Honolulu City Lights: How the Hawaiian Electric Company (HECO) Flipped the Switch on Hawaii's Solar Power Boom

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The following describes the challenges Hawaii has faced in creating an electrical utility provider that derives 100% of its energy through renewable energy resources. We describe how the rise of distributed solar electrical generation units created a safety and financial crisis for Hawaii Electric Company (HECO). Hawaii is the first state in the country where the success of solar and distributed power generation has become a potential existential threat to the utility company. The lessons learned in Hawaii can serve as a guide for other states as they strive to become less dependent on fossil fuel and more reliant on renewable energy resources for electrification.

INTRODUCTION

In 1973, the oil embargo raised global prices for petroleum by 400% (Oil Embargo - Office of the Historian). Gasoline shortages and rising prices may have been the most memorable effect of the embargo for the mainland United States but for some places like the state of Hawaii the impact was more far reaching than long lines at a gas station. For Hawaii, the embargo increased the cost of all forms of energy available to the island including electrical production and became not only an inconvenience and economic burden to the populace but also a security risk to the state (Cooney, 2013).

In 1976, Hawaii enacted the Hawaii Energy Tax Credits which allowed individuals and corporations to claim an income tax credit of 20% of the cost of equipment and installation of renewable energy systems. The intent of this rebate was not based upon environmental concerns but rather to reduce the amount of fossil fuels imported by Hawaii from foreign sources (Mangelsdorf & Shah, 2013).

Over the last forty years Hawaii has become a leader in the U.S. in renewable energy development and adoption. The reduction in the cost of PV systems, coupled with the continuation of state and federal tax incentives, shifted the adoption of renewable energy on the island from a state policy initiative to a market driven phenomenon (Boyd, 2009; Thompson, 2014). Hawaii was looked upon as a success story for advocates of renewable energy until, in 2012, the Hawaiian Electric Company (HECO), a long-time champion of residential solar panel adoption by its customers on the island of Oahu, abruptly announced that they would no longer allow their customers in some parts of the island to connect their roof-top PV panels to the island wide grid (Mulkern, 2013).

THE USE OF FOSSIL FUELS IN ELECTRIC POWER GENERATION IN HAWAII

Hawaii is the only state in the Union that derives virtually all its energy from foreign petroleum (Pintz & Morita, 2017). The islands have no fossil fuel resources and hydro-electric generation is limited. The state's power grid consists of 4 independent area grids supported by 6 companies (Hawaii profile analysis - U.S. Energy Information Administration, 2017). Compounding Hawaii's energy/electricity problems is the fact that there is no place on earth that is further removed from any continental landmass than these islands (www.50states.com).

The distance between the islands and the continental United States makes energy pipelines and electrical cables extremely problematic. The distance also created policy decisions such that oil powered electrical generation plants were chosen over coal fired power plants creating a dependence on oil, most of which is supplied by foreign producers. The states reliance on foreign oil has put the state at risk every time there is a price increase in the global oil supply chain. Approximately 1/6th of all discretionary spending in the state is on energy which has resulted in Hawaii's electricity being the most expensive in the United States (26.17 cents per kw hour compared to the national average of 10.42 cents per kw hour in 2015) (Energy Information Administration Electric Data Browser - 2015). On Oahu, the extensive military presence meant that high energy costs were not only a hardship on the local economy but also posed a risk to national security (Cooney, 2013).

It was these concerns that created the shift in policy to try to encourage the use of renewable energy. It began with the 1976 Hawaii Energy Tax Credits to promote the use of solar power and continued with additional tax credits and rebates, as well as the advent of net metering and other incentives from HECO, that positioned Hawaii as a national leader in becoming energy independent (Magill, 2015). The stage was set for the boom years of 2005 to 2012 when distributed energy in the form of rooftop PV units became a common site around the islands, particularly on the island of Oahu. Hawaii was also being championed as the country's leader in moving from a fossil-based to a renewable energy economy (Magill, 2015).

THE GOVERNMENT'S ROLE IN SOLAR DEVELOPMENT IN HAWAII

While the 21st century saw explosive growth in solar and other renewable energies, the government had actively supported the use of renewable energy, and particularly solar, since the middle of the 1990's (Murphy, 2013). Beginning with the Hawaii Energy Tax Credit in 1976 the state enacted several initiatives that were designed to promote renewable energy and subsequently reduce the states reliance on foreign oil. The Energy Tax Act (1978), a Federal tax credit, was a national response to the oil embargo earlier in the decade. Including a credit for solar power systems and water heaters the tax credits continued until the middle 1980's when they were phased out. In 1996, the Hawaii Solar Water Heating rebate resulted in over 50,000 solar powered water heaters being installed throughout the islands (American Council on Renewable Energy, 2014).

It was in the mid-2000's that renewable energy began to experience rapid development with the Federal Renewable Energy Tax credit in 2006. Hawaii followed that legislation with a bill in 2008 that allowed for the establishment of solar farms (HB 2502), a bill that would, by 2010, prohibit new housing construction that did not include solar powered water heater units (SB 644), a bill authorizing the Hawaii Public Utility Commission to offer a rebate for photovoltaic systems (SB 988) as well as a bill that allowed for net metering to be offered to residential and small business customers (HB 2550) (Haleakala Solar, 2014).

Finally, in July of 2008 Governor Linda Lingle approved three landmark bills that would set the stage for the solar explosion in the 2010's. The first was a bill to streamline the permitting process for renewable energy facilities (HB 2863), the second was to create a full-time facilitator to help the state quickly approve these renewable projects (HB 2505) and the third which would provide state funds to help facilitate the creation of renewable energy projects across the state (HB 2261) (Hawaii State Energy Office, 2008).

HAWAII'S EMBRACE OF RENEWABLE ENERGY

The effort of Hawaii to take advantage of the Federal and State support of renewable energy positioned Hawaii to be one of the country's leaders in the use of renewable energy. In 2001, Hawaii launched the world's largest hybrid energy power plant on the Big Island of Hawaii. The world's first photovoltaic power plant that included a battery storage system was launched in 2009 and the largest roof-mounted solar installation became operational in Kona, Hawaii (Haleakala Solar, 2014).

Not only were large solar projects becoming common in Hawaii so to was distributed solar PV generation. Residential solar power units saw a 20-fold increase in the amount of cumulative installed capacity from 2005 to 2010. 2010 was also a hallmark year in that these Federal, State, and corporate initiatives from HECO allowed solar power to reach grid parity with the average residential price for energy ($.25 per kw hour for solar generated compared to $.28 per kw hour for fossil fuel generated power). This parity created another explosion in residential solar systems which increased cumulative capacity by 400% from 2010 to 2012 (Haleakala Solar, 2014).

Hawaii was looked upon as proof that renewable energy can be a cost-effective alternative to fossil fuels. With 12% of Oahu residents having solar panels on their rooftops and over 20% having some form of solar powered units in place or on order it was a shock when in September of 2012 HECO told solar contractors on Oahu that they would no longer be able to connect any new rooftop PV units onto the HECO grid (Mulkern, 2013). The response created an uproar as customers of HECO claimed that this was a money grab on the part of the utility while HECO claimed it was necessary to maintain the integrity of the grid and the safety of its workers (Groom, 2013).

THE PROBLEMS WITH SOLAR

Net metering was considered a way to encourage the adoption of solar energy by private homeowners and small businesses. The ability to generate more power than what was being used personally and then sell the excess back to the power company made all distributed renewable energy system, but particularly solar photovoltaic (PV) systems, more attractive to consumers and, initially, to utility companies. However, when the first net metering programs were offered in the 1980's the fact that most grid systems on the mainland United States offered electricity at rates far below that of most residential PV systems made the mass conversion to a distributed system seem unlikely. With less than 1% of all residential customers having rooftop PV systems and utilities having large scale integrated grids that would allow excess power to be shipped to other regions of the country, the idea of net metering seemed like a good marketing strategy with little business risk for all utility companies (NREL, 2016).

The solar boom in Hawaii was quite different, and more impactful, than anywhere in the mainland United States. Net metering allowed residential PV systems to provide virtually free power to the homeowner with access to the utility company power always there as a back-up during times when the solar systems were not functional such as at night or during cloudy days. This meant that the number of HECO customers, particularly on the island of Oahu, that opted for a net metering home PV system reduced significantly the amount of revenue the company was generating to maintain their island grid (Cardwell, 2015).

An added risk was the fact that there was no outlet for grid over-capacity (or over-voltage), a problem that occurs when excess electricity from distributed PV systems is placed onto the grid. In regions with large connected grids this regional excess capacity can be routed to other areas in need. Hawaii, and particularly Oahu, did not have that capability with the resultant outcome being potential grid shutdowns and blackouts, long term damage to transformers, or at its most extreme, placing HECO employees at risk as they worked on the grid that suddenly experiences high power surges (Thompson, 2014).

It was these risks to its infrastructure that prompted the quick suspension of additional residential systems being added to the grid. The public outcry from homeowners and the renewable industry was swift. Homeowners complained that not being able to connect to the grid and take advantage of net

metering was forcing them to pay twice for their electrical power, with one payment to HECO and the other to the leasing company or bank that financed their rooftop PV system (Cocke, 2013).

The renewable industry in Hawaii also suffered significantly as customers could no longer connect to the grid and potential customers were no longer interested in purchasing a system that was rendered useless. The industry saw a 50% decline in business and a corresponding reduction in jobs (Walton, 2016). These changes in the marketplace stopped the solar explosion in Hawaii and in the minds of many industry observers and experts effectively killed the market (Shimogawa, 2016).

A rethinking of how to handle over-voltage on a regional grid would be necessary if Hawaii was to achieve its goal of generating 100% of its electrical energy by the year 2045 (Roselund, 2017). One solution was for HECO to develop a smart grid system that could handle overloads.

A SMART GRID SOLUTION TO "OVER-VOLTAGE"

The rapid growth of recent PV (Photovoltaic) deployments has led to numerous positive effects in energy security - by decreasing the need for imported energy – and helping to decrease the effect of environmental pollution through clean electricity production.

However, as described previously the widespread use of PV distributed energy has created technical issues that are not easily solvable with traditional power system control methods. The traditional electric power systems - used almost excessively around the globe – match the demand for electricity by carefully monitoring changes and adjusting the demand accordingly. This has worked quite well with the use of power plants whose power output is relatively easy to adjust due to the nature of the input fuel. The input fuels used (coal/peat/shale, oil, biofuels and nuclear material) are relatively easily storable and can be made available when needed.

When introducing a large amount (large relative to the size of the power system it is serving) of capacity producing electricity intermittently due to the nature of the input it uses, the system stability can suffer. Unexpected load changes, power backflow, and other operational issues can cause major problems in the uninterrupted supply of electricity. It was this concern of over-voltage that prompted HECO in 2012 to suspend connections of home installed solar power systems to the Oahu grid (Groom, 2013).

Distributed power was looked upon as a key element in Hawaii's plan to achieve its goal of obtaining 100% of its power from renewable energy by 2045 (Hoium, 2017). In order for this to occur HECO would need to create a system where energy management was utilized in a state-of-the-art way. A first step in resolving the generation of "over-voltage" and developing a smart-grid was a public-private partnership between HECO and the National Renewable Energy Laboratory (NREL) in Golden Colorado. This collaboration paved the way for a larger penetration of intermittent renewable sources such as solar and wind energy, as well as residential distributed power generation, and could be a possible benchmark for other states who wish to move away from fossil fuels and towards a renewable energy platform (Daigneau, 2016).

HECO, NREL, AND SOLAR CITY

The National Renewable Energy Laboratory is a federally funded research program supported by the Department of Energy. Created as a national laboratory in 1991, NREL has become a leader in all aspects of renewable energy research. In 2014, NREL collaborated with HECO to analyze and validate PV inverter technology to enhance the utility's power grid efficiency and stability (NREL(a), 2016). An additional collaborator, Solar City, had been working with NREL in their Energy Systems Integration Facility to determine the effectiveness of how residential solar power generation systems can integrate with a power grid (NREL(b), 2014).

Charged by the State of Hawaii to achieve a power grid that is supported by 100% renewable resources by the year 2045 (Bussewitz, 2017) this collaboration was an essential first step to achieving that goal or, if unsuccessful, to allow the utility enough time to plan a strategy that did not include distributed renewable energy. The success of the collaboration has led to a modernization of the grid that

is expected to increase the number of rooftop PV systems from 79,000 in 2016 to 165,000 by 2030 (Nelson, Nagarajan, Prebakar, Gevorgian, Lundstrom, Nepal, Hoke, Asano, Yeda, Shindo, Kubojiri, Ceria and Ifuku, 2016). The merging of public/private research with improving technology now makes Hawaii's goal of achieving 100% energy output through renewable resources a technical possibility. However, the traditional business model that utility companies have utilized for over a century has now become a primary obstacle to achieving energy independence when using distributed energy generation as a primary contributor.

WHO PAY'S FOR POWER?

For over a century the traditional business model for utilities has been to provide customers with power generated with large scale industrial electrical energy generation distributed over geographically broad grid networks. Additional power sources and networks to the grid would be added as warranted by customer demand. Power flow was one way, from producer to user, and adjustments to power flow, both over the short and long term, all controlled by the utility.

Net metering was introduced in the 1980's to encourage the use of renewable energy. Since then it has been a little used opportunity to promote residential power generation. However, in Hawaii as solar PV technology costs went down and the cost of traditional retail power from HECO continued to be the highest in the country, there was a rush to install residential PV systems. This rush created a boom in Hawaii leading to concerns of over-voltage resulting in HECO's decision to stop connecting units to their grid in 2012 (Groom, 2013).

However, as technical obstacles of distributed energy generation were being rectified through smart grid technology (NREL, 2016) the financial impact to HECO, as more customers changed into part-time suppliers, was quickly seen as an existential threat to the company. This concern regarding what the effects that net metering may have on the utility industry was first voiced by the Edison Electrical Institute in 2013 (Kind, 2013).

What the EEI had not described was at what level of distributed power generation would this threat to a utility company be created. Hawaii, being a self-contained, small grid system, became the proverbial "canary in the coal mine" and found that when over 10% of power was generated through distributed power and net metering the traditional business model would begin to fail (Cardwell, 2015; Fares, 2015) To solve the financial crisis caused by large portions of HECO's customer base no longer paying for electrical service or grid maintenance the state of Hawaii's Public Utilities Commission (PUC) in 2015 eliminated net metering (Shallenberger, 2015).

The intermittent nature of renewable power, especially solar and wind, forced homeowners to either go off-grid and invest in energy storage or stay connected to the grid as a fallback energy source. In response to community outrage to the stopping of net metering and the impact it had on homeowners the commission created a program that would allow HECO to charge a monthly fee to residential and commercial customers who had PV solar systems and were still connected to the HECO power grid (Pyper, 2015). The ruling was itself widely criticized by solar power companies on the island and had the effect of slowing to a virtual standstill the installation of new PV residential systems (Mendoza, 2015). The business model that had its origins in the 19th century simply could not support a power generation and distribution system powered by 21st century technical innovation.

The current smart grid distribution system supports industrial scaled power generation either through fossil fuels or large-scale renewable sources. It can also support a blended power grid that includes distributed power generation and energy flows from multiple sources. A 21st century business model that can financially support large scale multi-flow energy distribution must be developed that will allow the current grid distribution to be viably maintained (Magill, 2015; St. John, 2017). This may be the last innovation needed to achieve Hawaii's, and the country's, goals of becoming "green" in producing electricity (Mulkern, 2017; Fialke, 2018).

THE FUTURE OF RENEWABLE ELECTRICAL POWER IN HAWAII AND WHAT IT COULD MEAN TO THE REST OF THE UNITED STATES

Hawaii is a state unique unto itself and there are many reasons why it was in Hawaii that the opportunity of distributed renewable power being a significant contributor to a state's energy plans became a reality and why it also had to be abruptly stopped. Traditional costs of electricity in Hawaii was the highest in the country and subject to global variations in price for oil, the state's primary energy resource. Due in part to a lowering in the price of PV systems the cost of solar power continued to drop. State and federal tax credits, legislation to allow for net metering, as well as additional credits provided by HECO to enhance the use of renewable energy, and reduce reliance on foreign oil, further enhanced the attractiveness of solar power distributed power systems. Finally, Hawaii, with its collection of small regional grids that are not connected to each other or to the mainland began experiencing over-voltage from distributed power generation on home rooftops that could not be dissipated leading to damage to the grid and physical risk to utility workers (Fares, 2015). So, while the reasons why the experiences of Hawaii may be more impactful to the state than other parts of the country it does not mean that these lessons have no impact on the rest of the country.

Everyday more and more cities and states are declaring their intent to have all, or a majority, of their energy coming from renewable resources (Hulac, 2015; Mulkern, 2017; Ritter, 2017; St. John, 2017; Fialke, 2018). To accomplish these goal strategic choices by utility companies will include power generation from traditional fossil-fuel systems as well as mega-watt sized renewable power generation from solar, wind, bio-mass, tidal, and other renewable sources. Innovation in energy storage is continuing to be developed which in turn increases the reliability of renewables as a primary electrical power source. Arguments will continue to be made in favor of one technology or the other and government policy could shift from being a supporter of large scale renewable mega-watt projects on large tracks of public or private land to a broader roof-top distributed energy production (Grandoni, 2017).

As innovation solves power generation and storage, the notion of living "off-the-grid" (Martin, Chediak & Wells, 2013) continues to strengthen as an economic solution to high power bills or even as the only solution in developing or base-of-the pyramid countries (Bardouille & Muench, 2014). However, given the unpredictable nature of certain renewable energy production, the lag in innovation in energy storage, and the consumer expectation of uninterrupted access to energy on demand the challenges remain to create a blended system that can meet all of the requirements of a truly reliable "green" energy system.

Industrial power generation, small and microgrids, and home distributed power generation all seem to have an integral role to play in achieving a "green" energy system. But the cost of maintaining a national grid must be factored into every renewable energy strategy that does not have off-the-grid power generation as a goal. While there have been some possible business solutions offered to the utility companies (McMahon, 2014) these require rethinking a business model that has been in existence for over 100 years.

The innovative technology that is driving the cost of renewable energy, as well as beginning to address ways to store this excess energy for future use, is entering the marketplace. What is lagging is the design of business models that can provide stable and consistent electrical service in an economically viable manner so that these renewable energy infrastructures can be maintained. This is perhaps the key lesson to be learned from Hawaii's continuing drive to be a leader in renewable energy as the primary source of electricity in the near future. That the technical and business opportunities, and obstacles, of a 21st century renewable electrical generation and distribution system must be addressed and solved concurrently. Those legacy systems, as well as technical and business innovation, have a role in finding solutions that allow for consistent, affordable and renewable energy to become the primary source of electricity throughout the country and throughout the world.

REFERENCES

Renewable energy in the 50 states - Hawaii (2014). *American Council on Renewable Energy*. Retrieved from http://www.marketwired.com/press-release/acore-releases-its-2015-renewable-energy-in-the-50- states-western-region-report-2070881.htm.

Bardouille, P. & Muench, D. (2014). Get rid of the grid. *Stanford Social Innovation Review, 12*(4). Retrieved from https://ssir.org/articles/entry/get_rid_of_the_grid).

Boyd, R. (2009, June). Hawaii says Aloha (Greetings) to clean, renewable energy. *Scientific American.* Retrieved from https://www.scientificamerican.com/article/hawaii-renewable-energy/.

Brief history of solar and Hawaii photovoltaic highlights (2014). *Haleakala Solar*. Retrieved from http://www.haleakalasolar.com/hawaii-solar/brief-history-of-solar-hawaii-photovoltaic-highlights/.

Bussewitz, C. (2017, April). Hawaii Electric touts renewable energy progress. *Honolulu Star-Advertiser*. Retrieved on 8/24/17 at https:// http://www.staradvertiser.com/2017/04/21/breaking-news/hawaiian- electric-touts-renewable-energy-progress/.

Cardwell, D. (2015, April). Solar power battle puts Hawaii at forefront of worldwide changes. *New York Times.* Retrieved from https://www.nytimes.com/2015/04/19/business/energy-environment/solar-power-battle-puts-hawaii-at-forefront-of-worldwide-changes.html.

Cocke, S. (2013, October). Solar customers get burned in Hawaii. (2013). *Huffington Post*. Retrieved from http://www.huffingtonpost.com/2013/10/15/solar-hawaii_n_4101425.html.

Cooney, S. (2013, January). Military drives alternative energy in Hawaii. *Hawaii Business Magazine.* Retrieved from https://www.hawaiibusiness.com/military-drives-alternative-energy-in-hawaii/.

Daiogneau, E. (2016, July). From worst to first: Can Hawaii eliminate fossil fuels? *Governing*. Retrieved from http://www.governing.com/topics/transportation-infrastructure/gov-hawaii-fossil-fuels-renewable-energy.html.

Energy Information Administration Electric Data Browser (2015). Retrieved from www.eia.gov/electricity/data/browser.

Fares, R. (2015, December). 3 Reasons Hawaii put the brakes on solar - and why the same won't happen in your state. *Scientific American*. Retrieved from https://blogs.scientificamerican.com /plugged-in/3- reasons-hawaii-put-the-brakes-on-solar-and-why-the-same-won-t-happen-in-your-state/.

Fialke, J. (2018, April). As Hawaii aims for 100% renewable energy, other states watching closely. Retrieved from https://www.scientificamerican.com/article/as-hawaii-aims-for-100-renewable-energy-other-states-watching-closely/?print=true.

Groom, N. (2013). Clouds over Hawaii's Rooftop Solar Growth Hint at U.S. Battle. *Scientific American.* Retrieved on 9/29/17 at https://www.scientificamerican.com/article/analysis-clouds-over-hawaiis-roofto/.

Grandoniu, D. (2017, September). Zinke suggests solar projects may not be best use of land. *Washington Post*, Retrieved from https://www.washingtonpost.com/news/powerpost/paloma/the-energy-202/2017/09/29/the-energy-202-zinke-suggests-solar-power-may-not-best-use-of-public-land/59cd6a0d30fb0468cea81c8a/?noredirect=on&utm_term=.566b004d4475.

Hawaii. *50 states.com*. Retrieved from https://www.50states.com/facts/hawaii.htm.

Governor Lingle signs key legislation to boost renewable energy production (2008). *Hawaii State Energy Office.* Retrieved from http://energy.hawaii.gov/governor-lingle-signs-key-legislation.

Hoium, T. (2017, July). Hawaii's push to 100% renewable energy presents opportunity for solar energy. *The Motley Fool*. Retrieved from https://www.fool.com/investing/ 2017/07/22/hawaiis-push-to-100- renewable-energy-presents-oppo.aspx.

Hulac, B. (2015, April). Strong future forecast for renewable energy. *Scientific American*. Retrieved from https://www.scientificamerican.com/article/strong-future-forecast-for-renewable-energy/.

Kind, P. (2013). Disruptive challenges: Financial implications and strategic responses to a changing retail electric business. *Edison Electric Institute*. Retrieved from https://www.documentcloud.org /documents/1020804-disruptivechallenges.html.

Magill, B. (2015, May). Hawaii aims for 100 percent renewable power by 2045. *Scientific American*. Retrieved from https://www.scientificamerican.com/article/hawaii-aims-for-100-percent-renewable-power-by-2045/.

Mangelsdorf, M. & Shah, J. (2013, April). Time to sunset Hawaii's solar tax credit. *Green Tech Media.* Retrieved from https://www.greentechmedia.com/articles/read/time-to-sunset-hawaiis-solar-tax-credit.

Martin, C., Chediak, M. & Wells, K. (2013, September). Every home a powerhouse: Why the electricity grid's days are numbered". *Bloomberg Business Week*. 9/22/13. pp 58-63.

McMahon, J. (2014, March). Steven Chu solves utility companies' death spiral. *Forbes*. Retrieved from https://www.forbes.com/sites/jeffmcmahon/2014/03/21/steven-chu-solves-utility-companies-death-spiral/#529eb34d7715.

Mendoza, J. (2015). HECO new policy on PV purchases. *Hawaii News Now*. Retrieved from http://www.hawaiinewsnow.com/story/23490086/heco-starts-new-policy-on-pv-purchases).

Mulkern, A.C. (2013, December). A solar boom so successful, it's been halted. *Scientific American*. Retrieved from https://www.scientificamerican.com/article/a-solar-boom-so-successfull-its-been-halted/.

Mulkern, A.C. (2017, December). How states will hit 100 percent clean energy. *Scientific American*. Retrieved from https://www.scientificamerican.com/article/how-states-will-hit-100-percent-clean-energy/.

Murphy, K. (2013, January). Hawaii sets "breakthrough" framework for new solar power. *Los Angeles Times*. Retrieved from http://articles.latimes.com/2013/jan/30/nation/la-na-nn-hawaii-solar-power-20130130.

Nelson, A; Nagarajian, A.; Prabakar, K.; Gevorgan, V.: Lundstrom, B.; Nepal, S.; Hoke, A,; Asano, M.; Ueda, R.; Shindo, J.; Kubojin, K.; Ceria, R.; & Huku, E. (2016). Hawaiian Electric Advanced Inverter Grid Support Function Laboratory Validation and Analysis. *National Renewable Research Laboratory* (NREL/TP-5d00-6748). Retrieved from www.nrel.gov/docs/fy17osti/67485.pdf.

NREL(b), (2014). NREL + Solarcity and the Hawaiian electric companies *National Renewable Research Laboratory,* Retrieved from https://www.nrel.gov/docs/fy15osti/63435.pdf.

NREL, (2016). NREL Teams up to spur Hawaii's energy progress (2016). *National Renewable Research Laboratory*. Retrieved from https://www.nrel.gov/continuum/market-impact/market-demo.html

NREL(a), (2016). State, Local and Tribal Governments, Policy Basics. Net Metering. *National Renewable Research Laboratory*. Retrieved from https://www.nrel.gov/technical-assistance/basics-net-metering.html.

Oil Embargo. *Office of the Historian, Department of State, United States of America.* Retrieved from https://history.state.gov/milestones/1969-1976/oil-embargo.

Pintz, W.S. & Morita, H. (2017). *Clean Energy from the Earth, Wind, and Sun.* Springer International Publishing, Zurich. pp 15-34.

Pyper, J. (2015, October). Hawaii regulator's shut down HECO's net metering program. *Green Tech Media.* Retrieved from https://www.greentechmedia.com/articles/read/hawaii-regulators-shutdown-hecos-net-metering-program.

Renewable energy can provide 80 percent of U.S. electricity by 2050. *Union of Concerned Scientists.* Retrieved from http://www.ucsusa.org/clean_energy/smart-energy-solutions/increase-renewables/renewable-energy-80-percent-us-electricity.html#.Wbx5jq2ZNEI.

Ritter, B. (2017, April). What's the future of renewables in the US? *World Economic Forum*. Retrieved from https://www.weforum.org/agenda/2017/04/why-renewable-energy-isnt-going-anywhere-in-the-united-states-despite-president-trumps-executive-order.

Roselund, C. (2017, July). HECO grid plan could enable 3x's as much rooftop solar. *PV Magazine.* Retrieved from https://pv-magazine-usa.com/2017/07/06/heco-grid-modernization-plan-could-enable- 3x-as-much-rooftop-solar-in-hawaii/.

Shallenberger, K. (2015, October). Hawaii PUC ends net metering program. *Utility Dive*. Retrieved from https://www.utilitydive.com/news/hawaii-puc-ends-net-metering-program/407328/.

Shimogawa, D. (2016, October). Hawaii solar energy jobs way down, report says. *Pacific Business News*. Retrieved from https://www.bizjournals.com/pacific/news/2016/10/06/hawaii-solar-energy-jobs-way-down-report-says.html.

St. John, J. (2017, July). Hawaii utility's 100% renewable energy plan gets green light. *Green Tech Media*. Retrieved from https://www.greentechmedia.com/articles/read/hawaiian-electric-100-renewable-energy-plan-green-light.

Thompson, D. (2014, February). Flipping the grid. *Honolulu Magazine*. Retrieved from http://www.honolulumagazine.com/Honolulu-Magazine/February-2014/February-2014-Table-of-Contents/.

Hawaii - Profile analysis (2017). *U.S. Energy Information Administration*. Retrieved from https://www.eia.gov/state/?sid=HI.

Walton, R. (2016, July). *Utility Dive*. Retrieved from www.utilitydive.com/news/hawaii-solar-industry-reports-39-drop-in-employment-after-the-end-of-retai/422274/.