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Analysis of Solar Community Energy Storage for Supporting Hawaii's 100% Renewable Energy Goals

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Table of Contents

Abstract

Solar PV generation has become an integral part of the renewable energy industry. With state-level, renewable portfolio standards in place, solar power demand has substantially increased and become a competitive and economically viable energy solution throughout the world. Hawaii has one of the most aggressive renewable portfolio standards with a goal of 100 percent renewable generation by 2045. However, there are challenges that are preventing the growth of the solar PV market in Hawaii including equal accessibility to solar power and solar power overloading causing grid instability. With Hawaii's high annual solar radiation, PV generation could play a significant role in reaching 100 percent renewable generation as long as a solution is put in place to alleviate overload to the grid while also expanding the adoption of solar. Community solar and energy storage techniques could potentially provide the support the solar industry needs to achieve this goal in Hawaii. This paper evaluates the success of two solar community energy storage projects, the Detroit Edison Community Energy Storage Project and the Sacramento Municipal Utility District Anatolia Pilot Project, based on five criteria, the state's renewable portfolio standard, available funding, level of solar incentives, site location, and amount of annual solar radiation. Based on this analysis, recommendations for the implementation of solar community energy storage projects in Hawaii are provided to determine if solar community energy storage techniques can facilitate growth in the solar PV market by overcoming the grid instability and accessibility challenges affecting utility companies throughout the Hawaiian Islands.

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Acronyms and Abbreviations

CBRE	Community-Based Renewable Energy
CES	Community Energy Storage
CGS	Customer Grid-Supply
CSP	Concentrated Solar Power
CSS	Customer Self-Supply
DER	Distributed Energy Resources
DG	Distributed Generation
DR	Demand Response
HECO	Hawaiian Electric Companies
IOU	Investor-Owned Utility
IRS	Internal Revenue Service
kW	Kilowatt
KWh	Kilowatt Hour
MW	Megawatt
NEM	Net Energy Metering
POU	Publicly-Owned Utility
PPA	Power Purchasing Agreement
PUC	Public Utility Company
PV	Photovoltaics
REC	Renewable Energy Certificate
RPS	Renewable Portfolio Standard
TOU	Time-Of-Use
VNM	Virtual Net Metering

Chapter 1 – Introduction

1.1: Overview of the Current Solar Energy Market in Hawaii

Hawaii's solar PV market has taken off quickly because of the high cost of electricity and abundant irradiance from the sun. With imported energy costs close to four times higher than the rest of the contiguous 48 states, Hawaii was the first state to reach grid parity for photovoltaics in the United States and has over 670 megawatts of solar installations reported at the end of 2016 ("Hawaii Solar."). Hawaii is ranked 13th nationally in the solar industry by state with 170 thousand homes currently powered by solar. There are over three thousand jobs reported in the Hawaiian solar market with about 7.25 percent of the state's electricity currently coming from solar ("Hawaii Solar."). Hawaii also has one of the most aggressive renewable portfolio standards with a goal of 100% renewable generation by 2045 ("Hawaii Energy Facts & Figures", 2016).

However, Hawaii has had a challenging time balancing the energy flow of the area with large amounts of solar power being fed into the grid. The overload of distributed solar has led to interconnection issues forcing utility companies, like Hawaiian Electric Company (HECO), to impose restrictions on solar generators' loads. Since the Hawaiian Islands each have multiple grid systems there is a physical limit to the amount of daily electricity that can be fed into the grid, which is something the contiguous 48 states does not experience because of their interconnected power grids.

The Net Energy Metering (NEM) program allowed solar customers to offset their electricity use by receiving a retail rate credit for energy exported to the grid. Customers would pay a minimum bill, or non-energy customer charge, if the energy produced exceeded the energy used that month and customers would pay the net amount of the bill if the customer used more energy than they produced. The excess credits were carried over to future months and either forfeited or used to reimburse any previously paid energy charges of that 12-month billing cycle. After retail rate net metering was phased out in 2015, the Hawaii Public Utility

Commission (PUC) proposed two interim incentive options for customers planning to install a solar PV system.

The Customer Self-Supply (CSS) program was intended to create solar customers that put little stress on overloaded neighborhood grids. When the surplus of energy being fed back into the grid becomes overloaded, curtailment occurs forcing utilities to sell excess energy for little money or sometimes even having to pay to sell the excess power. There is a minimum bill amount set for residential customers at $25 and for small commercial customers at $50 (Shallenberger, 2016). The program is only intended for solar PV installations and customers may not be compensated for any export of excess energy into the grid. Therefore, unless the customer has a storage system, this option is less economical and has proved to be the least popular between the two programs since storage options for a single homeowner are currently not economically beneficial.

The Customer Grid-Supply (CGS) program is a grid supply option for all renewable energy sources, allowing customers to export excess power to the grid but still not at the retail rate. The PUC approved credits are determined by location between a fixed rate of $0.15 per kWh and $0.28 per kWh. Customers use these credits to offset the retail rate energy they are initially charged for that month. The minimum bill amount is $25 for customers whose credit exceed their energy charges and unlike the NEM program all excess credits are forfeited at the end of the 12-month billing cycle and not allowed for reimbursement ("Hawaii Energy Facts & Figures", 2016). This option has gained more traction with more than two thousand applications submitted for the CGS program as of August 2016 and only 34 applications submitted for the CSS program across all islands (Shallenberger, 2016). However, a cap was established for each service territory because the PUC believed it was not in the best interest of the public to allow unlimited growth that could inhibit other renewable forms of energy from becoming more cost competitive and prevent the option of community-based renewable energy for customers in the future. As of September 2016, all HECO companies have already reached the cap limit ("Hawaii Energy Facts & Figures", 2016).

There is a clear need for a more permanent solution in Hawaii that alleviates overloading to the grid while also increasing the adoption of solar. Each of the Hawaiian Islands has its own electrical grid that is not interconnected between islands, like the grid system used by the rest of the contiguous 48 states. Between these six different grid systems there are three main utility companies that serve about 93 percent of the electricity customers in Hawaii (Hawaii State Energy Office, 2016). Hawaiian Electric Company (HECO) serves Oahu, the most developed island, while Maui Electric Company (MECO) serves mainly Maui and Molokai, and Hawaii Electric Light Company (HELCO) serves the island of Hawaii (Figure 1). This segregation between grid systems limits the amount of energy each island can feed back into the grid without causing curtailment and, ultimately, slows down the growth of solar power in a state where solar generation has the potential to be extremely successful. Community solar integration can encourage an increase in PV generation, while solar energy storage can help mitigate the excess solar energy being fed back into the grid in Hawaii.

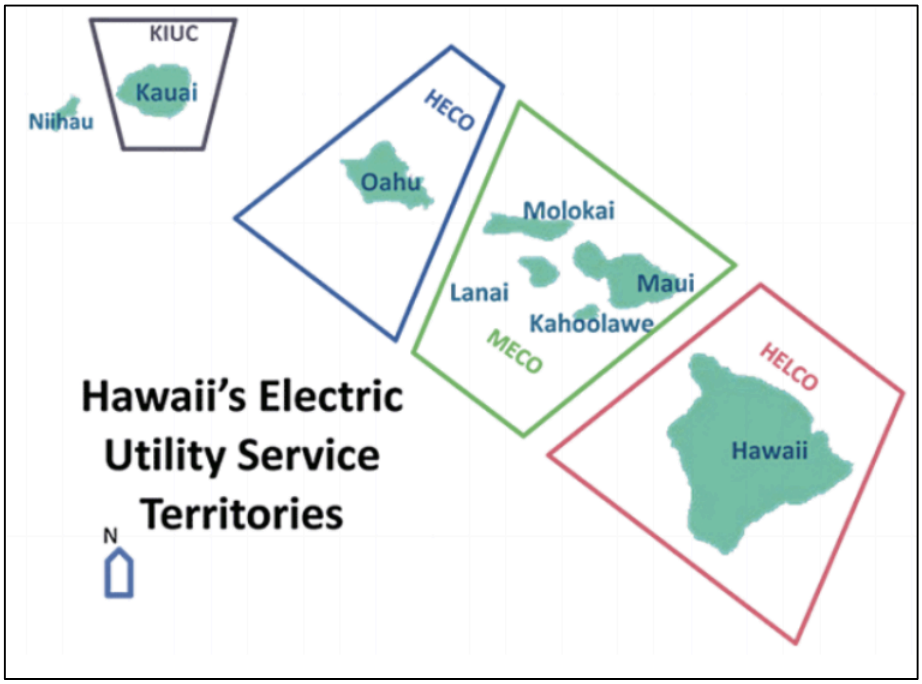

Figure 1 Map of Hawaii's Electric Utility Service Territories (from "Hawaii Energy Facts & Figures", 2016)

1.2: Community Solar Overview

Community solar programs are defined as solar PV systems that provide power and/or financial benefit to multiple individual community members by supplying renewable energy harvested from the sun. A study by the National Renewable Energy Laboratory (NREL) in 2008 found that only 22 to 27 percent of rooftops in the residential sector are acceptable to mount a PV system on (Coughlin et al., 2012). For this reason, a main goal around most community solar programs is to increase the participation and ownership of solar power for consumers with shaded roofs or renters living in apartments for shorter periods of time. Since ratepayers and taxpayers fund solar incentive programs, the economic benefits of solar energy should be extended to all contributors as a matter of equity. Other benefits from community solar programs include increased public education about solar energy, optimal project siting, local job creation, and improved economies of scale (Coughlin et al., 2012).

There are many different kinds of community solar programs with varying structures but the general purpose of a community solar program is to provide virtual net-metering in exchange for a financial contribution to the community solar project. Virtual net-metering allows multiple meters to benefit from the solar production of one system that is shared and distributed throughout a community. The financial contribution can be the up-front purchase of a panel or a section of the PV array or investors can make monthly contributions on their utility bill. As the system generates electricity that is typically fed directly back into the grid, the participants get credits reflected on their utility bill or another form of compensation that is equivalent to the amount of energy produced by the part of the system that the participant owns (Solar Powering Your Community, 2011). Members of community solar programs usually are not eligible for federal tax credits but some states now have incentive programs that include community solar projects. An example of this is the production-based incentives (PBIs) that are available to community solar participants of up to five thousand dollars per year. Utah also has a community solar income tax credit of 25 percent that customers can take advantage of as a participant of a community solar project (Solar Powering Your Community, 2011). Each individual state's policy will determine which type of community solar model will be most successful in implementing community solar projects in that area. For Hawaii, a model that also incorporates the integration of energy storage in community solar systems will be the most beneficial to help Hawaii reach its renewable energy goal.

1.3: Renewable Energy Storage Overview

With the growth of the renewable energy sector comes the unpredictability of energy availability during a time when supply and demand balance is crucial to achieving a stabilized power network that maintains load levels. An energy storage method is necessary in order to allow renewable energy resources to be easily adjustable to consumption needs, by releasing energy into the grid during peak hours when demand is high and storing energy during off-peak hours to increase the ability to load forecast with seasonal instability (Ibrahim et al., 2008). This requires network provisioning and usage regulations that establish optimal system operation.

Advantages of energy storage include leveling consumption at the final distribution point to utilize the full power output of existing networks, and reduce overall power installed that may overload the grid and increase the amount of curtailment from unstable renewable energy resources (Ibrahim et al., 2008). With lighter system designs, storage can compensate for load variations and make it possible to integrate grid transmission and distribution networks efficiently. Storage can ultimately help reduce curtailment in areas like Hawaii where an excess amount of solar energy is being fed back into an unstable grid.

These issues of decreased adoption of solar energy and grid overload and instability are preventing Hawaii from making essential progress towards their renewable energy goal. Community solar and energy storage can potentially alleviate these issues and allow solar to be the main contributor in reaching the goal of 100% renewable generation by 2045. This paper explores this possibility and asks:

> *Can the implementation of solar community energy storage systems in Hawaii alleviate their grid interconnection issues and contribute to the aggressive goal of 100% renewable generation by 2045?*

Starting in Chapter 2, this paper will first provide background on the solar PV market and its growth in the global energy industry. Chapter 3 will provide a more detailed overview of community solar and storage and how this relates to the integration of microgrid systems in the United States. In Chapter 4, a history of Hawaii's solar policies and incentives will be analyzed and the future plans for their renewable energy goals will be discussed. By looking closely at the overview of solar community energy storage and Hawaii's current solar energy market, Chapter 5 will provide a description of the methodology used in the research of this paper. Two solar community energy storage projects will be analyzed in Chapter 6 to determine if the projects were successful and what were the criteria that contributed to their success. Lastly, Chapter 7 will provide recommendations for a successful solar community energy storage project in Hawaii and summarize conclusions from the results of the analysis.

Chapter 2 – Solar PV Background

2.1: Overview of Solar Energy

Any resource that utilizes reoccurring energy from the natural environment to provide power can be considered a renewable energy source. Whether the sun's energy is used directly or indirectly, all renewable resources use solar radiation as the source of the power they produce. Each day solar radiation delivers ten thousand times the amount of energy needed by the planet to Earth (Chaar et al., 2011). However, with increased climate change, the natural processes that allow the sun to supply this amount of solar radiation daily may be compromised. For this reason, it is important to invest time and money in the development of renewable resources that will keep the natural ecosystems of the planet alive.

Solar energy generated by an inorganic solar cell was developed in the 1950s at Bell Laboratories. The first inorganic solar cell was based on silicon and had an efficiency of six percent (Spanggaard & Krebs, 2004). Silicon solar cells still dominate the industry today and have reached 24 percent efficiency in laboratory settings (Spanggaard & Krebs, 2004). In any PV panel, the solar cells are connected in series and in parallel creating a specific voltage and current level that maintain the wattage of the panel (Chaar et al., 2011). The goal of any solar development will always be maximum power at minimum cost; however, with a rapidly growing industry, this will depend on the materials and structure of the current technology.

There are four main types of photovoltaic technologies: crystalline, thin film, compound and nanotechnology. Crystalline structures are made of silicon and are the most prominent form found in the PV industry and are constantly being developed and improved. Mono-crystalline cells are used in 80 percent of the PV market because of the high efficiency from the single crystal ingot that is used. Poly-crystalline cells are less expensive but also less efficient than mono-crystalline cells. The benefits of converting to a multi-silicon cell are to decrease the flaws in crystal structures and reduce metal contamination (Chaar et al., 2011). Thin film technology lowers the cost of solar panels because there is less photovoltaic material used to manufacture the cells than with crystalline structures. However, a decrease in photovoltaic material results in lower efficiencies of the panel due to a decline in the ability to absorb incoming solar radiation (Chaar et al., 2011). Compound semiconductors are composed of a complicated stack of crystalline layers with varying band gaps engineered to absorb most of the solar radiation hitting the panel. This type of technology is used in concentrated PV (CPV) systems that use mirrors to focus the incoming radiation on solar cells. However, the expense of the substrate and the growth process cause this type of PV cell to be extremely expensive and compound semiconductors have only been able to break into the CPV market since this type of technology is not economically feasible for commercial and residential solar systems (Chaar et al., 2011). Lastly, nanotechnology being one of the newest solar technologies, aims to lessen the limitations seen in other PV technologies. This technology has the ability to control the energy band-gap that provides flexibility and inter-changeability and increases the probability of charge recombination (Chaar et al., 2011).

2.2: Types of Solar Installations and Storage Applications

Solar energy technology can be categorized as a PV system, concentrated solar power (CSP) plant or solar thermal installation for heating and cooling (Timilsina et al., 2012). PV systems consist of about 85 percent grid-tied installations that are either ground-mounted or racked to the roof of a building. These centralized grid-tied systems have exhibited the most growth in developed countries while off-grid applications are emerging in developing countries, like India and China, that have large rural populations that would benefit from electricity not tied to a conventional grid (Timilsina et al., 2012). Modern technology now allows PV panels to operate at 90 percent of its rated power capacity for up to 10 years and at 80 percent of its rated power capacity for up to 20 years (Devabhaktuni et al., 2013). There are many different companies that manufacture solar PV cells and panels but the top 10 manufacturers account for 45 percent of the total production (Devabhaktuni et al., 2013).

Concentrated solar power (CSP) uses mirrors to focus incoming solar radiation onto a smaller area that can efficiently convert this energy into power or heat (Devabhaktuni et al., 2013). The CSP market first appeared in the early 1980s but never took a strong precedence in the solar industry until 2007 to 2010 (Timilsina et al., 2012). Additionally, solar thermal systems used for heating and cooling are commonly found in the form of evacuated tube collectors and consist of a small but growing industry (Timilsina et al., 2012).

Solar power generation can benefit greatly from energy storage techniques that help reduce variability and curtailment that is caused by the unbalanced supply and demand system. The variations that cause these uncertainties are focused around seasonal and weather conditions, and location diversity. There is much controversy surrounding the debate of where energy storage will succeed first: at the distributed residential energy level, commercial solar level, or the centralized utility-scale level.

Residential rooftop solar allows the customer to have more control and understand the importance of how solar power works and benefits their daily lives. When incorporating storage into distributed solar power, quality can be improved by implementing storage resources at the end of distribution feeders. This is more effective and reliable than storage resources deployed centrally at the substation. In addition, the benefits extend to the utilities as well but provide flexibility and control from storage solutions incorporated with distributed energy resources. Since energy production does not typically match consumption it is important to create decentralized power stations that place energy production and storage at the same point as the load while also avoiding transmission costs (“The Big Question”, 2016).

Since the commercial and industrial energy sectors are being affected the most by the peak demand charges, some believe this is where most of the effort toward incorporating solar energy storage should be focused. For companies looking to increase self-consumption of the PV systems on their buildings, on site storage could help reduce the energy costs during peak hours and reduce potential carbon levies. This is exceedingly important in the commercial industry because, when outages occur, they affect whole businesses that sometimes rely on constant power even when the grid is down (“The Big Question”, 2016).

Overall, solar energy storage is economically infeasible for many small residential homes because of the high initial capital cost and longer payback periods. For this reason, utility-scale implementation has proven be the most cost effective form of solar energy storage in the current economic market. The implementation of centralized solar energy storage also provides ramp rate control and frequency regulation services. Larger utilities also have the ability to defer transmission and distribution system upgrades if storage solutions can serve the same function as the upgrade ("The Big Question", 2016). This also allows for a stabilization of load profiles and voltage and power flows at the distribution level. Excess power from PV installations is causing solar to expand at a lower rate because utilities are forced to limit system sizes to avoid curtailment of this excess energy. With these regulations in place, contractors can only build up to a certain size even if the space and funding are available to install a larger system. With the implementation of energy storage, solar PV will be able to expand at a greater rate without feeding excess energy back into the grid.

2.3: Global PV Market Growth

The PV market is growing at a rate of 35 to 45 percent annually which makes it one of the fastest growing industries in the world (Tyagi et al., 2013). Supporting this global growth of the solar industry are the renewable energy policies and incentives that encourage new industrial development and reduce the environmental impacts of the energy sector (Solangi et al., 2011). In 2015, more than 50 megawatts (MW) of solar capacity was installed bringing the global total to about 227 gigawatts (GW) (Sawin et al., 2016). Most of this global market expansion is occurring in direct response to rising economic competitiveness in PV, new government solar programs, increasing electricity demand, and an overall improved education of solar PV's potential to decrease CO_2 emissions and mitigate the effects of climate change (Sawin et al., 2016). By the end of 2015, all countries, except Antarctica, had installed at least 1 GW of solar PV capacity and 22 countries had installed 1 GW or more of solar PV capacity (Sawin et al., 2016). Figure 2 shows the total installed PV capacity for the top 10 countries, with the 2015 growth capacity added. This section will focus on the growth of the solar industry by country in 2015, as this is the most recent year referenced in the Renewables 2016 Global Status Report.

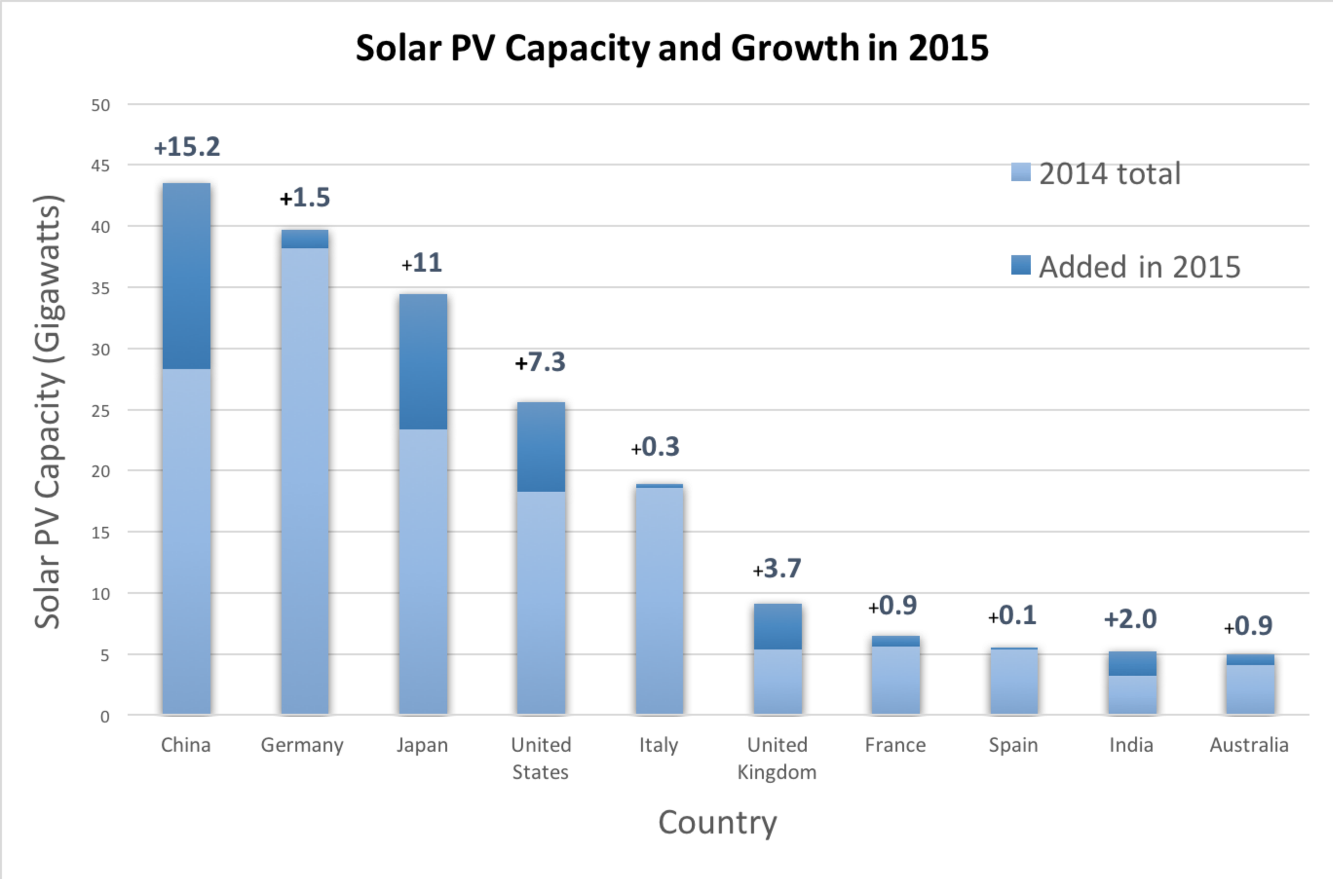

Figure 2 Graph showing the total installed PV capacity of the top 10 countries in gigawatts with the 2015 growth capacity added to the top (from Sawin et al., 2016).

Asia exceeded the growth of all other global markets in 2015 for the third year in a row, by contributing to 60 percent of the solar installation additions (Sawin et al., 2016). China now has a cumulative solar PV capacity of 44 GW, 19 percent of the world total, and contributed to 15.2 GW of the 2015 growth (Sawin et al., 2016). The majority of this total capacity is utility-scale power plants with small distributed rooftop systems only accounting for 14 percent of the total (Sawin et al., 2016). However, this rapid growth in PV capacity in China has caused grid congestion and interconnection delays that create curtailment in high overload areas. The government is urging these high penetration areas to prioritize construction of renewable transmission capacity and encourage energy-intensive industries to increase local consumption (Sawin et al., 2016).

Japan showed the second largest growth in PV capacity in 2015 with 11 GW added and a total capacity of 34.4 GW (Sawin et al., 2016). Similar to China, Japan's residential rooftop solar market contributed to less than one percent, 0.9 GW, of the total annual growth (Sawin et al., 2016). With the large percentage of commercial and utility-scale installations feeding the growth of Japan's PV market, land is becoming limited and contractors are turning to the use of abandoned farmland and golf courses. Japan is facing the same problems as China which are causing utilities to be forced to limit new interconnections and curtail excess power without compensation (Sawin et al., 2016).

The third largest growth in solar PV capacity of 7.3 GW was achieved in the United States where the current total capacity has reached 25.6 GW (Sawin et al., 2016). Much of this growth was attributed to the anticipation of the expiration of the federal Investment Tax Credit (ITC) that was extended through 2021 in late 2015 (Sawin et al., 2016). Utility-scale projects accounted for 4 GW of the total annual growth but the United States residential sector exhibited the fastest growth and new loan programs encouraged participation in direct ownership of solar PV systems (Sawin et al., 2016). California again contributed to the largest portion of the US annual growth with 3,266 MW installed, followed by North Carolina with 1,134 MW installed in 2015. About 39 percent of this PV capacity growth by the utilities was outside of the state renewable portfolio standard (RPS) mandate, which indicates many states were able to exceed their RPS goals. The challenges the United States is currently facing involves a battle over net metering and rate design (Sawin et al., 2016).

Europe has been struggling to increase their solar capacity for the past three years because of a shift in policy and deviation from the use of feed-in tariffs. Feed-in tariffs offer cost-based compensation to companies generating energy from renewable sources but have been phased out because solar power is becoming cost competitive in many markets and no longer needs to be incentivized. Therefore, Europe is moving towards a structure of tenders, where large-scale systems will have feed-in premiums and smaller-scale projects will be encouraged to use PV generation for self-consumption (Sawin et al., 2016).

In 2015, the United Kingdom was able to achieve the fourth largest annual growth in PV capacity reported at 3.7 GW. Germany contributed 1.5 GW of solar PV capacity to Europe's total capacity of 7.5 GW (Sawin et al., 2016). Germany has had a strong past of increased growth in the solar industry, ranking second globally of total installed solar PV capacity, but in the past few years the market has fallen significantly. The Netherlands and Italy also suffered a drop in the market even with the implementation of supportive renewable generation policies and low costs. Much of this decline is due to the challenge of finding a balance between making solar power cost-competitive while also adequately remunerating solar PV in the energy market. (Sawin et al., 2016).

In previous years, growth was concentrated in developed countries but there is now an emerging market in the developing world where demand for energy independent off-grid systems are growing. India grew substantially in 2015, ranking fifth globally in annual growth, 2 GW, with a total year-end capacity of over 5 GW (Sawin et al., 2016). The decreasing cost of PV and rising electricity demand in India lead to the increase in large-scale utility projects while the rooftop solar sector also experienced growth due to increased consumer awareness and a generous commercial tariff put in place in some states. India's main concern in reaching their goal of 100 GW by 2022 is congestion in the grid that is being caused by the rapid growth in PV projects (Sawin et al., 2016). This is similar to the situation in Hawaii where solar growth was halted in late 2015 when the Net Metering Law was removed and interconnection permits were limited.

The policies and incentives set in place have promoted the global growth of the solar industry and made solar an economically competitive energy option. However, issues surrounding reliability and accessibility of solar as an energy source are still present. Finding suitable roofs and/or space to install ground mounts that don't impede on natural habitats while also equally distributing the benefits of solar power to customers of all income statuses have been a challenge that community solar programs could provide a solution for. In addition, energy storage techniques are emerging as a viable option to smooth intermittency and unpredictability of solar power generation (Devabhaktuni et al., 2013).

Chapter 3 - Community Solar, Storage, and Microgrids

3.1: Community Solar Background

The National Renewable Energy Laboratory (NREL) lists three different community solar project models in their guide to community solar. The Utility-Sponsored Model is when a utility owns or operates a solar system that is open to voluntary ratepayer participation. The Special Purpose Entity (SPE) Model allows individuals to implement a community shared solar project by joining together in a business enterprise. Lastly, the Nonprofit Model is a community solar project administered and managed by a nonprofit organization on behalf of donors or members. Each can vary with respect to the system owner, system host, installation size, participation agreement, electricity distribution, REC (Renewable Energy Certificate) retention, and number of participants. RECs can also be referred to as Renewable Energy Credits and are considered a tradable energy commodity representing proof of 1 megawatt/hour (MWh) of renewable energy generation that was fed back into the grid. RECs are commonly sold on the open market or kept in compliance to laws that require a certain percentage of electricity to be produced by renewable resources (Coughlin et al. 2012).

The current barriers slowing the growth of the community solar energy market stem from old rules and regulations that favor large-scale development. With updated community, solar policies, the economic benefits of transitioning to a renewable energy economy can be achieved with the expanding participation in solar power generation. It is important to address all parts of what make a specific community solar project successful (Farrell, 2010).

Many community solar projects find it difficult to overcome the barriers to financial incentives that make solar more enticing to consumers. The structure of federal tax incentives makes it difficult to take advantage of the 30% solar Investment Tax Credit because entities like rural cooperatives and municipal utilities do not pay taxes, but are ideal organizations for community solar because they are member-owned and have experience producing electricity generators, controlling financing, and regulating the grid Farrell, 2010). Community solar programs that are not eligible for federal tax credits and accelerated depreciation have the option to use federally subsidized clean energy bonds or public and private grants, however, this means that most of the projects utilizing this form of financing will not be easily duplicated because of the complicated work done by the utilities and individual groups that put these programs together (Farrell, 2010).

Ownership structures provide another challenge to the implementation of community solar projects. In many community solar programs the participants and investors are not treated as owners. The project developer, the utility or special purpose entity, claims ownership rights and the investors are power purchasers via a subscription or lease that allows limited access to electricity generation for a fixed time. The limited access of this agreement is sometimes shorter than the payback period leaving participants without electricity generation access while still paying back the capital investment made in the solar project (Farrell, 2010). The appeal of third-party ownership comes from the risk of equipment failure and ongoing maintenance that is usually required with any solar installation. Residential customers with little knowledge of the technical background involved in solar systems may be more inclined to join a third-party solar ownership programs like SunRun and SolarCity to minimize these concerns. However, this structure commoditizes solar energy, making it feel the same as buying nonrenewable electricity from the utility (Farrell, 2010). Ownership of an individual solar array allows the consumer to have a tangible sense of the balance between production and consumption and the importance of investing in renewable energy generation. Community solar projects run the risk of commoditizing solar if the installation is not owned by the participants and cannot provide the tangible effect of investment in renewable energy. However, as long as the community solar array is within a limited distance of the participants this can be minimized (Farrell, 2010).

Cost and affordability are also important aspects of community solar projects that need to be addressed. Generally, community solar projects will have lower upfront costs due to economies of scale that allow for lower installed cost per Watt than a typical rooftop installation. One-time money from grants and renewable energy bonds helps lower this upfront cost as well as federal incentives helps projects allow for a superior payback to individuals participating in these programs. One-time money and federal tax incentives are both helpful but should be assessed on a per project basis to decide which option would provide an opportunity for funding on future projects and help expand the community solar market (Farrell, 2010). In general, a fixed price guarantee would be a better investment than federal tax credits or a one-time grant because the low risk would allow the financing costs for community solar projects to decrease dramatically. It can be seen from analyzing different community solar projects that community solar makes solar more accessible to a wider range of individuals but is not necessarily more affordable at this time (Farrell, 2010).

Site location is another challenge community solar programs struggle to successfully implement in their projects. Preserving open space is an extremely important part of environmental awareness that the solar industry needs to focus on when selecting locations for solar installations. This is mainly a concern for utility-scale projects that should not be located near habitats of endangered species that may become unintentionally segmented from their natural ecosystem. By using existing structures or unusable land, community solar projects can gain a competitive advantage against utility-scale PV systems. Utility-owned community solar projects generally use open fields on utility property. This is advantageous when trying to easily tap into the existing grid structure, however, these installations could have been located on existing buildings surrounding that area to preserve open space (Farrell, 2010).

Lastly, reliability and replicability of a community solar project is an important challenge that will allow future projects to be successful. Since the community solar industry is not yet a mature industry it is imperative that a model based on successful community solar installations be created that other communities can use in the future. The reliability of a replicable community solar structure is largely associated with the community solar policy of that area. Colorado, for example, has had success in implementing policy that will help create a legal structure for communities to overcome the barriers discussed in this section (Farrell, 2010). The model used for implementing community solar policy in Colorado will be used in Chapter 7 to suggest a similar policy structure in Hawaii.

3.2: Types of Renewable Energy Storage

Energy storage options, specifically in the solar energy sector, can be split into two types: electricity storage and thermal energy storage. Electricity storage can be classified by electrical, mechanical, or chemical storage with associated usage in the form of bulk energy, distributed generation, or power quality. Thermal energy storage, on the other hand, can be stored directly as sensible heat storage, like steam or hot water, as sorption storage, where two chemicals are separated using solar power and produce energy when released, or chemical energy storage, where transportable fuel is produced by endothermic chemical transformations (Hou et al., 2011). Thermal energy storage will not be discussed in detail in this paper as the focus of this research is on electrical energy storage options for integrated community solar systems.

In small-scale system,s energy storage methods are used with low- and medium-power applications usually to feed transducers and emergency terminals. In large-scale systems, energy storage tactics are integrated into power quality control and network connection applications with peak leveling (Ibrahim et al., 2008).

Pumped hydroelectric storage (PHS) and compressed air energy storage (CAES) are both large capacity storage systems that require unique geographic site locations. In pumped hydroelectric storage systems, excess energy generated during off-peak hours will be used to pump water from a lower reservoir to an upper reservoir, converting electrical energy to gravitational potential energy (Ibrahim et al., 2008). PHS has the largest storage capacity that is commercially available and can have up to an 87% efficiency rating (Hou et al., 2011). The main advantage of this type of storage is that it is readily available and can store energy for long periods of time. In Compressed Air Energy Storage, off-peak excess energy is used to compress air and the residual heat that is recovered is used to heat the air and expand it in a combustion chamber before releasing it to gas turbines that generate electricity during peak hours (Ibrahim et al., 2008). Along with a lower overall efficiency of 70%, the main drawback of this system is the use of fossil fuels for the gas turbine in a heat recover steam generator (HRSG) that emits greenhouse gases during operation (Hou et al., 2011).

A flywheel storage system uses energy to spin a mass via a motor during peak hours and at discharge the motor becomes a generator that produces electricity inside a low-pressure case to reduce self-discharge losses (Hou et al., 2011). This type of energy storage has an efficiency of up to 90% but only for a limited duration, after which the efficiency drops to 78% within 5 hours and 45% after one day (Ibrahim et al., 2008). Therefore, FES systems are usually only applicable for short-time bridging storage situations.

Fuel cells are another type of energy storage where water electrolysis is used to produce hydrogen from external supplies of restored spent energy. The hydrogen produced from electrolysis and oxygen from air produce electricity and water in the fuel cell (Hou et al., 2011).

There are many different kinds of fuel cells that are differentiated by the electrolyte used, operating temperature, design, and application. They are used in decentralized applications in low-power residential areas, in mid-power cogeneration networks, and centralized electricity production without upgraded heat (Ibrahim et al., 2008). They can be used in isolated areas where the installations of power lines are required and generally too expensive. Fuel cells have a limited life expectancy and are a low-efficiency solution with just 50% efficiency associated with the fuel cell and up to 70% efficiency with the electrolyzer.

Lastly, flow batteries use two electrolytes in a liquid state that are stored separately and pumped through an electrochemical cell that overcome the limitations of standard batteries by expanding the limitations to capacity (Hou et al., 2011). They have negligible self-discharge and are mainly used for long-duration storage. The overall efficiency of these systems is about 75% (Ibrahim et al., 2008). Drawbacks to flow batteries include an efficiency reduction and power density limitations caused by the energy used for pumping and energy loss in chemical reactions.

Currently, the most common storage method used in the solar industry to alleviate curtailment of excess energy and support backup generation when the grid is down is battery storage. Batteries have commonly been too expensive for residential and commercial customers to purchase but are coming down in price due to an increase in peak hour electricity pricing that is causing greater demand (Hou et al., 2011).

Overall, a standard battery is the most common form of energy storage currently used in the solar industry. A battery converts stored chemical energy to electrical energy but, when that chemical reaction is reversed, electricity can be stored when energy from solar systems are supplied. Batteries are evaluated on characteristics such as energy capacity, efficiency, lifespan, depth of discharge and energy density (Hou et al., 2011). There are many types of batteries now used as storage methods, of which lead-acid is the oldest and most mature. The Li-ion battery is most suitable for small portable devices and has a high cost with a short lifetime. NiCd and lead-acid batteries supply high power capacity in short time spans, known as pulsed power, but are larger devices made of toxic materials and experience sever self-discharge. Lead-acid batteries are also commonly used in the residential solar market. The NaS battery is a more compact batter and lighter in weight but requires a constant heat input for operation. The metal air battery is lower in cost with a high-energy density but is extremely difficult to recharge. Overall, the Li-ion, NaS and NiCd batteries are leading in the technology advancements of high-power-density battery applications (Hou et al., 2011).

Expanding the advantages of energy storage to a community setting is important in a state like Hawaii that has an aggressive renewable portfolio standard. Focusing on the development of community energy storage in the solar energy market is one of the first steps to achieving this high renewable energy goal in a state with extremely high solar potential but an instable power grid.

3.3: Community Energy Storage Applications

3.3.1: What is Community Energy Storage?

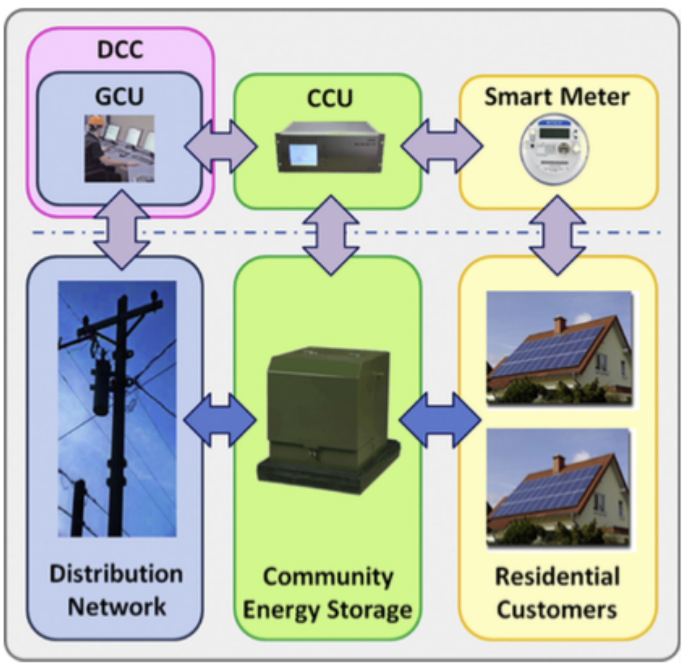

Figure 3 Diagram showing a hierarchical CES system control layout (from Arghandeh et al., 2014).

Community energy storage (CES) systems are small distributed energy storage units connected to transformers that are capable of simultaneously feeding real and reactive power into the grid. These distributed energy storage systems (DESS) act as large battery systems that create a small microgrid downstream for the CES and provide reliability benefits to the end-user ("DTE Energy", 2015). The reliability provided by the CES systems comes from the connection between numerous storage units that are unlikely to all be out-of-service at the same time. These systems operate under a hierarchical control system where the CES Control Unit (CCU) maintains secondary voltage and serves the load while also controlling the charge and discharge commands set by the Group CES Control Unit (GCU). The Distribution Control Center (DCC) is where forecasted load, operational alerts, and Locational Marginal Price

(LMP) data are gathered and analyzed to be able to prevent future transformer overloads and low voltages (Arghandeh et al., 2014). The CES system integrates with residential level distributed loads to perform transformer-level peak shaving (Figure 3).

3.3.2: Benefits & Challenges

There are many advantages to CES that focus around the flexibility and fast-responding nature of the system that enhances stability and power quality throughout the electricity grid. In order to flatten demand profiles and improve load factors CES shaves the peak load by storing off-peak energy that is released to the grid during on-peak hours.

The ability of the CES system to generate peaking power during the peak load period allows for a reduction in gas combustion turbine plant costs. Additionally, CES promotes energy arbitrage which leads to the direct benefit of buying energy at a low price during off-peak hours and selling it back to the grid at a higher price during on-peak hours. Energy loss reduction is another benefit seen from CES discharging power to the grid that causes a reduction in the peak demand.

If the CES system is located in the right area it may allow a deferral of the transmission and distribution (T&D) system upgrade. That amounts to the annual revenue of utility ratepayers and covers the single-year cost. This cost could be avoided with the integration of a CES system that serves the local peak demand by providing power locally. Also, there is reduction in CO_2 emissions by the peak electricity demand shaving of CES systems and reactive power (VAr) support that maintains the voltage levels on the distribution and transmission systems (Sardi et al., 2017). Overall, with CES systems installed at the customer level, instead of the transmission or distribution station level like typical storage systems, an electrical supply of power can be reliably delivered to the consumer on a daily basis.

Most of the challenges with implementing CES systems result from the lack of successful pilot projects to reference and replicate when aiming to create a model framework encouraging policy incentives in the community energy storage field (Pathways to community energy storage, 2015). Additionally, the economic barriers of most battery systems are slowly decreasing but may require more research and technical development before entering the renewable energy market as a viable storage option (Pathways to community energy storage, 2015). The development in this area can be used to make microgrid systems more robust and reach a wider range of consumers.

3.4: Microgrid Communities

3.4.1: Microgrid Objectives

A microgrid is a network of smaller electric power systems with distributed energy resources (DERs), energy storage units, and loads capable of supplying a local community with electric power. The microgrid concept was proposed by the Consortium for Electric Reliability Technology Solutions (CERTSs) and can operate interconnected with the grid or islanded with the intention to enhance the local flexibility and reliability of electrical power systems (Tan et al., 2013). A remote microgrid is most useful for distant locations that cannot easily connect to the central grid. Grid-connected microgrids are similar to large central electric grids but with a much smaller footprint and can include energy storage and electric vehicles. These microgrids do not only offer backup capabilities, they also include smart energy management as well. This allows for a decrease in energy costs for customers of the larger grid while also maximizing efficiency of the central grid. Community microgrids ensure consumers receive critical services during a grid outage.

Community microgrids help cities face three major challenges: infrastructure, finance, and economic development (Community Microgrids, 2015). They help keep critical services, like police stations and hospitals, operational during an outage while also strengthening the central grid by accepting excess energy that the central grid cannot during extreme hot and cold that put strain on the central grid and cause it to become overtaxed. With ancillary services community microgrids offer, the frequency of the grid can be monitored and maintained at a stable level and grid security can be improved. Community microgrids also promote the participation in demand response programs that likely offer financial compensation. The improved economics and bankability of community microgrids comes from the highly efficient and cost-effective nature of the microgrid system that allows for the use of heat that is usually discarded (Community Microgrids, 2015). The European Research Project Cluster is investigating the integration of renewable energy and distributed generation in the safety and telecommunication infrastructure of microgrids (Ibrahim et al., 2008). This shows the wide range of applications throughout the world that microgrid models can have an effect on.

The integration of renewable energy resources and microsources, like PV solar power, with battery storage facilities creates a modern concept of the microgrid which allows distributed energy resources (DERs) to give customers a scale of energy flexibility by relieving stress on transmission and distribution systems (Basak et al., 2012). With distributed generation (DG) alone there are many barriers that can be solved with the addition of a microgrid. The fluctuations due to weather conditions make it difficult for the grid to rely on distributed generation as a main source of power especially considering the lower voltage levels DG units operate at, requiring additional electronic devices to make the power compatible with the grid. Most importantly the energy imbalance between the generation and load in a system where distributed generation units are transmitting energy into a central grid is inefficient (Mahmoud et al., 2014). The integration of microgrids can help solve these problems and become the models for future smart grid solutions.

3.4.2: Microgrid Projects in the United States

In the United States, the Konterra Solar Microgrid project was a completed in 2013 in Laurel, Maryland. The microgrid consists of a 402kW solar canopy with 300kWh of battery back-up capabilities and two electric vehicle charging stations. This is one of the nation's first commercial microgrids, allowing Konterra to gain energy independence and grid integrity for participation in ancillary services in the electricity market. During peak hours, the parking lot solar canopy will provide up to 20 percent of the building's annual energy production and assist in demand reduction and peak shaving ("Konterra Solar Microgrid Project.", 2016).

In Hawaii, a lithium ion phosphate battery was used in the Zerobase Ocean Vodka PV Microgrid project. Zerobase is a renewable and hybrid distributed power company specializing in rugged, off-grid, remote systems. The family-owned organic farm and distillery on Maui now contains a 100kW microgrid with a 60kW PV system and 600kWh energy storage capabilities. The system is capable of going off-grid when necessary and experiences independence from volatile energy costs, and continued operation with grid instability. The project was able to take advantage of federal and state tax credits that brought their payback period down to under 3 years (Zerobase).

Another example of a microgrid system in Hawaii used a lead-acid battery application and was commissioned and constructed by Lanai Sustainability Research in 2011. A 1.2MW solar farm was installed in La Ola, Lanai with the intent to power the island's residents and resorts but was found to only represent 30 percent of the islands peak generation in Lanai's 4MW grid. During an analysis of the system, it was revealed that the solar farm had to maintain an unachievable ramp rate of 360kW per minute and a power factor of 0.95 to avoid negatively impacting grid reliability. Along with these qualifications, the PPA that Lanai Sustainability Research signed, required frequency response data to be provided that was not achievable with the current system. Therefore, the Lanai Sustainability Research was forced to curtail the La Ola farm to 600kW to meet the local utility regulations. With only half of the solar system producing useful energy, Lanai Sustainability Research partnered with Xtreme Power to design a 1.125MW storage facility that provides ramp rate control, power quality management, and frequency response. This allows La Ola to provide the largest percentage of solar penetration reliably and efficiently to the first independent island grid in the world ("Solar PV-Storage: Lanai Sustainability Research Dynamic Power Resource (DPR®) Energy Storage").

These two microgrid projects in Hawaii emphasize the importance of implementing a storage technique that also provides monitoring and PV variability control in communities. With the implementation of community energy storage technology into solar microgrid systems Hawaii could have the potential to become a state with 100 percent renewable generation by 2045.

Chapter 4 – Hawaii's Solar Energy Industry

The rapid expansion of the solar industry in Hawaii was largely attributed to the solar incentives and policies that were established over 30 years ago. Since then Hawaiian customers have taken advantage of the large amount of solar radiation they receive adopted solar power as one of the fastest growing renewable energy sources of that state. With high electricity prices due to the import of all fossil fuels to Hawaii, solar has become one of the most economically feasible renewable energy solutions for the future.

4.1: History Before Removal of the Solar Incentive Tax Credit

With new research and development in the solar technology field, efficiency is increasing rapidly and the policies to encourage the adoption of solar power are changing with it. In 1976, Hawaii enacted its first tax credit to promote the purchase of solar equipment and reduce the reliance on fossil fuels, which was initially intended to be a “limited-time-only” incentive for businesses and homeowners but was extended for years following. In response to the energy crises of the 1970’s, the Energy Tax Act was passed as part of the National Energy Act in 1978. This bill included a two-thousand-dollar tax credit for solar installations and a 40 percent tax credit for solar space and water heaters, both of which were phased out in the mid 1980’s ("Brief History of Solar and Hawaii Photovoltaic Highlights.", 2014).

In 2006, the federal government issued a renewable energy tax credit in which homeowners were given a 30 percent tax credit for solar PV systems installed in addition to the state credits already in place. In 2008, Hawaii announced its Clean Energy Initiative that aims to meet 70 percent renewable energy by 2030 (Energy Agreement Among the State of Hawaii, 2008). That same year the Hawaii Legislature focused their initiatives on the approval of multiple bills directly related to the promotion of Hawaii’s solar industry. House Bill 2502 allows solar energy installations to be located on less-productive agricultural lands and Senate Bill 988 allows the Hawaii Public Utility Commission to enact a solar rebate, while House Bill 2550 encourages net metering for customers with residential or small commercial systems ("Hawaii State Legislature.", 2017). In 2013, Senate Bill 1087 created the foundation for the Green Energy Market Securitization program (GEMS) that promotes a financial model aiming to make solar more accessible and practical for renters, non-profits, and lower-income homeowners (GEMS (Green Energy Market Securitization) Program Frequently Asked Questions, 2014).

In October of 2015 the Net Energy Metering interconnection model was phased out that would no longer allow solar power to be supplied in surplus back to the grid and receive credits at the retail rate for those solar kilowatt-hours. This phase-out is supposed to last until the Distributed Energy Resources docket releases phase two of the PUC plan. This transition decreased the number of solar permits issued dramatically on Oahu, Maui, Lanai, Molokai and Hawaii. The peak year for number of permits issued was 2012 for Oahu, 2015 for the Big Island and Maui, and 2014 for Kauai (Mangelsdorf, 2017) (Figure 4). These statistics include data from 2016 but every island experienced a decrease in permits issued in 2016. Since October of 2015, homeowners interested in adopting solar in Hawaii must do so under the Customer Self Supply (CSS) program which adds additional complexity and cost from not being able to feed back into the grid and the requirement of battery storage additions to the system. This has led to less enticing return on investments and longer payback periods (Mangelsdorf, 2017).

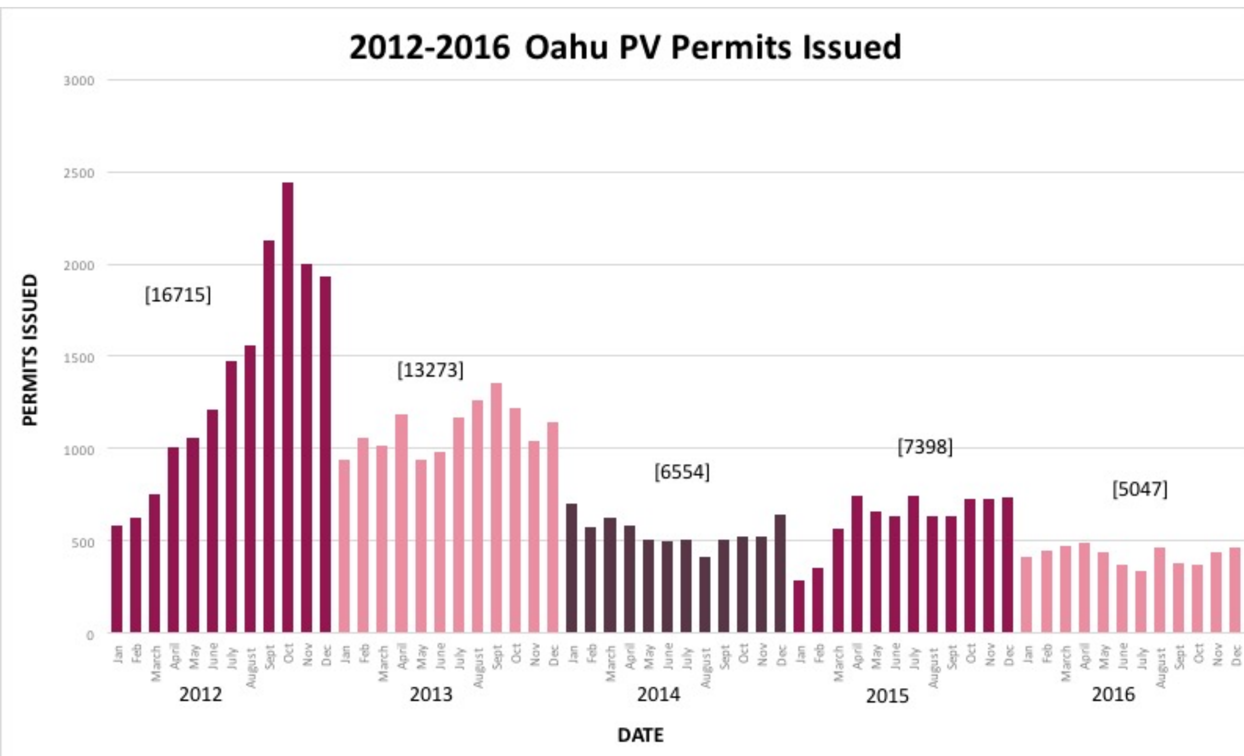

Figure 4 Graph of PV Permits issued from 2012 to 2016 on Oahu showing a significant drop, with 2016 being the lowest year (from Mangelsdorf, 2017).

4.2: Community Solar Policy in Hawaii

The Hawaiian PUC is working on implementing a community-based renewable energy (CBRE) program that would allow customers to buy interest in the electricity generated by a community solar project that is installed at diverse locations on specific islands. It is difficult for most Hawaiian residents to take advantage of solar power because more than 40 percent rent their homes and 37 percent live in multi-unit properties (Shimogawa, 2017). HECO filed its CBRE plan in 2015 under SB1050 that requires electric utilities in Hawaii to establish a community-based renewable energy program. Under the proposed program, an average consumer that uses 500 kWh of energy per month pays an upfront cost of $5,711 with a $200 enrollment fee and small monthly maintenance fees. The consumers will see about a 45 percent reduction in their electricity bill with credits received based on the current utility-scale solar power market rate ("Hawaiian Electric's Community Solar Program.", 2015).

However, the Hawaii PUC found many issues with the proposed pilot community solar program. The program limited flexibility by including flat bill credits and cost calculations while not encouraging features like dispatchability, that allows solar plants to deliver a consistent volume of energy to consumers that is comparable to or better than conventional power plants. The Hawaii PUC staff expressed the importance of time-of-use rates that should be used to set the value of the bill credits. The value the project provided to the grid should be directly related to the compensation that is received. The staff proposed an alternative CBRE plan that drew core elements from the Kauai Island Utility Cooperative (KIUC).

The PUC staff's proposal suggested three credit rate caps for Mid-Day, On-Peak, and Off-Peak in which there is higher compensation for peak generation. This framework allows prices to be set based on market signals for all project sizes and types. The tiered structure included in HECO's original plan stayed in the PUC's proposal. The first tier would avoid the higher administrative costs of small systems while keeping the installations at a community-scale by only accepting projects from 25kW to 250kW in size. Tier two is selected through a competitive reverse-auction bidding system for projects over 250kW in size in hopes of encouraging diversity through the Hawaiian solar industry (Trabish, 2106).

HECO responded to the PUC staff's proposal with three major issues. First, the plan lacks appropriate customer protection standards that promote business models that require registration under state and federal security laws. Second, the program will increase implementation risk and administrative costs because of the complexity of the TOU credit rate caps and project tiers. Lastly, the plan does not account for a potential cost-shift for non-participating customers that would experience a premium increase because of the high credit rate caps that are much higher than the current marginal costs. It is important to find a balance between cross-subsidization and credits that are high enough to incentivize customers that have previously been denied from participating in the solar energy market. There has been much back and forth between HECO and the PUC but Jeffery Ono, the executive director of the Hawaii Division of Consumer Affairs, said the most important thing is to assess the shortcomings of the NEM program and apply the lessons learned to the CBRE program (Trabish, 2106). The Hawaii regulators were set to make a decision at the end of January 2017 but news has not yet been released to the public.

4.3: The Future of Hawaii's Renewable Energy Portfolio

The Hawaii State Energy Office (HSEO) is directing the clean energy initiative with support from the Energy Resource Coordinator (ERC). Hawaii's State Administration declared 100 percent renewable energy generation by 2045 as the new renewable portfolio standard that will ultimately help Hawaii achieve energy independence by decreasing dependence on fossil fuels and harnesses the natural resources Hawaii's land has to offer. This clean energy vision was part of HB623 passed in 2015 that also increased the interim target to 30 percent by 2020. This bill began an inspiring relationship between the State of Hawaii, the U.S. Department of Energy, and the military and private sector that helped to create the next phase of the Hawaii Clean Energy Initiative (HCEI). HCEI 2.0 is aimed at enhancing the interconnection and interoperability at the distribution and transmission level and creating an efficient energy market that supports both producers and consumers. Hawaii has reduced electricity demand by over 1,500 gigawatt-hours and has been recognized as the nation's leader in performance contracting on a per capita basis for the last three years ("Hawaii's Clean Energy Future"*, 2015*).

Even with these promising renewable energy goals, Hawaii will not be able to achieve them without an efficient way to store energy while also still encouraging the growth of the solar industry. The removal of the net metering credits and the additional caps put in place under the new incentive programs will effectively decrease the overload to the grid but will dramatically halt the growth of the solar industry in a state that has an incredibly high solar radiation potential. Policies directly supporting the growth of community solar and storage projects in Hawaii need to be expanded if Hawaii plans to reach their goal of 100 percent renewable generation by 2045.

Chapter 5 – Methods

The viability of community solar and storage for helping Hawaii achieve its renewable energy goals will be explored by analyzing two existing solar community energy storage (CES) projects: Detroit Edison Community Energy Storage Project and Sacramento Municipal Utility District Anatolia Pilot Project. First, the success of each project will be determined based on the completion of the project goals that were set. Both projects had different goals that were specific to the solar CES system used in that project but for the purpose of this analysis each project will also be evaluated based on its ability to decrease intermittency of PV generation, reduce utility system peak loading that causes overload to the grid, and develop an integrated communications system to sufficiently utilize the full capacity of the battery system. Next, the characteristics that made these projects successful will be analyzed based on five criteria: the renewable portfolio standard of that state, available funding, level of solar incentives, site location, and available solar radiation. Lastly, this analysis will be used to provide recommendations for future solar community energy storage models and policies that would create successful projects in Hawaii based on the success of these projects and the challenges they faced.

The two solar CES projects chosen for the research of this paper were selected because they provided the most complete information on details of the project that are necessary in evaluating the criteria of success for each project. Since community solar and energy storage are both extremely new and underdeveloped technologies, projects involving the integration of community solar and storage together are few. Therefore, even though Michigan and California have vastly different climates and grid structures than Hawaii, these two solar CES projects were used to assess the viability of solar CES as a potential solution to grid overloading and instability but the results of other projects or programs that more closely relate to Hawaii may be used to recommend models of success for solar CES projects in the future. The lack of available information on a variety of different solar CES projects will diminish over the next few years when energy storage becomes more cost competitive and information on projects more closely related to the situation in Hawaii will become accessible and analyzed based on the same methodology of this research.

Each of these five criteria are important considerations in the success of solar community energy storage projects. A renewable portfolio standard (RPS) is a regulation requiring utilities to produce a certain amount of energy from renewable sources in an effort to reduce fossil fuel generation. They can be used to provide "carve out" provisions for a particular renewable energy technology that mandate a specific percentage of the renewable energy of that state be generated by a particular technology, like solar or wind. The most successful plans are implemented in combination with the federal tax credit and twenty-nine states now have an established RPS that can help enhance economic development, diversify the energy mix and reduce greenhouse gas emissions ("Renewable Portfolio Standards.", 2015). Most states measure the goals for their RPS by percentages of kilowatt hours of retail rate electricity and set targets that ramp up steadily over time (Durkay, 2015). This is an important criterion of success for a soar CES project because states with aggressive RPS goals will be more likely to support projects that help them reach the overall renewable generation goal that state has set.

Funding for solar projects is largely based on the RPS of the state, however, federal funding is also a viable option. However, with the current government administration future solar CES projects may be less likely to get federal funding and may have to rely on state incentives. It is important to analyze this criterion to determine if the type of funding received contributed to the success of the project and can be implemented into a model used in Hawaii.

Funding received for a specific project will generally be used to help cover the capital cost of the project while state solar incentives can be utilized to help reduce the electricity cost for end-users. With the federal investment tax credit no longer in affect as of December 31st 2016, many solar installers and contractors will have to rely on state incentives to promote the adoption of solar in the residential and commercial energy sectors. More specifically, community solar programs and incentives will be evaluated for the state each project is located in. This is an important criterion to evaluate the success of solar CES projects to determine what type of state incentives and tax credits benefit the growth of community solar and storage programs.

Solar CES technology targets a specific community that is either experiencing power outages or limitations in the amount of solar energy that is allowed to be produced and fed back into the grid. For this reason, it is important to identify characteristics of the selected site location of the two solar CES projects in order to determine what type of community was targeted and why. This criterion will be important in evaluating the areas of Hawaii where the proposed solar CES projects would have the most impact on the surrounding community.

The available solar radiation of each city that the solar CES project is located in will be evaluated using Google's Project Sunroof tool and other spatial pattern maps showing overall annual solar radiation of an area. Solar radiation variability and patterns are essential to consider when assessing potential site locations for new solar installations. The most intense radiation occurs when the incident radiation is perpendicular to the surface and can be affected by location, time of day, current season, cloud cover and atmospheric fluctuations ("Solar Radiation of Hawaii.", 2014). The Google Sunroof application gives the total estimated rooftop solar potential as a percentage of total roofs in that area along with the total solar capacity in megawatts. This tool only takes into account space on roofs that do not contain obstructions like, chimneys and skylights, and have enough space for at least four solar panels. Since only rooftop solar potential is measured in Project Sunroof the results of the states evaluated in the solar CES projects will be taken in general terms and directly related to the type of installation that was part of the project, rooftop or ground mount solar. This analysis will also be important in establishing the probability of success for projects implemented in Hawaii and will be used to determine the type of solar installation in high solar radiation areas that would benefit the most from a community energy storage integration.

Research on the specific storage programs already established in Hawaii and the solar incentives for each of the four utility grids will be assessed based on the relevance to the successful solar CES projects presented. The geography limitation of each area and the potential sponsors for the creation of new community solar and storage generation will be obtained. The information from these case studies and Department of Energy project reports will be analyzed to give recommendations on how the Hawaiian PUC should move forward in the energy market while supporting the growth of distributed solar power that can be available to everyone without over loading the grid. Maps showing the areas of each island with the highest overloading of distributed energy resources will be used to recommend ideal locations for potential solar community energy storage projects. The success of these pilot projects will be based on the ability to relieve overloading stress on the utility grid, as this is the main concern delaying the increase in solar energy that can, ultimately, help Hawaii get to their goal of 100% renewable generation by 2045.

Chapter 6 – Analysis of Solar Community Energy Storage Projects

The community energy storage (CES) market is an extremely new industry and the integration of solar PV systems into CES projects is an even more recent development. For this reason, the projects that will be assessed in this chapter are considered pilot projects and may not be fully developed. The structure and model used to implement the project will be analyzed based on the replicability of a similar project on the Hawaiian Islands.

First, each project will be analyzed based on the goals set by that specific project and if these goals were successfully met. Next, an analysis of the five criteria stated in the previous chapter will be provided to determine the factors that contributed to the success of that project. These criteria include the renewable portfolio standard of that state, available funding, level of solar incentives, site location, and available solar radiation. Both projects may prove to be successful but the criteria that have the most influence on the success of the project may vary, and one project may be more applicable to the implementation of future solar CES projects in Hawaii than another.

6.1: Detroit Edison Community Energy Storage Project

Detroit Edison has initiated multiple CES projects, one with residential units and another utilizing a community college as the location for the system. Detroit Edison's goal was to install 20 CES systems across the utility territory with the integration of a renewable energy source. The CES devices were programed with peak shaving and demand response capabilities while providing ancillary services to the grid by the use of energy storage devices ("DTE Energy", 2015).

The residential CES units use a 500kW lithium battery with energy conditioning capabilities allowing it to locate backup power near the customer. Each 25kW CES unit is integrated with a PV solar module and placed in 20 different residential homes. The systems will demonstrate demand response, peak shaving, voltage support, and emergency load relief with islanding during outages. The Monroe County Community College received funds from the American Recovery and Reinvestment Act in 2011 to install the 500kW solar. A 500kW battery was integrated into the PV system allowing the energy from the solar system to be discharged more steadily throughout the day. The distributed energy resource management systems (DERMS) used by DTE Energy enabled the CES units to act individually or as a fleet demonstrating flexibility in a distributed system. In these CES units a circuit breaker is used as protection and when open, creates a local microgrid that delivers energy to the customer until the side voltage is restored and can switch back to a grid-tied system or until the battery energy is depleted ("DTE Energy", 2015).

6.1.1: Was the Project Successful?

The team performing this project proposed many goals that focused on the functionality of a Li-ion battery community energy storage system integrated with a solar installation. They also tested a secondary-use electric vehicle battery as a storage option. Even though the initial attempts to utilized a refurbished electric vehicle battery failed, this issue was resolved before the installation of the CES units and, therefore, did not affect the outcome of the project and can still be considered a successful project.

The fluctuations in PV generation were minimized by shifting the solar production from the middle of the day when solar would usually generate the most energy to hours of the day when PV systems normally contribute a small amount of energy to the distribution circuit. This shift was caused by the ability of the CES units to dispatch energy as needed during the day while the PV system was generating energy charging the batteries for later use ("DTE Energy", 2015).

To address the goal of reducing the overall system peak load and avoiding overloading to the grid the CES systems were able to provide voltage support and frequency regulation that detected these loads before becoming detrimental to the grid. While monitoring the CES systems it was reported that no known overload incidents occurred at the test feeder or circuit feeder level ("DTE Energy", 2015). However, there was an issue regarding the varying time in which solar cells would hit max voltage of the panel which would cause the whole CES inverter to stop charging. This left the solar panel with more energy generation potential but nowhere to convert and store the energy. Once the cells were confirmed to hit the same max voltage and the CES system was able to accept additional energy from other cells when the max voltage of one cell was hit, the CES system was able to effectively reduce the peak load of the utility grid system ("DTE Energy", 2015).

Detroit Edison was able to establish a distributed energy resource management system (DERMS) that acted as a communication system for distributed energy storage system. The DERMS approach used a cellular communication medium as the most economical solution to manage a fleet of distributed energy storage units ("DTE Energy", 2015). Overall, the project was successful because it met the goals that were set by the team after necessary revisions were made that became apparent after multiple test runs.

6.1.2: What Made the Project Successful?

Michigan currently has an underdeveloped renewable portfolio standard (RPS) with a minimum generation level of 10% that has already been met by the two largest utilities in the state, Detroit Edison and Consumer's Energy. They have a goal to raise the renewable generation to 15 percent by 2021 and a nonbinding agreement to potentially reach 35 percent by 2025 (Talberg et al., 2017). This is a weak RPS that will not successfully encourage the growth of solar and other renewable forms of energy in Michigan. Additionally, electricity prices in Michigan are the 12th highest in the nation which means there is large opportunity to save on electricity costs but not as much incentive as there is for customers in California or Hawaii that have even higher energy costs (Talberg et al., 2017).

The Detroit Edison Solar CES project was funded in part with a grant from the U.S. Department of Energy and the Office of Electricity showing that federal funding played a larger role in making this project possible than Michigan state incentives. Also, even though Michigan does not have a strong renewable portfolio standard, Detroit Energy is one of the two most prominent utilities in Michigan that is largely responsible for the state's ability to hit their renewable energy goal and, therefore, is likely to get funding for projects that help contribute to the renewable percentage for that year. This provides benefits to only a select few utility companies and does not provide an equal opportunity for funding of other projects not supported under these utilities.

The net metering laws in Michigan allow Net Excess Generation (NEG) to be carried over at the full retail rate of the surplus electricity from that calendar year. The interconnection law in Michigan supports residential solar systems becoming grid-tied and the application fees are capped at $75. However, Michigan has no specific solar incentives including tax credits and performance payments (Talberg et al., 2017). Most importantly, Michigan does not have a shared renewable program in place that would help encourage the growth of community solar.

This project is located in Monroe, Michigan at Monroe County Community College. Monroe has a population of about 20 thousand and is within a short proximity to Lake Erie. Distributed Engineering Workstation (DEW) modeling was used to determine the best site location for the CES systems. Since CES can be used as a resource during an outage DTE collected data on the customers that had experienced an outage during the last five years ("DTE Energy", 2015). Once these customers were selected, the DEW circuit model determined customer voltages in the area to see where CES could provide the most voltage support if needed. This information along with the location accessibility allowed DTE to select the most ideal location for this project.

The solar radiation potential for solar PV systems in Michigan is low. This is mostly due to cloud cover and weather patterns that allow very little direct solar radiation to reach the surface of the Earth frequently or over a large time span. Michigan has an average monthly solar radiation level of 4.26 kilowatt hours per square meter per day (kWh/m^2/day) (Figure 5) and only experiences about 4.2 hours of sun per day, as shown in Zone 5 of Figure 6 ("Solar Energy and Solar Power in Michigan.", 2017 & "Solar Insolation Map.", 2017). More specifically, Google's Project Sunroof shows 70 percent of rooftops in Michigan have potential for solar, amounting to about 24 thousand megawatts of power ("Project Sunroof - Data Explorer | Michigan", 2017). This means that about 30 percent of the roofs in Detroit are too small or not suited for a solar installation because of the age or type of the roof. Although, the large amount of estimated solar capacity for these roofs indicate there is a substantial amount of space for solar on the roofs in Michigan. These solar radiation statistics are not encouraging for the development of potential solar CES projects and was likely not a driving factor contributing to the success of the Detroit Edison solar CES project.

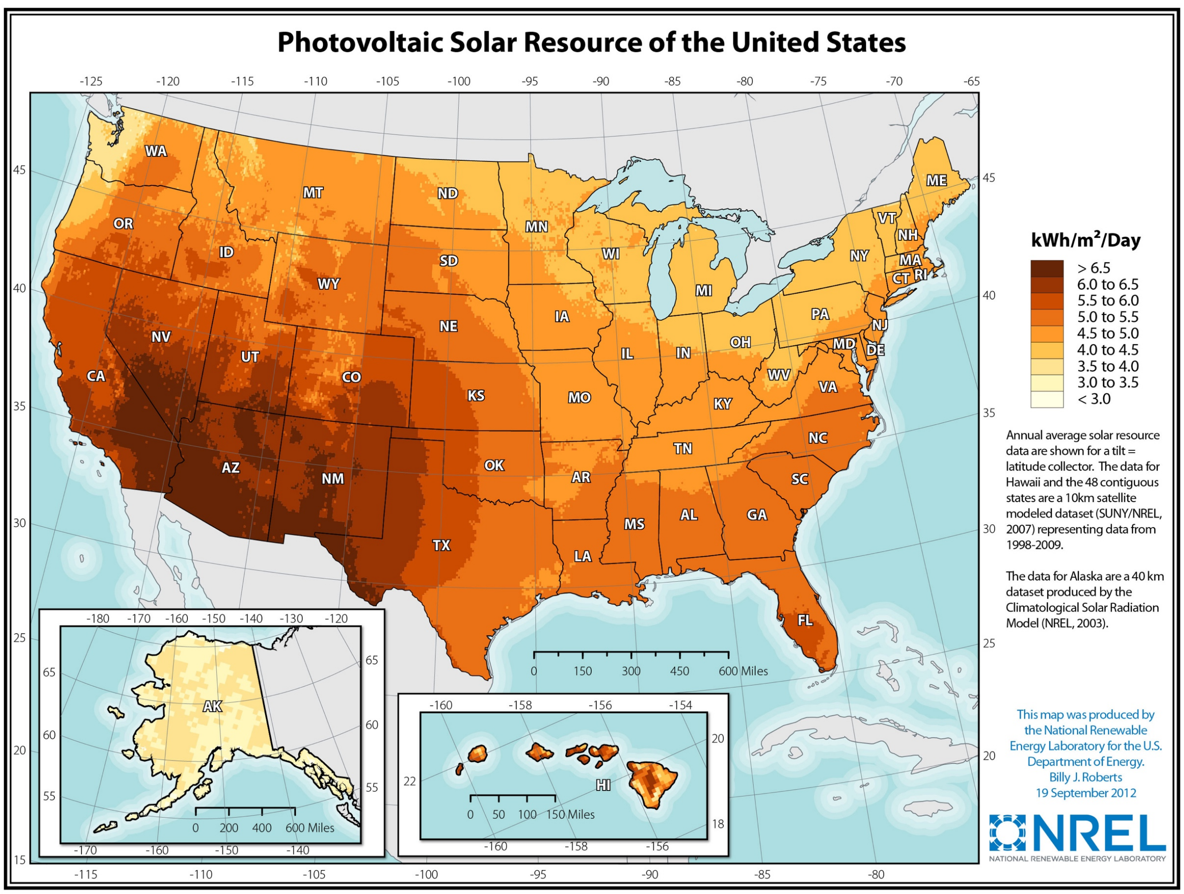

Figure 5 Map of United States showing average annual solar potential for a fixed-tilt, south-facing solar PV system (from "Solar Maps", 2016).

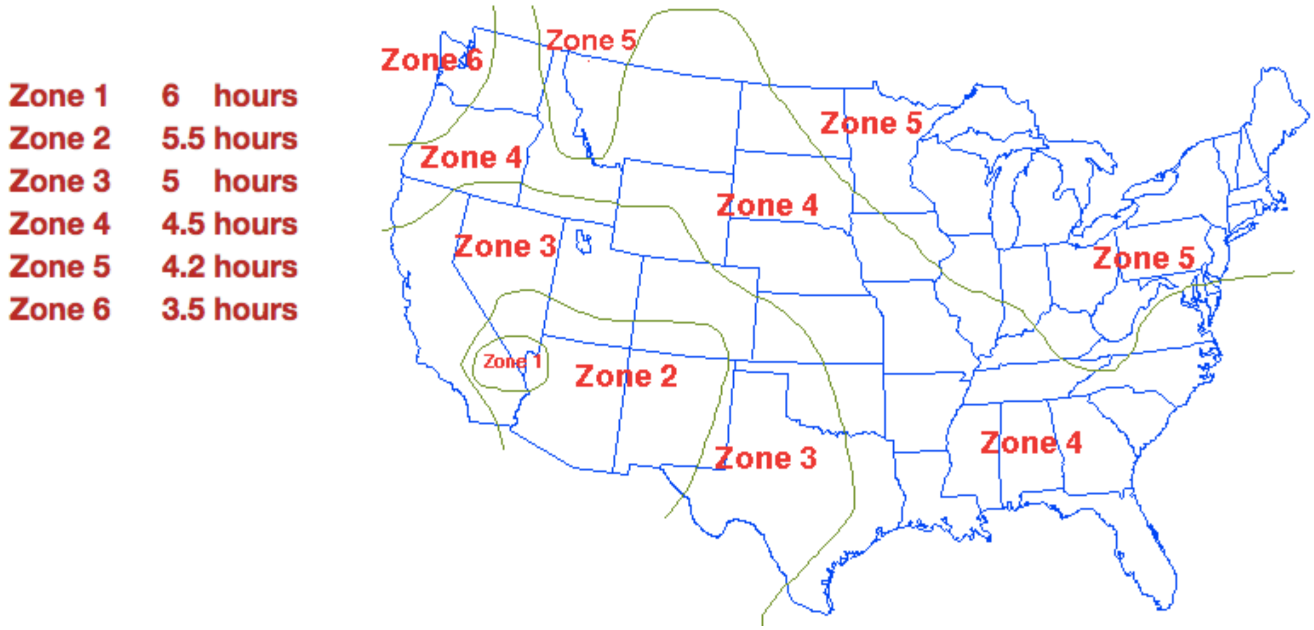

Figure 6 Solar Insolation Map of sun hours/day in the United States (from "Solar Insolation Map", 2017).

6.2: Sacramento Municipal Utility District – Anatolia Pilot Project

The Sacramento Municipal Utility District (SMUD) was funded by the U.S. Department of Energy to build residential energy storage (RES) units and community energy storage (CES) units in the Anatolia III Solar Smart Homes Community. Fifteen 7.7kWh residential Li-ion battery systems were installed behind the customers' meters and connected to 2kW of PV arrays. This allowed the customers to get an accurate view of their daily energy consumption and showed the amount of energy sent back into the grid and how this can be a response to dynamic price shifts. Three CES units, three times larger than the residential units, were installed and shared between five to ten homes. Each of these units consists of Li-ion batteries with 34kWh of usable energy storage and a monitoring and communication interface that reports on the battery status (Rawson & Sanchez, 2015).

Results of this pilot project show success in smoothing the distributed PV capacity and customer load profiles that was more easily attained in the CES units than the RES units because there is a lower change at the transformer level and the CES units were able to charge and discharge in response to this change. SMUD also showed that the location of the storage unit can affect the utility's ability to manage the resources. With CES units, multiple homes can be serviced without the homeowner risking liability issues and the customer does not have to be constantly involved beyond the point of installation. However, this also means a distribution crew is required for all maintenance activities and the units are installed outside where they are vulnerable to natural weathering. With RES units, the customer's garage can encase the unit and keep it safe while also lowering the customer's bill by the rate structure of the area. However, RES units require coordination with the homeowner that may impair the efficiency of the system, raising the overall bill. Overall, the SMUD pilot project was able to manage high penetrations of PV by shifting the load that mitigates ramping in a system wide power supply and smoothing the PV capacity by balancing out fluctuations that may occur (Rawson & Sanchez, 2015).

6.2.1: Was the Project Successful?

The main goal of this project was to demonstrate the benefits of CES and RES system when implemented into a solar PV installations. Both CES and RES units were able to provide load-shifting and load-smoothing to the overall system but the CES units were able to provide greater smoothing by reducing the ramp rates at the transformer level while in the RES systems the smoothing was less dramatic and the ramp rates actually increased (Rawson & Sanchez, 2015).

The RES and CES units were able to reduce the peak load of the area but were not guaranteed to affect consumers outside of Anatolia. The energy storage systems were able to use the battery storage to power homes within the Anatolia area when solar would normally be ramping down, however, Anatolia only represents 10 percent of the peak load utility which would have a minimal impact on the total demand of the area. The PV arrays also never produced enough energy to back feed into the grid which would provide an inaccurate representation of whether the system would be able to prevent an overload to the grid if the situation were to arise. However, the goal of this project was to demonstrate the functionality of reducing peak load in the Anatolia area only which was achieved (Rawson & Sanchez, 2015).

The communication system that was developed for this project was a smart meter used for PV inverter control. This system included a customer portal that monitored PV generation and energy consumption while also providing the customer with energy conservation tips based on their specific energy use patterns. Customers were not able to physically control the storage units but were encouraged to change their behavior if consumption increased. The RES units were connected to the communication device via broadband and the CES units were connected via cellular modems (Rawson & Sanchez, 2015). Ultimately, the project was a success in that it was able to reach the goals set by the utility, although there would be concerns that would need to be address if the goals were set to cover a larger area in the future.

6.2.2: What Made the Project Successful?

California's renewable portfolio standard (RPS) is much stronger than Michigan's, with a goal of 50% renewables by 2030. This is important for California because utilities have to pay a large fee back to the state if they don't reach their RPS numbers, which incentivizes them to promote renewable energy generation. California has the 7th highest electricity prices in the nation with strong net metering laws still in place. However, there will be an increase in the fees and payments to the utility companies after July 1st, 2017 (Renewables Portfolio Standard Quarterly Report, 2016). The interconnection laws exempt small renewable from paying costs associated with distribution modifications and application fees but they still require disconnect switches and liability insurance that, while important for larger commercial systems, are not necessary for small residential installations.

With California's strong RPS, the Anatolia CES pilot project received funding from the U.S. Department of Energy and the Energy Commission with project goals set in place that would benefit the future of California's renewable energy sector. In this case, the California RPS and associated renewable energy laws helped the Anatolia project get funding and can be applied as an option to other potential programs throughout California. This does not apply in the Detroit

Edison project that likely only received funding because Detroit Edison is one of the few large utility companies that contributes to reaching Michigan's low RPS goal and, therefore, funding of this kind will likely not be an option for projects outside of the Detroit Edison territory elsewhere in Michigan.

California has many solar incentives in place. There are solar rebates to encourage the increased development of solar in California with the goal of three thousand megawatts of new solar installations by 2017. Locally, Sacramento has a Single-Family Affordable Solar Homes Program (SASH) that allows lower-income families that live in an affordable housing home to receive a rebate that may cover the entire cost of a newly installed solar array (Renewables Portfolio Standard Quarterly Report, 2016). Additionally, California has a Virtual Net Energy Metering (VNM) tariff arrangement in place that allows one solar system to supply credits to the whole community of tenants under a multi-meter property. Virtual Net Metering provides equal opportunities to low-income tenants that are renting an apartment in a multi-unit building to receive the benefits of solar energy as homeowners in higher-income communities ("Virtual Net Metering", 2017).

California also has a Green Tariff/Shared Renewables (GTSR) Program that allows customers of Pacific Gas and Electric Company (PG&E), Southern California Edison (SCE) and San Diego Gas and Electric (SDG&E) to receive 50 to 100 percent of their electricity from solar energy generation. A customer can pay a green tariff that is equal to the difference between the cost of adopting between 50 to 100 percent of their electricity from solar and their current electricity rate. While another option is to purchase part of a solar project directly from the solar contractor and receive credits from the utility in exchange. The whole program is capped at a total capacity of 600 megawatts of solar generation and the utility customers that are not able to participate will not be affected by fluctuations in electricity costs caused by the GTSR Program ("Green Tariff/Shared Renewables Program (GTSR).", 2017). This will not only facilitate the growth of community solar in California, it will also provide a more equal opportunity for customers to participate in solar and create even more opportunities for storage to be integrated in community solar projects.

The site location of this project was in Rancho Cordova, California in Sacramento County. The population of this area is about 64 thousand with high employment around the area. This community was selected as the location for the project because it had a high concentration of existing PV systems, homes with similar vintage, and a location that was at the end of a distribution circuit (Rawson & Sanchez, 2015). This area was selected strategically and allowed SMUD to test RES and CES systems in the same ideal location.

Solar radiation potential for PV systems in California is high. Generally, California has less variation in season and, therefore, has less cloud cover throughout the year allowing solar radiation to reach the Earth's surface more frequently and for longer periods of time. California has an average monthly solar radiation level of 5.62 kilowatt hours per square meter per day ($kWh/m^2/day$) (Figure 7) and experiences anywhere from 4.5 to 6 hours of sun per day, Zones 1,2,3, and 4, in Figure 8 ("Solar Energy and Solar Power in California.", 2017 & "Solar Insolation Map.", 2017). More specifically, Google's Project Sunroof shows 87 percent of rooftops in California have potential for solar, amounting to 133 thousand megawatts of power ("Project Sunroof - Data Explorer | California", 2017). This is a high percentage of potential rooftops that could support solar and likely had a significant impact into the success of the implementation of the SMUD Anatolia project since the site location was selected by determining an area with high penetration solar PV systems already established.

6.3: Summary of Analysis

The five main criteria that contributed to the success of these projects are summarized in Table 1. In addition, cost and affordability of the project and replicability and reliability for modeling of future projects was analyzed in each case study but was not considered a main criterion because in some cases there was not enough information provided to adequately assess the success of these criteria.

Analysis of Successful Criteria for Solar CES Projects

Criteria	Detroit Edison Community Energy Storage Project	Sacramento Municipal Utility District Anatolia Project
Renewable Portfolio Standard	• Michigan has a weak RPS – 15% renewable generation by 2021 and nonbinding agreement to reach 35% by 2025	• California has a strong RPS – 50% renewable generation by 2030
Available Funding	• Funding from Federal Organizations	• Funding from Federal Organizations
Solar Incentives	• Few – Net Excess Generation allows full retail rate of electricity to be carried to next calendar year but no other specific solar incentives in place	• Many – Net metering is still in place but payback is less than retail. There are also solar rebates in place and the Single-Family Affordable Solar Homes Program
Location	• Ideal – Selected customers that had experienced an outage in the last 5 years and would benefit from the most voltage support	• Ideal – Selected a community with a high concentration of existing PV systems that was at the end of a distribution circuit
Solar Radiation	• Average – 70% of rooftops with 4.26 kWh/m^2/day of solar radiation	• Above Average – 87% of rooftops with 5.62 kWh/m^2/day of solar radiation

Table 1. Sources: "DTE Energy", 2015; Talberg et al., 2017; Rawson & Sanchez, 2015; Renewables Portfolio Standard Quarterly Report, 2016; "Solar Energy and Solar Power in Michigan.", 2017; "Solar Energy and Solar Power in California."; "Project Sunroof - Data Explorer | Michigan.", 2017; "Project Sunroof - Data Explorer | California.", 2017; "Solar Insolation Map.", 2017

The cost and affordability of the Detroit Edison project proved to be a negative attribute. The CES systems could not be economically justified in peak shaving mode or frequency regulation services mode based on the high capital cost. A sensitivity analysis was conducted to determine the cost-effective price for this test system. This analysis showed $705/kWh to be the break-even cost of the battery with the capital cost and distribution upgrade cost effecting the fluctuation in price most dramatically. The battery used in this project was over $2,000/kWh and DTE does not expect this to be an economically viable solution until 2020 ("DTE Energy", 2015).

The cost and affordability in the SMUD project was analyzed as the effect to the consumer instead of taking into account the capital cost of the system, as the Detroit Edison project did. For end users, the cost was highly beneficial in the RES systems due to time-of-use (TOU) Energy Cost Management Applications that reduced the overall costs for electricity by using energy storage devices. During off-peak hours, the energy storage unit charged while electricity prices were low and during peak hours, when TOU energy prices apply, the storage unit would discharge energy so the consumer did not have to buy the energy from the grid (Rawson & Sanchez, 2015). Since the two projects analyzed cost and affordability based on different factors, capital cost and TOU rate management, this was not considered a criterion of success that could be compared between the two projects. However, this is an important factor to consider and verifies that the criteria that were most influential to the successful of the Sacramento Anatolia project, contributed to the economic viability that participants of this project experienced.

The replicability and reliability of both projects were low because of the lack of an established model that had been tested in other locations. The Detroit Edison project used of refurbished electric vehicle batteries that proved to have a high rate of failure. Electric vehicle batteries were tested as an option for storage devices but the high failure rate of the refurbished batteries caused them to be decommissioned. The refurbished batteries are economically feasible for many CES projects; however, the reliability of these batteries was questioned in this experiment. The batteries used were from EV packs during the prototype phase that were tested on harsh environmental driving conditions and likely not in ideal shape to be used after the lifetime of the vehicle had faded. A more complex refurbished battery that was not used during the prototype phase of EV vehicle would be a more reliable option for community energy storage units (“DTE Energy”, 2015). Improvements to this model that need to be made include integration of energy storage evaluation software that perform a cost analysis and the engagement of all groups within the participating utility before the project is initiated (“DTE Energy”, 2015).

The SMUD Anatolia project could be replicated based on the same methods used in the pilot project, however improvements would need to be made. Since this project was a pilot project it does not have a high reliability but can be improved by determining the exact amount of battery storage required to produce the desired benefits so the battery selected will not be under or over used. To increase the reliability of smoothing peak demand curves there needs to be advancements in control and communication devices that are integrated into the solar battery systems and PV inverters. Specifically, for CES units, a model that prevents reverse back feed power flow is necessary for future project implementation and additional equipment that initiates islanding capabilities and provides uninterrupted service to the consumer needs to be tested in a CES system (Rawson & Sanchez, 2015). These projects provide general modeling for the implementation of future solar CES projects but the improvements and adjustments mentioned above need to be taken into consideration.

Challenges with the integration of these systems stem from the uncertainty of the technology and the reliability and affordability of the installation. With the failures surrounding the use of refurbished electric vehicle batteries in the DTE project, it is clear that much more research and testing must be done to determine the most ideal energy storage method for solar community energy storage. Affordability of these types of projects depends on the utility commission's ability to receive funding for solar CES projects which is directly related to the renewable portfolio standard of that area and the policies and incentives that drive those state goals. Even though it may take another few years for battery storage to be affordable for residential customers, solar CES projects funded by the government in places with high electricity rates would have immediate economic benefits for customers because of the decreasing price of solar equipment, as well as long term benefits for utility companies that are required to reach a certain renewable percentage.

When analyzing the different community solar models it is clear that the utility-sponsored model would work the best with the integration of battery storage since many of these projects require large amounts of funding from government organizations. Many of the solar energy storage projects that have been successful were funded by the Department of Energy and, therefore, would be the most easily implemented into utility-sponsored community solar models that are usually managed by an established utility company and government entity. Federal funding, however, may be less likely with the current government administration's adversity to environmental spending. Recommendations for state funding and incentives will be presented in the following section addressing the opportunity for the implementation of solar CES projects in Hawaii.

Locations of these solar CES projects should follow the guidelines of the community solar projects discussed in Chapter 3, in that, only open space land that would otherwise be unusable and roofs of schools, churches, or other community buildings are acceptable for solar installations. The purpose of the use of renewable forms of energy is to decrease the amount of greenhouse gases being emitted into the atmosphere from fossil fuels that are altering natural ecosystem processes. Installing solar systems on land that contains endangered species or that would segment habitats would be counterintuitive to the preservation of these natural processes. The next section will discuss recommendations for locations of potential solar CES system in Hawaii.

Chapter 7 – Conclusions and Recommendations

The previous chapter demonstrates the potential effect that community energy storage could have on the solar industry. With solar power's seasonal and daily variability due to the availability of sunshine during only a portion of the daylight hours, community energy storage has the ability to store excess energy for later use and avoid overloading the grid. In addition, solar community energy storage systems can provide peak shaving and demand response capabilities that will allow the growth of the solar industry to continue without overloading the grid.

A review of these five criteria show that in many cases the Sacramento Anatolia project proved to be more successful project. California has a stronger renewable portfolio standard with more solar incentives in place than Michigan and a virtual net-metering program that encourages the growth of community solar. California also has the advantage of receiving more average solar radiation throughout the year than Michigan, and more sun hours per day. These benefits allowed the Sacramento Anatolia project to successfully implement a time-of-use energy management system that reduced the overall electricity rates for customers in that area. This is an extremely important aspect to consider when analyzing potential for solar community energy storage in Hawaii. Hawaii has high electricity rates that could decreased with the implementation of community solar, but energy storage needs to be incorporated as well to accommodate the segmented grid structure in Hawaii. Analysis of the Sacramento Anatolia project shows a distinct connection between the success of these criteria and the ability to lower electricity rates, which is an important challenge that the energy industry in Hawaii currently faces.

7.1: Recommendations for Solar CES Project Implementation in Hawaii

Hawaii's renewable portfolio standard is very encouraging with a goal of 100 percent renewables by 2045. Since almost all of the energy generation in Hawaii is attributed to imported fuels and fossil fuel generation, their electricity prices are the highest in the nation. This also means there is substantial room for solar energy to have a positive effect on the electricity prices in Hawaii. With the removal of net metering in Hawaii came the Customer Self-Supply and Customer Grid-Supply systems which promotes battery storage for residential customers that can afford it. For customers that cannot adopt solar for financial reasons or because their roof will not allow it, there is community solar that when paired with storage can alleviate the interconnection issues Hawaii is experiencing with the overloaded grid.

Hawaii's RPS is stronger than both Michigan and California's providing confidence that solar CES projects can get state and federal funding from the government. Programs already in place like the SunShot Initiative, funded by the Energy Department's Solar Energy Technologies Office (SETO), have goals that span over the next few years, and can take advantage of that timespan to get federal funding for projects that bring the state closer to its renewable energy goal. The SunShot Initiative aims to make solar energy resources more accessible and affordable to United States residents with a specific goal or achieving electricity rates at $0.06 per kilowatt hour by 2020 ("Solar Energy Technologies Office", 2017). With the Department of Energy committed to initiatives like these, solar CES project could likely still get federal funding with projects implemented in the next few years. After that, Hawaii will likely have to rely on state funding, which should also be accessible because of the high renewable energy goal they have set.

Communicating the benefits that solar CES projects provide to utilities is an important step in the development of the solar community energy storage industry. Investing in unique solutions, like solar CES, persuades local utilities to support demand-side management and distributed energy storage programs instead of new upgrades to current systems (Bovarnick, 2016). Solar CES systems also improve the overall grid resiliency that can be a benefit to utilities that earn revenue through market-based performance measures that support the reliability of grid performance for customers (Bovarnick, 2016). Determining the rate structures that would incentivize customers to adopt energy storage while also benefiting the utility is an important step to address in the early stages of solar CES programs (Rawson & Sanchez, 2015). With more market incentives in place in the Hawaiian renewable energy industry, utilities like HECO will be encouraged to support solar CES projects in the future.

Hawaii's proposed community-based renewable energy program, described in Chapter 4, is a good step to increasing the adoption of community solar projects, but following a structure of policy in which other states have experienced success with their shared renewables programs should be strongly considered. Current net metering policies make it difficult to share electricity credits with participants in a community solar program. These regulations need to be revised to allow multiple meters to aggregate under a single project and share the electricity output and economic benefits of net metering. This is an issue that the idea of virtual net metering addresses and is supported by a tariff arrangement in place in California that would be beneficial to implement in Hawaii. With a Virtual Net Metering (VNM) plan in place in Hawaii, more low income, multi-unit, family residents can receive benefits of renewable generation because a single solar system will be used to supply the electricity for all communal tenant areas connected to the same service ("Virtual Net Metering", 2017). However, since the net-metering law was removed in Hawaii due to overloading of the grid, storage would be a necessary part of a virtual net metering program to ensure Hawaii's segmented grids do not become overloaded and cause curtailment.

Additionally, Colorado has a Community Solar Garden Legislation in place that is referenced here as a recommendation for Hawaii to adopt because it is an easily replicable model used to encourage the growth of community solar generation. The solar gardens in

Colorado are required to be 2 megawatts or less in size and owned by 10 or more subscribers (Farrell, 2010). These participants must live in the same county and buy at least one kilowatt of the solar system but this cannot exceed 120 percent of their electricity consumption (Farrell, 2010). Utilities are required to target renters and low-income customers for participation in this community solar program (Farrell, 2010). With the rules and regulations clearly laid out for utility companies and customers to easily participate and subscribe to a community solar garden in Colorado, this model is the most reliable to replicate in other state legislatures around the United States. Therefore, Hawaii should implement legislation using this model to establish a community solar presence that can increase solar generation for all members of the community equally and, ultimately, help Hawaii reach its renewable portfolio standard goal.

Locational value maps are used by Hawaiian Electric to provide a visualization of the percentage of distributed generation in distribution circuits of daytime minimums and peak loads of PV. The locations presented in Figure 7 show the areas within Maui where the highest percentage of distributed generation is occurring and exceeding the minimum daytime load. Figure 10 shows the locations where the highest percentage of PV generation occurs in the distribution circuit ("Locational Value Maps", 2013). A direct connection can be seen between where overloading is occurring and where the highest concentration of PV generation is. From this analysis, we can assume distributed generation of PV in these areas would benefit the most from a solar community energy storage system. These are the areas where solar CES projects can have the most impact if successfully implemented. These areas will also need to be analyzed for the best site locations of the project. This may only include rooftop areas of buildings structurally able to support solar and able to distribute energy to the surrounding local community or open areas that would otherwise be unusable. Also, areas at the end of distribution circuits should be considered ideal locations for these projects as that was a criterion for the location of the SMUD project.

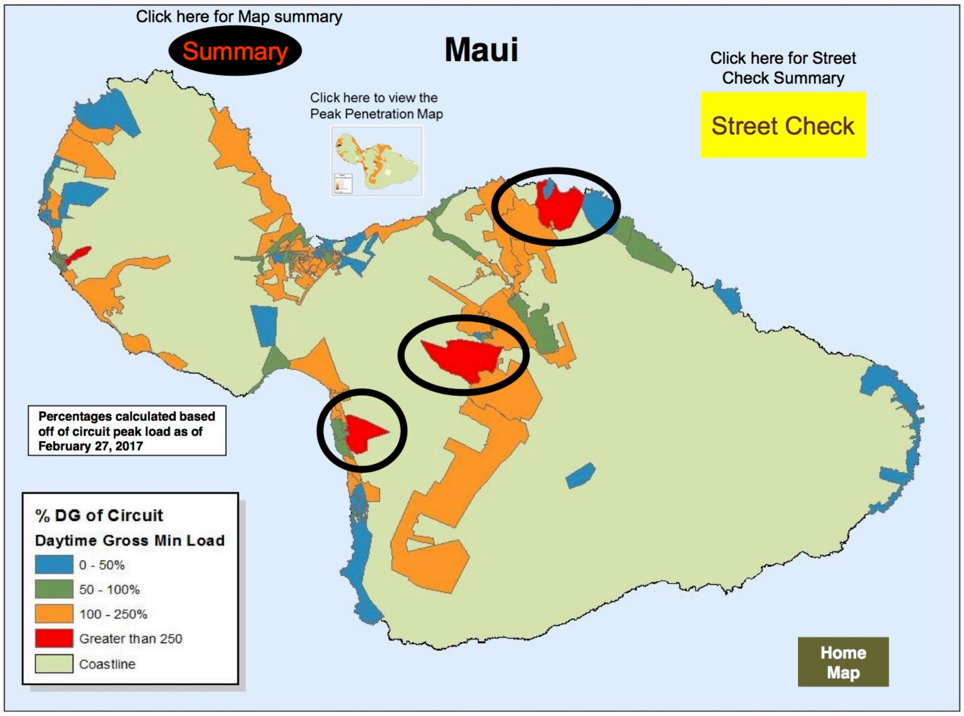

Figure 7 Locational value map of Maui showing areas with greater than 250% of the daytime minimum load requirement provided by distributed generation (from "Locational Value Maps", 2013).

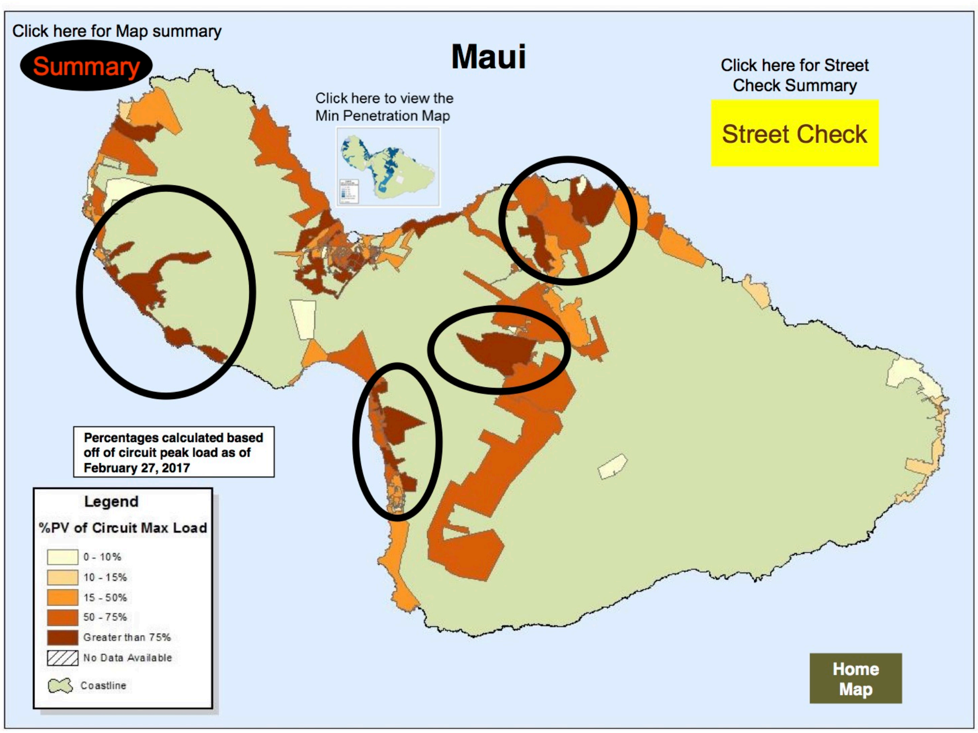

Figure 8 Locational value map of Maui showing areas with greater than 75% of the circuit max load attributed to PV generation (from "Locational Value Maps", 2013).

Part of selecting ideal locations for solar CES projects involves the consideration of solar radiation intensity throughout the islands. Using Google Sunroof we can estimate the potential for increased adoption of rooftop solar in Hawaii, and by examining interactive annual solar radiation maps of the whole island, space for possible ground mount solar installations can be determined as well. The areas that would be developing solar projects on open space need to be analyzed to determine whether natural habitats would be negatively affected. If so, these are not viable locations. The Geography Department at the University of Hawaii at Mānoa created a Solar Radiation of Hawaii website that provides interactive maps depicting the spatial patterns of solar radiation, along with potential evapotranspiration and climate and land characteristics ("Solar Radiation of Hawaii.", 2014). Figure 9 shows the mean annual solar radiation of Hawaii and can be used to identify areas in Hawaii that receive the most solar radiation annually. This map should be used in combination with the locational value maps to determine which of the high PV load areas receive the most annual solar radiation. In addition, Hawaii's solar radiation level can be analyzed by using the same data sources that were mentioned in the previous section. The average monthly solar radiation level of Hawaii is 5.72 kilowatt hours per square meter per day (kWh/m^2/day) (Figure 5) and Google Sunroof reports 94 percent of buildings to be viable for solar installations, equating to four thousand

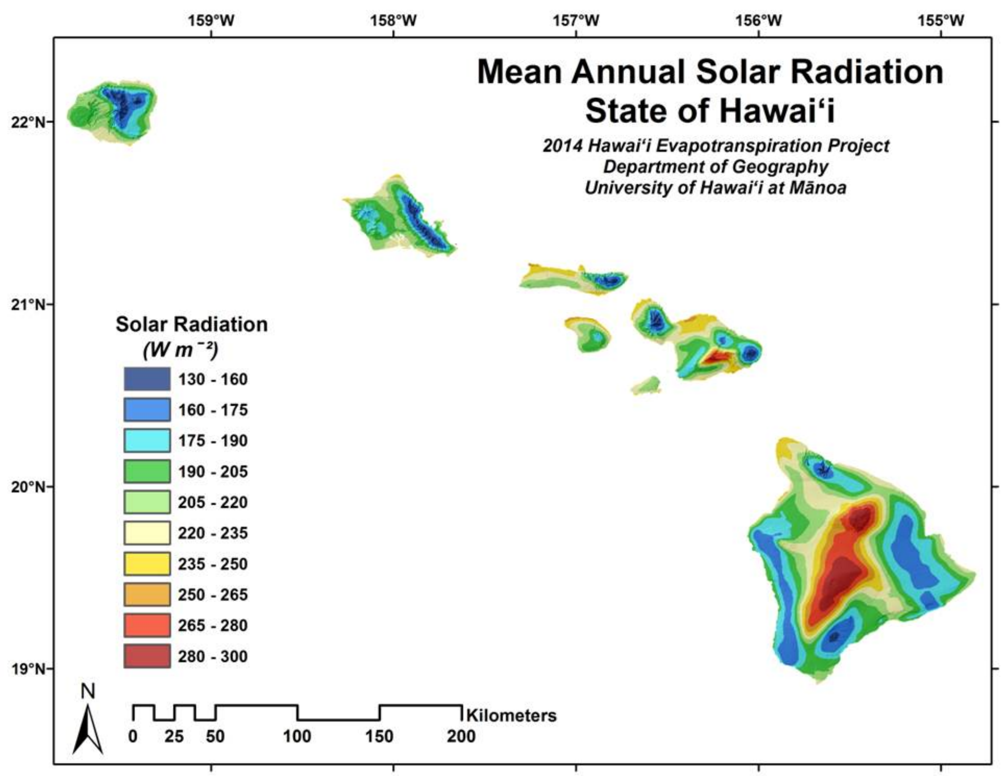

Figure 9 Map of spatial patterns of mean annual solar radiation in Hawaii (from "Solar Radiation of Hawaii.", 2014).

megawatts of power ("Solar Energy and Solar Power in Hawaii", 2017 & "Project Sunroof - Data Explorer | Hawaii", 2017). These statistics are greater than the average solar radiation levels and rooftop percentages for both Michigan and California, however, the average estimated PV capacity is much lower indicating available rooftop area is limited in Hawaii. However, considering these statistics compared to each state's consumption levels shows the production capacity of each state to be relatively the same. For example, California's average solar capacity of 133 thousand megawatts of power generated from 87 percent of viable roofs is equal to 4 thousand megawatts of power generated from 94 percent of the roofs in Hawaii because the average annual consumption in California is about 30 times higher than in Hawaii. Therefore, the data represented in this section shows substantial potential for the growth of solar PV generation in Hawaii since Hawaii has the highest annual solar radiation between these three states.

Hawaii's ability to implement successful solar CES projects was analyzed by using the five criteria mentioned earlier and showed promising potential for the development of the solar CES industry since each criterion was met by equal or higher standards than the Detroit and Sacramento solar CES projects. Therefore, a model similar to the DTE or SMUD pilot project should be used and the recommendations for future projects these reports provide should be followed in Hawaii. These recommendations include determining the exact amount of battery storage needed to produce a desired amount of energy before the project is implemented so the responsible organization does not invest in a larger storage system that is not fully utilized. Also, SMUD recommends the improvement of time series load modeling and weather/irradiance modeling that was used in the Anatolia pilot project (Rawson & Sanchez, 2015). Both pilot projects suggest using the algorithms provided in that study to create and develop new algorithms that promote the smoothing of demand curves and that can be integrated into distributed energy resource management systems (DERMS) to determine greatest economic value for distributed energy storage and to manage distributed assets ("DTE Energy", 2015). These suggestions can be used for future implementation of solar CES projects in Hawaii. The following is a summary of the recommendations proposed in this section:

Summary of Recommendations:

- Communicate benefits that solar CES projects provide to utilities
- Invest in unique solutions, like solar CES, instead of upgrades to current systems
- Solar CES projects can provide grid resiliency that benefits utilities that earn revenue through market-based performance measures
- Clearly laid out rules and regulations for community solar programs allow for easy participation
- Locations with the most reported annual solar radiation and the highest overloading of distributed solar generation will benefit most from the implementation of a solar CES project
- Applying lessons learned from these pilot projects to future solar CES projects will allow for the creation of a reliable model and increased success
  - Determine exact amount of battery storage needed so to not over or undersize a system
  - Improvement of time series load modeling and weather/irradiance modeling
  - Develop algorithms that promote smoothing of demand curves

With these recommendations taken into consideration, a successful solar CES pilot project can be implemented in Hawaii within the four different utility commissions. Hawaii has more potential for the adoption of solar CES projects than many other states because of the high electricity rates that are encouraging customers interest in solar power and the segmented power grids that are motivating the development of energy storage in response to the limited capacity of each electricity grid. Battery storage systems are following the trend of solar PV and already showing dramatic decreases in prices that will likely lead to the affordability of solar energy storage systems in the coming years. The integration of community solar programs needs updated policy structures that follow the regulations of Colorado's shared renewable programs as these are the most reliable and successfully replicable models. Results from these pilot projects can be used to establish what alternations need to be made to these models to allow storage to be a successful component in solar CES programs in Hawaii. The time-of-use energy management system implemented in the Sacramento Anatolia project should be replicated in future solar CES projects in Hawaii to ensure a decrease in customers' utility bills. This will encourage the growth of community solar and energy storage as a way to stabilize the grid while transitioning off the dependence of imported fossil fuels that causes Hawaii to have the highest electricity rates in the nation.

7.2: Conclusion

Solar power has finally matured into an industry that is becoming economically competitive in the energy market. Variations to standard solar PV systems like community solar and solar energy storage projects, however, are just starting to take off and best practices for implementation of these types programs have not been fully developed. Therefore, further research on community energy storage technologies and their interaction with solar power are recommended to implement a successful solar CES project. Ultimately, the addition of solar CES projects to Hawaii's energy industry will make their aggressive renewable goal a more achievable reality but will require policy adjustments and program modeling that can be derived from current successful pilot projects.

Despite the limitations stemming from the lack of reported research in the area of solar community energy storage, the analysis provided in this paper can be used to assess the success of other solar CES projects going forward. With PV generation providing 35 percent of the renewable energy in Hawaii in 2015, it is imperative that community solar and storage techniques be adopted to decrease overload to the grid and help Hawaii reach their 100 percent renewable energy goal by 2045 ("State of Hawaii Energy Resources Coordinator's Annual Report 2015", 2016). Solar energy storage has proven capabilities to stabilize the grid by storing solar power during off-peak hours and using the stored energy during peak-hours when retail rate electricity is at its highest. When solar energy storage systems are implemented into a community setting they essentially act as a small grid, or microgrid, that can store and supply energy to surrounding consumers without the development of a complicated distribution and transmission system. This technology is specifically applicable to Hawaii's energy industry because community solar can help expand the adoption of solar power to consumers that have financial or structural constraints, while solar energy storage can help relieve the overload to the grid. The combination of these solar technologies can help Hawaii reach their renewable portfolio goal. By utilizing the recommendations compiled from the results of the Detroit Edison and SMUD projects Hawaiian Electric and other major utilities will be able to integrate solar CES projects in Hawaii and provide a model that can guide other markets towards the development of solar community energy storage programs as well.

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