector has played a strong role in EV growth, by developing EV-friendly policies, attracting industry investment, and coordinating public-private efforts such as the Honolulu Clean Cities Program [11]. Hawaii's limited driving range, moderate climate and supportive state legislation represent a positive environment for EVs [11]. The islands of Hawaii provide an ideal location to quantify the synergies of integrating EVs into power grids characterized by high penetration of intermittent renewable energy. Modeling and analysis are critical to help inform technical directions, planning, and policy decisions. Thus, determining the value of grid-connected vehicles is essential in achieving Hawaii's 100 percent renewable energy goal.

The reports indicate that there are negative impacts on total cost of EV ownership and life cycle emissions due to Hawaii's electricity costs and heavy reliance on fossil fuels for electricity generation [11]. Small changes in scenario assumptions, such as the levels of EV adoption, operational changes by the utility, or renewable energy levels, yield significant impacts on future outcomes [6]. Utilities in Hawaii, having small, remote, and isolated island electricity grids, face unprecedented technical and economic challenges to meet the 100 percent renewable goals. Power system reliability, cost controls, and stability are essential. Along with balancing intermittent renewables, the opportunity of using EVs as a grid stabilization service includes power reserves, frequency and voltage regulation [6].

4.1. EV Charging Infrastructure

The HSEO implemented an "EV Ready" grant and rebate program in 2010, supported by $4 million in American Recovery and Reinvestment Act funds from the US DOE, together with another $2 million in cost-share from industry partners. This program provided grants to support infrastructure development with the installation of public charging stations, along with purchase rebates of up to $4,500 for an EV, and up to $500 for electric vehicle service (charging) equipment (EVSE). The rebate program ended in May 2012 with more than 450 rebates issued [11].

As the EV market share grows, controlled EV charging will be needed to diminish impacts to the electric grid. The HNEI reports state that controlled charging of EVs can:

- improve integration and efficient use of renewable generation into the electric grid.
- improve grid reliability, efficiency, and resiliency.
- provide economically stable transportation fuel alternatives.
- improve efficiencies and reduce emissions for both ground transportation and electricity generation.
- help mitigate variations in power generation resulting from extremely high levels of photovoltaic (PV) penetration at the circuit level [6].

Coordinating EV charging with peak generation from PV systems would be beneficial in areas with high concentrations of PV that have load balancing issues due to the intermittency in PV resources. Controlled charging of EVs offers demand response by lowering or halting charging to help match renewable energy generation with load. It also helps prevent transformer overheating as EV charging becomes concentrated in some points of the grid. EVs could also provide energy storage services to the grid [6].

Controlled EV charging profiles can play a key role in helping to increase clean, renewable power generation, as well as to help improve operational efficiency and reliability of the power grid in Hawaii [6]. Currently when demand for electricity to charge EVs is added to the Oahu grid, additional petroleum is used for electricity generation.

Some of the obstacles to the installation of public charging stations mentioned in the HNEI reports are: Unknown consumer demand, installation complexity, and competing business priorities. The lack of a standard for DCFC equipment also contributes risk. Property owners have also expressed concerns with public relations issues if parking spaces reserved for EVs are unused, limiting parking for other customers [11].

Hawaii's humidity, salt content in the air, and intense solar radiation can lead to degradation and malfunction of equipment. For example, Maui Electric Vehicle Alliance staff reported charging station equipment that rusted within months of installation at one site. Higher costs are incurred in purchasing protective covers or more frequent replacement costs [11]. Furthermore, many older properties across Hawaii do not have enough electric capacity to accommodate the additional load of charging an EV and thus have required upgrades to their electric wiring and equipment. Solutions to minimize costs include analyzing and planning for optimal charging site locations based on traffic patterns, environmental, geographic, permitting, and other factors [11].

4.2. Oahu Electric Vehicle Charging Study

HNEI contracted General Electric (GE) International in 2013 to perform detailed, electrical dispatch modeling to estimate the amount of curtailed energy avoided through controlled charging of many EVs. Renewable energy base cases were modeled with 600 MW to 1000 MW of combined wind and PV capacity on the future Oahu grid with a peak load of about 1200 MW. For the renewable energy base cases before EVs were added, between 10 and 23 % of the combined wind and solar energy were curtailed when the grid attained its physical limit for renewable integration. Wind power resulted in more curtailed energy than PV due to the higher variability of wind. Grid-connected EVs were explored for their potential to reduce the curtailed energy.

Approximately 10 to 30 % of light-duty (passenger) vehicles on Oahu were replaced with EVs in one scenario of this study [11]. Although EVs can be more efficient than comparable conventional gasoline-powered vehicles, additional load on the Oahu power grid results in additional power generation from oil [11]. Thus, additional petroleum for electricity generation was quantified for each future scenario's EV load to account for wind and PV intermittency. The day-to-day variations in total wind and solar curtailment reduced the effectiveness of controlled EV charging in avoiding curtailed energy [11]. Assuming all EVs follow a practical, controlled charging profile, curtailed energy was reduced 18 to 46% [11]. However, further improvements in the electric grid were also recommended to reduce curtailed energy.

With hourly EV load and curtailed energy data from the GE models as input, a simple spreadsheet proved to be accurate (less than one percent error) in calculating the amount of curtailed energy avoided. The spreadsheet could be used when actual hourly data becomes available for curtailed energy and EV load. An EV analysis was performed to quantify the effects of curtailment on electrified transportation.

Other results showed the fuel and emissions savings from EVs. The average mileage gasoline vehicles achieve is less than 22 mpg, compared to EVs with approximately 32 miles per gallon equivalent to gasoline (MPGe) [11]. These gasoline savings from EVs would be comparable to improving all of Oahu's passenger vehicles by 1 to 4 mpg overall.

5. EV DEMONSTRATION PROJECT: JUMPSMART MAUI (2011-2017)

JUMPSmart Maui was a demonstration project, incorporating EV solutions, smart grid, and high penetrations of renewable energy. The project's collaborative team included Japan's New Energy and Industrial Technology Development Organization (NEDO), Hitachi Corporation, HNEI, HECO, Maui Electrical Company (MECO), the State of Hawaii, the County of Maui, and the Maui Economic Development Board [12]. The project used Hitachi's proprietary smart grid technologies and software with integrated distributed and central station renewable energy, EVs, energy storage, and controllable loads. Direct investment was provided by NEDO with the collaboration of Hawaii State and county governments, private companies in Japan and Hawaii, MECO, and the academic and research communities.

Energy data from owners of the Nissan LEAFs and residents on Maui were collected and evaluated [6]. Smart utility system controls were developed and installed to connect advanced EV charging management systems to the electric utility system controls. The utility managed EV charging to balance power demand with distributed PV and wind energy generation. The findings from this renewable energy-based, decentralized, and networked energy project could be a model for the larger grids on other Hawaiian islands, as well as other parts of the world [6].

The project accounted for existing utility generation with management of distributed energy resources, EVs, and energy storage while controlling the loads [12]. Hierarchical controls were used in an EV energy control center for the following:

- batteries providing energy to the grid and storing energy from the grid
- EVs providing demand response service
- EVs as a power source to homes.

The main goal was to integrate the maximum amount of renewable energy using demand response and storage, and to provide control using an energy management system and advanced inverters [12]. Direct load control responded to fluctuations in supply and demand, thus stabilizing and balancing the grid. The project also studied the effects of EV charging at home. A network of EV charging stations were deployed as part of the project. Consumer-based information and communication tools and platforms were used to evaluate improvements in quality of life. Multiple elements of an island energy transition were tested in the initial Maui project phase, including EV load-shifting, direct load control of water heaters, bulk battery operation, and power quality control of solar PV via smart inverters for a group of volunteer residential customers.

The project helped to establish the EV charging station infrastructure in Maui. It also provided important information about the charging behavior of EV owners that will inform future operations and growth. Furthermore, the project demonstrated the potential of EVs to help the smart grid in the coordination of grid needs, and the demands from residential and commercial clients. After the project ended in 2017, NEDO transferred the network to the Maui Economic Development Board (MEDB), which renamed the EV network "EVohana." The PUC authorized MECO to operate four of those EV charging stations [13]. As of 2020, there were ten locations with DCFCs in Maui, operated by MEDB, a third party, and MECO.

6. UTILITY APPROACH TO EV INTEGRATION

Hawaiian Electric Companies serve 95 percent of electric power customers in Hawaii through HECO, MECO, and Hawaii Electric Light. Because of its planning and operating role, Hawaiian Electric holds a key leadership position to realize the electrification of transportation goals in the state in collaboration with community planners, customers, third-party charging providers, automakers, technologists and other stakeholders [14]. In 2010, the PUC approved three EV pilot rates, two residential rate options, and a commercial rate option, for a three-year pilot [15]:

- Schedule TOU EV (Residential Time-of-Use Service with Electric Vehicle Pilot) a residential customer that combines EV charger load with all other household loads under one meter.
- Schedule EV-R (Residential Electric Vehicle Charging Service Pilot) a residential customer that has a separate electric meter for the exclusive purpose of charging batteries for on-road EVs.
- Schedule EV-C (Commercial Electric Vehicle Charging Service Pilot) a commercial customer utilizing a separate electric meter for exclusive use of charging batteries for on-road EVs.

Thus, Hawaiian Electric has 10 years of experience in developing EV rates, with varying degrees of success [15].

In 2012, Hawaiian Electric requested to own and operate public DCFC stations to: Facilitate the development of the EV market, enable the public charging during the daytime; prepare for the increased integration of EV charging on the grid, and provide public DCFC service to EV end-users in areas that lack EV charging infrastructure [15]. In 2013, the PUC approved new tariffs EV-F and EV-U as a five-year pilot project. Schedule EV-U supports the EV market by allowing the utility to install and operate public EV charging facilities in strategic locations, support the rental EV market, and increase EV acceptance by residents in multi-unit dwellings (MUDs). The EV-F rate encourages the development of public EV charging facilities by start-up EV public charging operators [16].

In 2016 the PUC mandated Hawaiian Electric to create an EoT strategy. In 2017 an Electrification of Transportation Department was established to provide more resources to Hawaiian Electric's EV initiatives, and the EV pilot program was extended to June 2023 by the PUC [10]. Three new charging stations were opened on Oahu and one station on Hawaii Island. The PUC approved a change in the tariff rate structure from a flat fee to a per kilowatt-hour ("kWh") basis for the pilot [10]. The new rates were also priced to encourage charging during the mid-day period (9 a.m. to 5 p.m.) to coincide with the peak excess solar energy. Hawaiian Electric is refining the siting analysis to include indicators of high utilization and have conducted customer surveys regarding EV charging behavior and preferences [10].

Overall utilization of DCFC stations increased from 2017 to 2018, a 68 percent increase in number of sessions and a 14 percent increase in amount of energy consumed. For the first time since 2013, the revenues exceeded the operating and maintenance expenses for five of the eight charging stations in the Oahu pilot program [16]. In 2018, two DCFC stations were added on Molokai and on Hawaii Island, and an E-BUS Program tariffs were proposed to incentivize bus fleet operators to adopt clean transportation vehicles [16].

Following a PUC order, an EoT Roadmap was prepared [15]. The EoT Roadmap has ten key initiatives and established the need to identify the critical charging infrastructure needed to support the growth of EVs. A critical backbone of public DCFCs would ensure a constant, reliable charging network to address range anxiety and promote EV adoption. However, the public charging infrastructure would be larger, and would include third-party charging providers as well [16]. HECO

filed a Critical Backbone Study in 2019. Later in 2019 a workplan was presented to implement the actions listed in the roadmap. The following sections summarize some of the key plans and actions contained in the EV roadmap, the critical backbone study, and the workplan.

6.1. Electrification of Transportation Strategic Roadmap (March 2018)

The EoT Roadmap outlines the utility's proposed role to optimize, facilitate, accommodate, and integrate EoT within the service areas according to near-, medium-, and long-term actions. The roadmap also establishes guiding principles that drive the utility's priorities with respect to programs and policies [15]. The PUC acknowledged that the utility involved stakeholders and used industry best practices in developing the roadmap [17].

The key short-term stages of the plan are [14]:

- Boosting EV adoption by working with automakers, dealerships, and advocates to lower cost and educate customers.
- Accelerating deployment of charging infrastructure, with emphasis in workplaces and multi-unit dwellings.
- Providing a critical backbone of reliable, public utility-owned chargers as a foundation for the creation of a broader electric transportation and third-party charging market.
- Identifying and providing 'make-readies' (parking spaces wired with the electrical infrastructure to support EV charging [18]) in gap areas to create opportunities for third party chargers that optimize grid and customer locations to meet driver needs.
- Supporting bus operators in transitioning to electric with targeted outreach and programs that reduce the upfront cost and provide practical charging solutions. Trucks and heavy equipment would be included later.
- Creating grid service opportunities by leveraging demand response programs and rates that incentivize EV charging to align with grid needs.
- Coordinating with ongoing grid modernization and planning efforts to ensure smooth integration of EVs into power distribution networks and maximizing use of renewable resources.

The plan will help Hawaii to prepare for the EV market growth, ensuring needed grid upgrades, educating stakeholders, and avoiding retroactive fixes. Hawaiian Electric leveraged on a structured, data-driven process, and also on engagement with stakeholders, transportation and technical experts, policymakers, and non-government organizations to develop this workplan [14]. In collaboration with Drive Electric Hawaii, customers with and without EVs were surveyed about their transportation needs and interests. The results yielded guiding principles that helped prioritize the plan's actions. Immediate strategies include [14]:

- Working with automakers, dealerships, and EV advocates to lower vehicle prices and educate consumers.
- Partnering with third-party providers to build the charging network, increasing the number of chargers owned by Hawaiian Electric.
- Pursuing demand response incentives to optimize charging periods.

The development of beneficial EV charging rates and deploying additional vehicle charging infrastructure are critical to incentivize EV adoption. The roadmap establishes that the availability of

new and more effective charging rates will not only bring value to the grid, but also value to customers. Deploying make-ready infrastructure that incorporates smart meters and demand response technology will provide customers, hosts, and third-party businesses a simpler option to install charging infrastructure. Hawaiian Electric also plans to leverage lessons learned while electrifying their own fleet and operating public DCFC infrastructure to support the deployment of make-ready pilots [15].

Charging cars, trucks, buses, and heavy equipment will help to integrate 200,000 new private rooftop solar systems and new utility-scale renewable systems. The estimated savings in avoided gasoline and vehicle maintenance costs are around $60 million. The state economy could have a positive $200 million impact which could increase if strategies to optimize EV charging are adopted and widely accepted by customers [14].

Stakeholder comments about the EoT Roadmap were positive, with strong support for the initiatives, improving charging infrastructure, customized rate design, and continued stakeholder engagement [19]. On the other hand, stakeholders were concerned about the role of Hawaiian Electric in the electrification of transportation, standards development, and data management and sharing. The Hawaii Energy Policy Forum published a booklet with a summary of stakeholder input that was filed in the roadmap's PUC Docket No. 2016-0135 [20].

Implementing the roadmap requires effective rate design, expanded charging infrastructure, and safe grid interactions. The PUC states that Hawaiian Electric is "uniquely situated to support electrification of transportation by ensuring the success of these core components." Rate design and charging infrastructure were identified by the PUC as top priorities [19].

6.2. Electric Vehicle Critical Backbone Study: Planning Methodology (July 2019)

The Hawaiian Electric Companies' Electrification of Transportation Strategic Roadmap (EoT Roadmap) outlines their role to optimize, facilitate, accommodate, and integrate EoT within its service area. As a first step in support of the roadmap, Hawaiian Electric analyzed the need for EV charging infrastructure in the near future [21].

The transition to EoT in Hawaii will require investment in charging infrastructure to meet the growing energy needs. Since 2014, the utility has expanded their role in EV charging infrastructure development to establish pilot public charging stations with guidance from the PUC [21]. The EoT Roadmap points to the need to expand public charging and to identify a critical backbone of EV charging infrastructure.

The Critical Backbone analysis sought to [21]:

- Understand the need for public charging required to support EV adoption
- Identify the total universe of forecast charging infrastructure needed in 2025 and 2030
- Inform potential to increase the electric driving range
- Support increased charging opportunities near or at MUDs and workplaces
- Develop a planning methodology that will help identify a Critical Backbone subset of public EV charging infrastructure
- Increase use of company-owned charging locations as well as the potential increase in stations
- Enable grid impact or upgrade analysis

- Inform potential grid support services.

The study indicates that 3,600 public chargers would be needed by 2030 on the five islands in addition to an estimated 47,000 private chargers in homes and workplaces. Multi-family housing and townhouses will need more public charging options due to increased demand for EVs. The study supports the expansion of the public charging network. The utility plans to expand its EV charging network based on these forecast results to identify a Critical Backbone for public charging infrastructure program. The Network Expansion filing to the PUC will outline the parameters for a permanent infrastructure program, including rates, administration, operation and maintenance (O&M), and outreach.

6.3. Electrification of Transportation Workplan (October 2019)

The PUC ordered the utility to develop a workplan to implement the EoT Roadmap, initially focused on rate design and charging infrastructure [19]. The EoT Workplan is an 18-month plan that implements the actions listed in the EoT Roadmap, establishing a timetable with a focus on EV rate design and charging infrastructure in the near-term [15]. A key role that Hawaiian Electric can play is to provide insight into opportunities that third parties can leverage to bring electrification to the market in an efficient and attractive manner.

Hawaiian Electric's priorities and plan leverage on ten years of EV experience in rates and infrastructure, education and outreach, and fleet and bus electrification. EV adoption is forecasted to increase regardless of utility programs; however, new electrification programs can accelerate this growth and align customer behavior with state energy goals and grid needs [15]. Utility programs can also create a structure for future programs when technology, resources, and business cases evolve by helping to identify customer and grid needs. This will help address challenges from increased demand while increasing EV benefits [15]. The roadmap's near-term actions (one to three years) are to: educate and conduct outreach; identify grid service opportunities; electrify the utility's fleets; deploy and support charging infrastructure; and support bus fleet electrification.

Key components of electrification are the development of rates to incentivize EV adoption, support the grid, and encourage energy usage during periods of lower cost. The success of the EoT transition lies in part in the successful deployment of rates that not only compete with gasoline but provide a cheaper alternative that makes a compelling argument for conversion to EoT [15]. Another key area of development is supporting the potential EV drivers who live in MUDs. MUDs typically lack adequate EV charging infrastructure and present a significant barrier to adoption of EVs, particularly when charging behavior shows a preference to charge at home [15].

The costs of serving this increased EV load will be significantly less than the revenue generation potential, which should create an opportunity to make prudent and efficient investments that support and amplify the growth of EVs [15]. However, the planned large-scale transition to electric transportation can be significant and third-party funding and key partnerships should be leveraged to mitigate infrastructure costs [15].

7. CONCLUSION

The EoT is essential for Hawaii's energy goals [19]. An EoT strategy complements other energy policy goals, increases clean energy impacts, and provides customer value [17]. The EV process that emerged in Hawaii can be an example to other locations, albeit avoiding some of the "growing pains" and hurdles. The following list, based on Hawaii's EV experience, could be a guiding framework for electrification of transportation efforts elsewhere:

1. Start with an overarching energy goal/objective based on a vision built with support of a broad base of stakeholders.
2. Turn that objective into law and policy, with clear expectations and roles for key stakeholders.
3. Develop planning and pilot projects with close regulatory oversight and stakeholder participation.
4. Develop a strategic plan (roadmap) leveraging on initial experiences.
5. Create more refined planning to further develop a roadmap.
6. Perform needed studies.
7. Implement the roadmap's actions.
8. Evaluate effectiveness/success of actions; fine-tune or make changes as needed.
9. Maintain close regulatory oversight and stakeholder participation.
10. Go back to previous steps as circumstances require or to fine-tune.

In Hawaii, the utility has a key leadership role in growing the EV market. With guidance from the PUC, HECO is leveraging its experience and knowledge of the electric system to achieve an EV strategy that is integrated within the broader state energy context. However, the participation of key stakeholders is essential, and possibly a non-utility entity might be better positioned in other locations to assume the leadership role regarding the electrification of transportation.

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APPENDIX A. A SAMPLE OF PAPERS RELATED TO HAWAII'S ELECTRIFICATION OF TRANSPORTATION

Paper Title	Brief summary
All Options on the Table: Energy Systems Integration on the Island of Maui [22]	This paper examines a diversified portfolio of mitigation options to reduce renewable energy curtailment on the island of Maui. The options included changes to the operational practices of conventional generators, utilization of a BESS, and introducing EV charging to modify the system load [22].
Electric Vehicle Lifecycle Cost Assessment for Hawaii [23]	Raustad and Fairey developed a model for calculating total lifetime ownership costs for vehicles including purchase/finance, insurance, maintenance, and resale value. This paper tailors the findings of Raustad and Fairley for the case of Hawaii. The time frames considered are 5, 10 and 15 years of ownership. The paper also assesses decisions regarding vehicle leasing and analyzes the local utility's pilot and "time-of-use" (TOU) rates for households with EVs.
Integrating electric vehicles and residential solar PV [24].	This study determined that the total cost of ownership of EVs tends to be higher than the internal combustion engine vehicle or hybrid electric vehicle. However, both the federal tax credits and access to residential solar PV makes EVs quite attractive [24]. The environmental benefits of EVs depend critically on the source of electricity [24]. Additional policy tools are needed to match places and times with high levels of renewables with EV charging.
The viability of vehicle-to-grid operations from a battery technology and policy perspective [25].	The authors of two major studies (including one in Hawaii) reconcile their previous conclusions by providing clarity on how methodologies to manage battery degradation can reliably extend battery life [25]**.** The paper also reviews the associated technology and policy implications of better managing battery use in vehicle and electrical grid applications.
EV driver characteristics: Evidence from Hawaii [26].	This study identifies differences in zip code EV registrations in Hawaii through 2018 using demographic and transportation behavior characteristics, as well as fuel prices and charging infrastructure. Income and level of education are positive and statistically significantly related to zip code EV registrations [26]. While all public charging infrastructure is found to have a positive and statistically significant relationship to EV registrations, the magnitude is larger for fast charging stations (Level 3) [26]. Trip distance is not linearly related to EV adoption: zip codes with commute time under 20 minutes and also commute times of 45 min and more were associated with fewer EV registrations [26].
Island energy transition: Assessing Hawaii's multi-level, policy-driven approach [12].	This study applied a sustainability principles, a case study with document analysis and in-depth interviews with energy stakeholders, to assess progress on Hawaii's energy system transformation and associated socio-technical innovations [12]. One of the focus areas studied was EVs and their potential system benefits: storage, grid support services and stability at the circuit level.

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