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Geothermal Energy in Hawai‘i:

A Comparative Analysis of Wind, Solar, and Geothermal Energy Resources

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1. Introduction

Despite being wholly volcanic in origin, Hawai‘i has had only one commercial geothermal production facility operating over time. In May 2018, this sole geothermal plant, Puna Geothermal Venture (PGV) ceased operations due to the nearby eruption along Kīlauea’s East Rift Zone (KERZ). Hawai‘i’s geothermal resources are potentially vast, yet they are largely uncharacterized (Lautze et al. 2015). One study completed by GeothermEx Inc. in 2000 estimated that the state of Hawai‘i could have more than 1500 MW of geothermal energy potential, enough to meet nearly three-quarters of the state’s electricity demand (Hawaiian Electric Company Inc. 2016b; GeothermEx 2000). There are cultural sensitivities around geothermal energy production in Hawai‘i, which initiate debate that can be a roadblock to further geothermal development. Fully understanding and analyzing such sensitivities is beyond the scope of this report. Instead, this report focuses on geothermal energy’s potential in Hawai‘i by comparing wind, solar, and geothermal resources in terms of cost, land use, and associated hazards. Facts show that geothermal is a clean, baseload renewable energy that can enable Hawai‘i to achieve its green energy goals. The subsequent discussion will show that geothermal resources in Hawai‘i have competitive cost projections, low land use, and hazards that are generally well understood and manageable.

1.a. Motivations

There are two general motivations to pursue renewable energy resources. The first motivation is related to climate change. There is an increasingly large body of data linking anthropogenic greenhouse gas emissions with ocean acidification (Hoegh-Guldberg et al. 2008), sea level rise (Caldeira et al. 2003), and global warming (Matthews et al. 2009). Sea level rise is already having notable financial impacts. In 2016, the U.S. government allocated $48.3 million to the state of Louisiana to relocate the community on the Isle De Jean Charles, which had lost more than 90% of habitable land to sea level rise over the previous 60 years (State of Louisiana 2019).

According to a congressional report from 2009, 31 villages in Alaska are at risk from sea level rise, 12 of which already relocated at the time of this writing (U.S. Government Accountability Office 2009). The United Nations estimates that more than 600 million people live in coastal areas that are less than 10 meters above sea level (United Nations 2017). If not managed properly, the inundation of coastal areas could displace millions more people.

Climate variability is a normal part of Earth's history. Many fields of science agree that the Earth has experienced several periods of warming and cooling, where the sea level may have fluctuated by as much as 400 meters (Hallam 1984). The Earth has many complex systems that equilibrate large thermal gradients over many thousands of years. The ocean has often been referred to as the "great flywheel of the Earth" (Charney et al. 1979). It absorbs and dissipates heat gradually through ocean currents, storms, clouds, glaciation, and even photosynthesis. Though the ocean is uniquely equipped to stabilize Earth's climate, it requires time. Therefore, the rate of the current global warming poses the major risk to the environment. Charney et al. (1979) concluded that a doubling of atmospheric CO_2 was likely to occur within the 21st century, and that such an increase in CO_2 concentration would lead to a net surface heating increase of 4 Wm^2, eventually resulting in a global temperature increase of about 3°C (Charney et al. 1979). Such a dramatic increase in temperature could cause sea level rise by as much 48 cm by 2050 (Cooper et al. 2013). Charney et al. (1979) also concluded that reducing fossil fuel consumption could stall global temperature rise by more than a century. Slowing the rate of CO_2 emission could give the Earth's oceans the time needed to mitigate the impacts of climate change.

The countries that are best equipped to cope with climate change are those doing the most to cause it. Americans have the highest per capita greenhouse gas emissions in the world (MacKay 2013). Industrialized nations consume massive amounts of energy per capita. Nearly every facet of industrialized society hinges on access to cheap, abundant energy. Material manufacturing, child rearing, commuting, air travel, and heating and cooling are among the most energy intensive activities (Wynes et al. 2017; MacKay 2013).

At a glance, the State of Hawaiʻi may seem to be exemplary, ranking 49th in per capita energy consumption and 43rd in total greenhouse gas emissions (U.S. Energy Information Administration 2019). A closer look, however, reveals that Hawaiʻi residents contribute significantly to both national fossil fuel dependence and climate change. U.S. states, on average, produce less than 1% of their electricity by burning liquid petroleum (U.S. Energy Information Administration 2019). In 2018 Hawaiʻi produced 67% of its electricity with liquid petroleum (U.S. Energy Information Administration 2019). For comparison, in 2018, the U.S. generated 35% of its electricity from natural gas, 25% from coal, 19% from nuclear, and 17% from other non-nuclear renewables (U.S. Energy Information Administration 2019).

In the past, fossil fuels were a logical energy source for Hawaiʻi in many ways. Hawaiʻi's geographical isolation, high population density, and economic and military significance pose unique challenges for energy generation. These constraints require abundant, high-energy density resources. Fossil fuels deliver massive amounts of energy with relatively low mass or volume. In fact, one gallon of unleaded gasoline contains more than 30 kilowatt-hours (kWh) of energy (U.S. Dept. of Energy 2013). A standard AA battery contains about 4.2 Wh of energy, so in terms of energy, one gallon of gas is the approximate equivalent of more than 7000 AA batteries (Alley 2019). Standard home photo-voltaic systems in Hawaiʻi can be expected to produce roughly 30 kWh of energy throughout an entire clear and sunny day (Fig. 1).

Fossil fuels are a finite resource, despite their many advantages. The EIA estimates that the current worldwide supply of fossil fuels will be adequate to meet world demand only through 2050

(U.S. Energy Information Administration 2017). While the timeframe is highly contested, humans will eventually deplete fossil fuel reserves. It will take considerable planning, resources, and time to generate equivalent amounts of energy with renewable resources.

Hawaiʻi is situated to take advantage of multiple forms of renewable energy. Hawaiʻi lies 22° north of the equator and receives 11 to 13 hours of sunlight throughout the year ("Honolulu" 2019). Lower latitudes also generally have higher solar irradiance, which is a measure of the average energy absorbed by an area over a year. Hawaiʻi solar irradiance varies from about 100 W/m2 (poor) to 300 W/m2 (good) (University of Hawaiʻi at Mānoa Dept. of Geography 2019). This variability is driven largely by atmospheric conditions and weather patterns (University of Hawaiʻi at Mānoa Dept. of Geography 2019). Hawaiʻi also lies directly in the path of the consistent Northeast trade winds, which contribute to Hawaiʻi's pleasant climate and make Hawaiʻi an ideal location to harvest wind and—potentially—wave energy. Lastly, Hawaiʻi sits on an upwelling of heated molten material from deep within the Earth that geologists call a "mantel hotspot". The Hawaiian hotspot is responsible for the creation of the entire Hawaiian-Emperor Seamount Chain. It has been a consistent source of geothermal heat for millions of years and has been harvested in some form by Hawaiʻi's inhabitants for hundreds, possibly thousands, of years. With such an abundance of natural, renewable energy, Hawaiʻi has a special opportunity to be a global leader in the pursuit of energy independence.

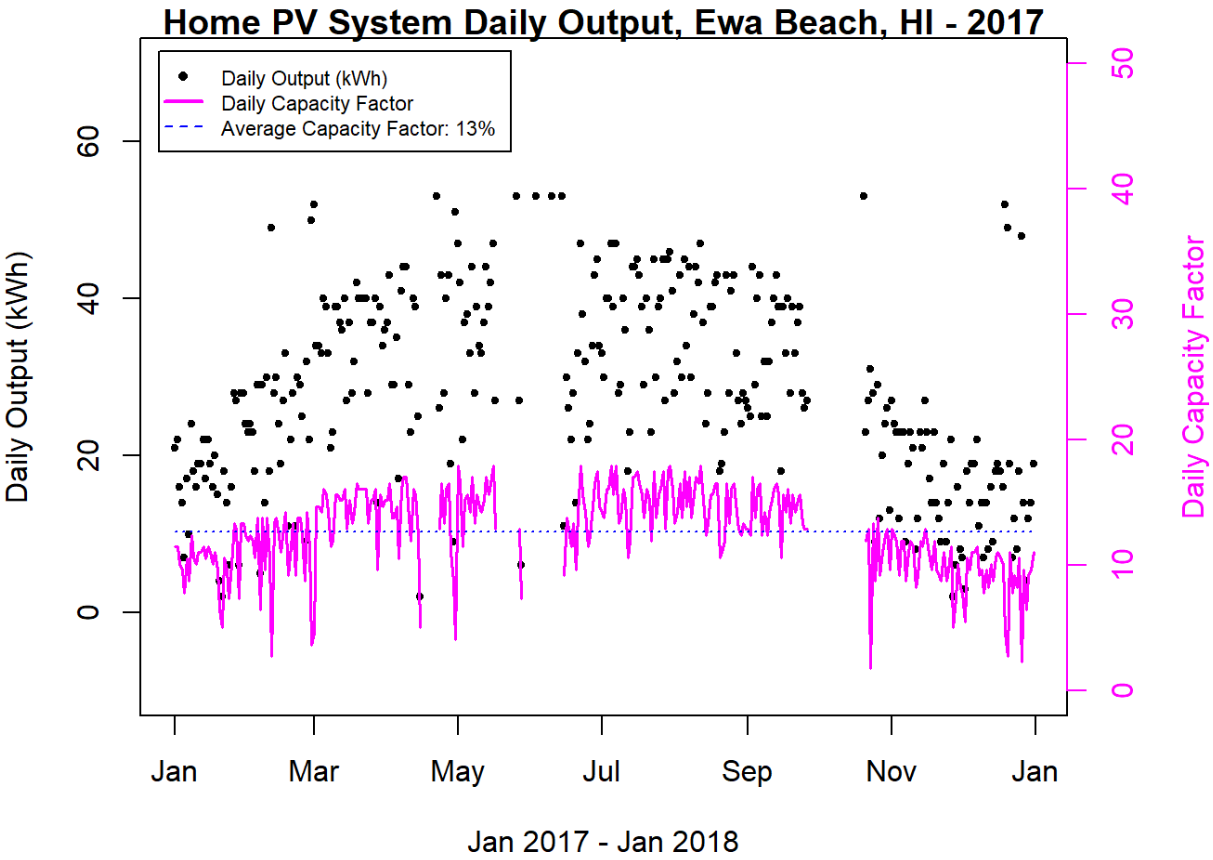


Figure 1: Data from private home rooftop solar system in Ewa Beach, HI, retrieved from Tesla, Inc. website. Solar system consists of approximately 9 m^2 of panels. Gaps in the plot indicate periods where no data was collected by Tesla Inc. Daily capacity factor and peak output varied dramatically. The convex scatter of the data points indicates seasonal variation in daily sunlight.

1.b. Energy consumption – How does energy translate into electricity?

The *Systeme International* (SI) unit for energy is a Joule (J). A Joule is defined as one Newton-meter, or the energy transferred into an object when a force of one newton acts on the object over one meter. This definition is not intuitive. We tend to think of energy in terms of electricity. So how does a Newton-meter translate into keeping the lights on in a home? It is convenient to think of electricity in terms of kilowatt-hours (kWh) since this is the unit commonly shown on electricity bills. A Watt is a rate of energy transfer: one Joule per second. You can attach SI prefixes to the Watt to modify the number of Joules per second. One kilowatt is 1000 Joules per second, one megawatt is one million Joules per second, etc. You can also attach a suffix to the Watt to specify the period over which energy is transferred. One kWh is equal to "one thousand Joules per second for an hour." Dimensional analysis shows that time is in both the numerator and the denominator of the expression, which leaves only Joules.

The energy industry has settled on the kWh as the standard unit of electricity because it is a convenient quantity of energy for discussing everyday activities, like turning on a light or running a dish washer. "The kilowatt-hour per day is a nice human-sized unit: most personal energy-guzzling activities guzzle at a rate of a small number of kilowatt-hours per day" (MacKay 2013, 24). A common 40W lightbulb, for example, consumes electricity at a rate of 40 Joules per second, which amounts to approximately 1 kWh of energy if left on for 24 hours. One kWh is equivalent to 3.6 million Joules.

Residents of industrialized nations, particularly the U.S., tend to live energy-intensive lives. The EIA estimates that the State of Hawai‘i consumed 83 billion kWh of energy in 2016 (U.S. Energy Information Administration 2019). Hawai‘i's population in 2016 was 1.43 million. Hawai‘i residents therefore consumed 57,794 kWh per year, or an average of 158 kWh per day. In other words, in 2016, each person in Hawaiʻi consumed about as much electricity as 150 continuously burning 40W lightbulbs. One could also think of each Hawaiʻi resident in 2016 as a giant continuously burning 6,000W lightbulb. These numbers are likely larger than those one could calculate from an electricity bill. Individual energy consumption includes much more than what one consumes in a home. Infrastructure, material manufacturing, entertainment, defense, and many other normal (often necessary) aspects of life in industrialized nations all require energy. Even a moderately affluent lifestyle, one characterized by daily commuting, child rearing and occasional airline travel, is extremely energy intensive. MacKay estimated that residents of Great Britain in the late 2000's consumed an average of 195 kWh/d: 40 kWh/d for commuting; 30 kWh/d for air travel; 37 kWh/d for heating and cooling; 4 kWh/d for lighting; 5 kWh/d on "gadgets"; 15 kWh/d on food, farming and fertilizer; 48 kWh/d on material consumption and manufacturing; 12 kWh/d on material transportation; and 4 kWh/d on defense and civil security (MacKay 2013, 109). The energy consumption problem is likely far greater than we tend to think.

2. Background

2.a. Hawaiian island & hotspot geology

The Emperor Seamount Chain, of which the Hawaiian Islands are a small part, was created by a mantle hotspot that currently underlies the southeastern portion of Hawaiʻi Island. The hotspot supplies magma, which periodically reaches the surface and forms shield volcanoes. The magma is a source of geothermal heat. The Hawaiian hotspot is thought to be fixed with respect to the Pacific Plate that overlies it. The Pacific Plate, in contrast, has been moving northwest over the Hawaiian hotspot, such that Kauaʻi is the oldest of the main Hawaiian Islands. Each island is composed of one or more shield volcanoes. Hawaiian volcanoes generally go through four stages: a) pre-shield, b) shield building, c) post-shield, and d) rejuvenation, although not every volcano experiences each stage. The shield building stage supplies the largest volume of magma. During this stage, most eruptions occur at a caldera that sits above the main conduit rising from the mantle plume, and along rift zones that extend outward from the caldera. Magma can be transported laterally from a shallow reservoir below the caldera into a rift zone within a few kilometers of the surface. Rejuvenation phase eruptions are thought to be smaller in magnitude and shorter in duration, occurring over a period of days or weeks and extruding a relatively small volume of magma. Rejuvenation phase volcanism typically occurs after a pause of 0.5–2 million years following the end of the shield stages of activity (Bizimis et al. 2013). On the island of Oʻahu, for example, the Koʻolau volcano shield stage ended approximately 1.8 Ma, but the most recent rejuvenation activity occurred ~80 ka. The Koko Head, Diamond Head (Leʻahi), and Hanauma craters, all features of Honolulu, are products of rejuvenation phase eruptions.

There are volcanoes in each volcanic stage throughout Hawaiʻi. The submarine volcano Lōʻihi is in the pre-shield stage. Kīlauea and Mauna Loa on Hawaiʻi Island are in the shield building stage. Hualālai and possibly Mauna Kea on Hawaiʻi Island and Haleakalā on East Māui are in the post-shield stage. Though no Hawaiian volcanoes show signs of rejuvenation volcanism currently, several volcanoes on the older islands are within the wide time period where rejuvenation stage volcanism is possible. Further, researches identified direct evidence of thermal anomalies in water wells across most of the islands, including Kauaʻi, and this evidence may indicate that all stages of volcanism can contribute geothermal heat to the shallow crust (Thomas et al. 1979; Thomas 1985).

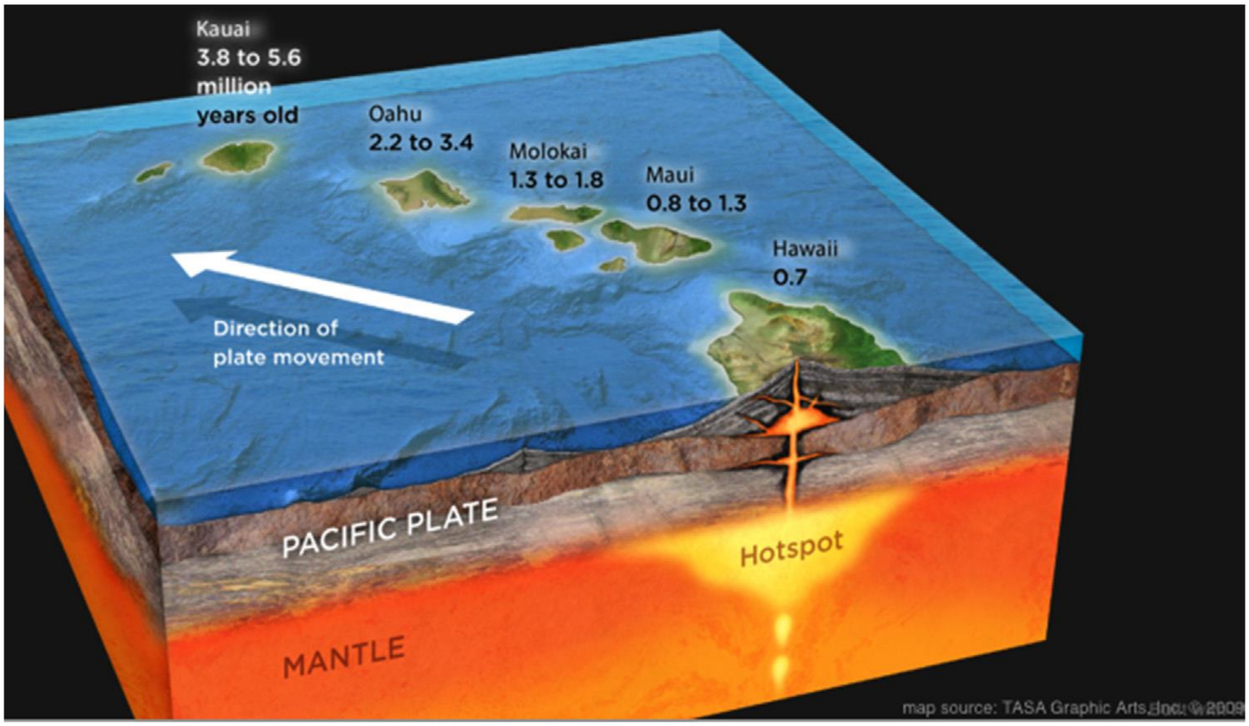


Figure 2: Hawaiian Hotspot. The map shows the mantle hotspot origin of magma, which provides the heat for Hawai‘i’s geothermal resource. The names of the state’s five biggest islands and the average age of the shield building stage of volcanism are shown. Note this age increases to the northwest. (Map Source: TASA Graphic Arts Inc. © 2009).

2.b. Geothermal energy

Geothermal is a simple, clean, renewable energy resource. Heat within the Earth is caused by the decay of radioactive elements in the Earth's interior, and from the diffusion of latent heat from the Earth's formation. Geothermal energy can be produced where elevated temperatures are present closer to the earth's surface, for example, in the vicinity of magma bodies in the crust, or where the earth's crust is thin due to tectonics. Geothermal power plants harness this heat by drilling wells in such locations, where heat is concentrated near the Earth's surface. Several factors contribute to whether geothermal energy can be harnessed from an area. Depth is an obvious constraint, since the deepest humans have ever drilled is 12.3 km (Ault 2015). The rock surrounding a geothermal resource must be saturated with water and sufficiently permeable to allow heated fluids to flow. In cases where permeability is insufficient, the rocks can be fractured and inundated artificially through hydraulic fracturing, a process that involves pumping pressurized fluids into the subsurface to widen existing fractures and allow fluid flow between wells. Most geothermal power plants consist of a series of production and injection wells (Fig. 3). Production wells pull hot, pressurized fluid from the ground and pump it into a steam turbine system, which relieves the pressure and flash boils the fluid, spinning one or more turbines. The cooled geothermal fluid is then collected, cleaned, and pumped back into the ground through an injection well. Greenhouse gas emissions from geothermal power plants, while not always zero, are far lower than those of fossil fuel burning plants (Table 3). The environmental impacts from replacing fossil fuels with geothermal resources are positive (World Bank 2012).

The temperature of a geothermal resource determines how it is used. Hydrothermal systems with temperatures that exceed 182°C (360°F) can be used in a flash steam plant, which is the most common type of geothermal power plant (U.S. Dept. of Energy, Office of Energy Efficiency &

Renewable Energy. 2019b). Systems with temperatures from 150°C - 182°C (300 °F - 360 °F) are suitable for binary cycle power plants (World Bank 2012). Binary plants use moderately heated hydrothermal fluid to heat a secondary fluid with a lower boiling point, typically a purified hydrocarbon. The binary fluid boils and produces vapor which spins turbines in a closed system. Resources below 150 °C (300°F) are the most abundant geothermal resource. Significant portions of geothermal electricity in the future could come from binary cycle plants. Resources below 125°C (257 °F) are suitable for direct uses, such as home and water heating.

Geothermal energy has been growing steadily for more than a century and is expected to continue to grow. The U.S. Geological Survey (USGS) estimated that the outer 10 km of crust beneath the US stores $33 \pm 4 \times 10^{24}$ J of thermal energy (U.S. Geological Survey 1975). In 2017, the U.S. consumed 82×10^{18} J of energy in 2017, six orders of magnitude less than the estimated amount of thermal energy stored in a small sliver of the crust. As many as 40 countries could possess enough geothermal potential to satisfy their entire electricity demand (World Bank 2012). The U.S. and the Philippines are the largest geothermal energy users, hosting approximately 3,000 and 1,900 MW of installed capacity respectively, but this is changing as smaller, bourgeoning nations are beginning to produce geothermal energy (World Bank 2012). The largest geothermal power plant in the world is in the U.S. The Geysers operates on 45 square miles of natural steam beds in Northern California and has an installed capacity of 725 MW, which is adequate to meet all the electricity demands of a large city such as San Francisco (Calpine Corporation 2019).

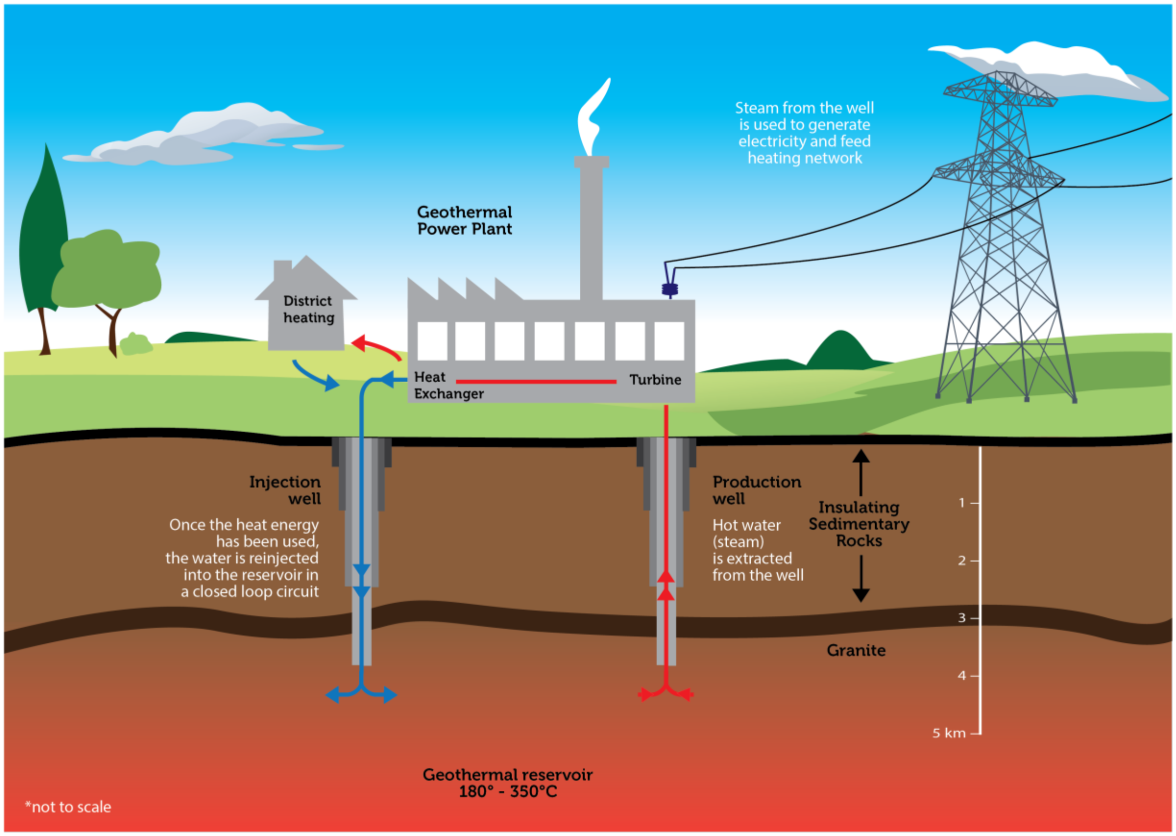


Figure 3: Simplified diagram of a geothermal power plant. Geothermal power plants use heated fluids to spin turbines and generate electricity. Some geothermal facilities must inject water into fractured bedrock. Others exploit geothermal resources that are naturally inundated with water. Fluids hot enough to flash boil, or boil a secondary fluid, are collected and reinjected into the bedrock after they are used to spin turbines. The image is not to scale. (Vallourec 2016)

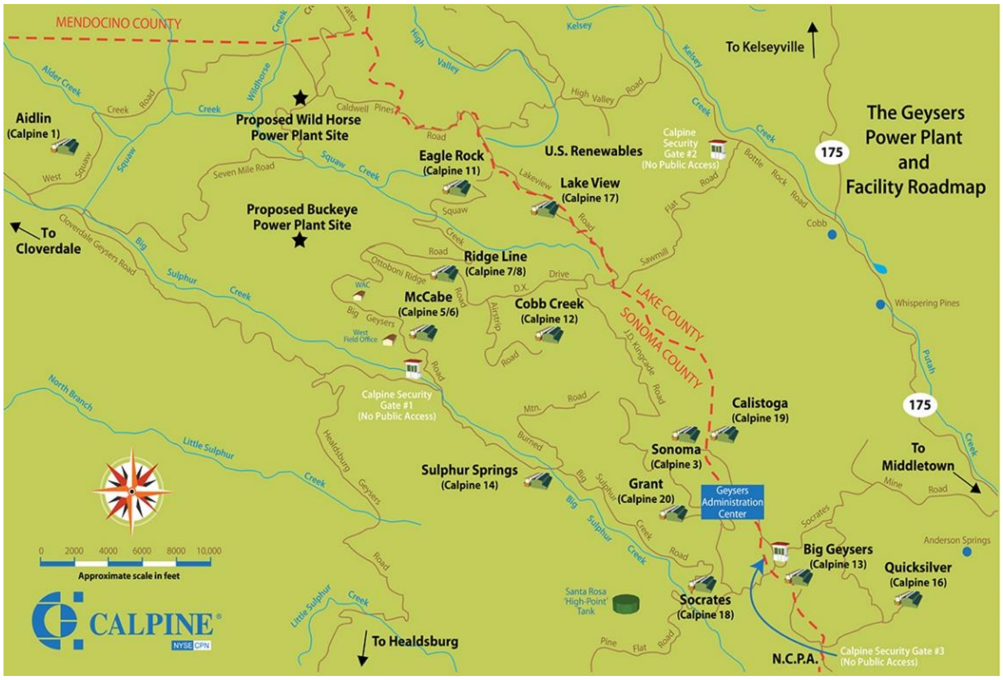


Figure 4: The Geysers is the largest geothermal power plant in the world. Located in Northern California, The Geysers has an installed capacity of about 725 MW and provides approximately 60% of the total electricity demand of the North Coast region. The Geysers is a large complex of power plants spread out over 45 square miles, consisting of 322 production wells and 54 injection wells (Calpine Corporation 2019).

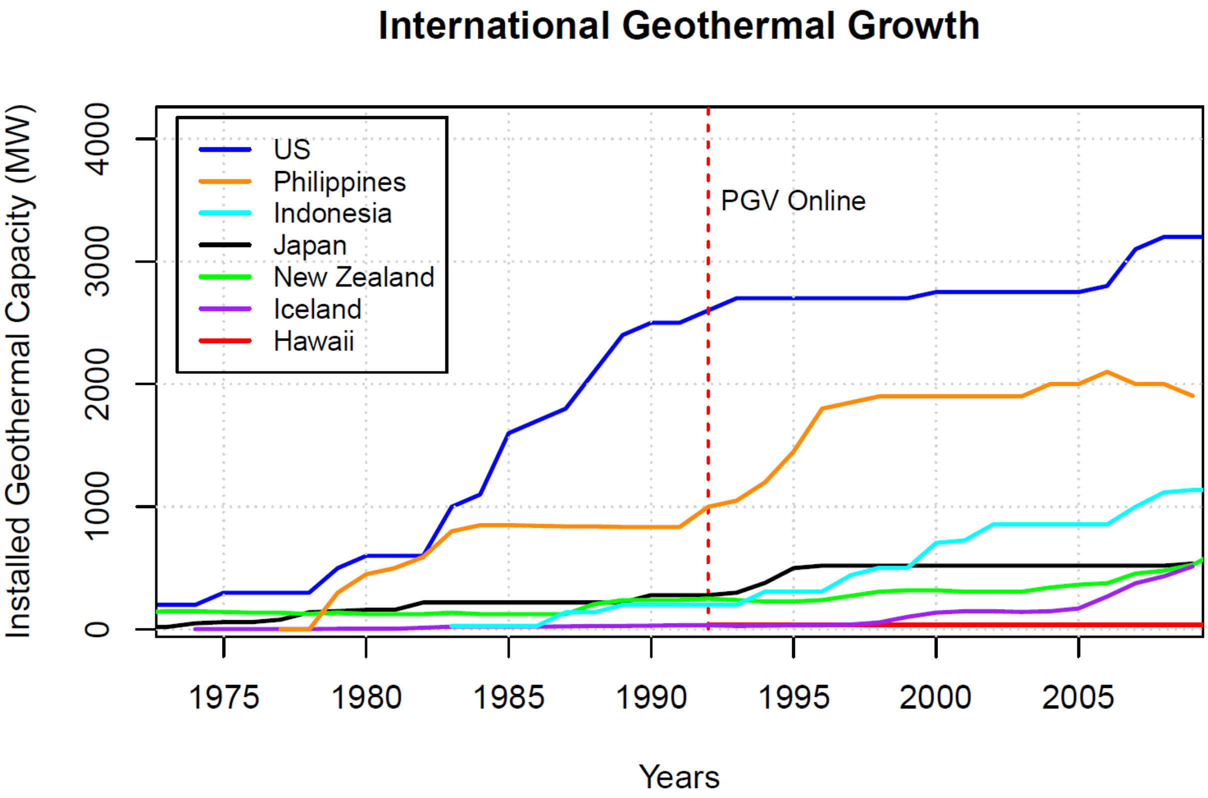


Figure 5: Installed geothermal capacity change with time in countries with the highest installed geothermal resources. The sharpest period of geothermal growth occurred in the 1980's. The 1970's energy crisis forced many countries to develop renewable energy resources as a protection against a volatile oil industry. In Hawai'i, geothermal exploration was accelerated during this period but did not produce any economically viable resources. Geothermal exploration in Hawai'i has since stagnated.

Philippines data: Clemente et al. 2016
Indonesia data: Mansoer 2015
Iceland data: Kettilson et al. 2010
Japan data: Geothermal Research Society of Japan, 2019
New Zealand data: Harvey et al. 2012
US data: "2016 Annual U.S. & Global Geothermal Power Production Report"
Hawai'i data: Hawaiian Electric Company Inc. 2019

2.c. Geothermal energy history in Hawaiʻi

Geothermal exploration efforts in Hawaiʻi have been limited predominantly to Maui and Hawaiʻi Island. The Kīlauea East Rift Zone (KERZ) has been the epicenter of geothermal exploration and development for the last fifty years. The KERZ is a part of Kīlauea, Hawaiʻi's most active volcano (Puʻu ʻŌʻō, Kīlauea's most recent eruption, lasted 35 years and erupted 4.4 km^3 of lava) (U.S. Geological Survey 2019). The KERZ has proven to be a reliable source of geothermal heat. More than two dozen wells drilled throughout the KERZ over the last 50 years have revealed abundant hydrothermal resources with temperatures in excess of 360°C (680°F), with most resources lying between 4,000 and 7,000 feet below the ground surface (GeothermEx 1994; Hawaiʻi Groundwater and Geothermal Resource Center 2019). The KERZ is home to Hawaiʻi's only geothermal plant, Puna Geothermal Venture (PGV), a 38 MW geothermal plant which operated from 1991 to May 2018, when it closed as a result of a nearby volcanic eruption. PGV is owned and operated by Ormat Technologies Inc., a Reno, NV, based company that supplies 910 MW of renewable energy internationally (Ormat Technologies 2019). Before closing, PGV was supplying more than a quarter of Hawaiʻi Island's energy needs.

Early geothermal exploration efforts in the KERZ were productive. In 1961, the Hawaiʻi Thermal Power Company drilled four shallow wells in the KERZ ranging in depth from 216 to 689 ft and encountered temperatures ranging from 109° to 203° F (Patterson et al., 1994b; Gill, 2011). In 1975, after an extensive geophysical survey, the University of Hawaiʻi used federal, state, and county funds to drill the resource discovery well "Hawaiʻi Geothermal Project-Abbott" (commonly known as "HGP-A") in the lower KERZ, the initial vent site of the 1955 eruption. HGP-A was completed in 1976, reached a depth of 6,450 ft, and recorded a maximum temperature of 676°F (358°C) (Thomas, 1982; Boyd, 2002). HGP-A powered a 2.8-MW demonstration plant from 1981 to 1989 without any significant change in flowing pressure or steam fraction (Patterson et al., 1994b). The well was plugged and closed in 1989. Geothermal exploration expanded outside the KERZ in 1978 when Pu‘u Wa‘awa‘a Steam Company (STEAMCO) and Geothermal Exploration and Development Company (GEDCO) financed two exploratory wells on Hualālai Volcano on the western side of Hawai‘i Island. Neither of these wells encountered temperatures high enough for power generation. Barnwell Industries and Thermal Power Company drilled six additional wells in the vicinity of HGP-A from 1981 to 1985. Five of these wells encountered commercial heat levels, though none was ultimately used for energy generation.

Puna Geothermal Venture’s origins were tumultuous. In 1989, Ormat Technologies, Inc. acquired 500 acres in the KERZ in the Puna area of Hawai‘i Island and began construction. PGV crews drilled three wells initially (KS-3, KS-7, and KS-8), each of which failed. One well (KS-3) was subsequently repaired and converted to an injection well. The KS-8 blowout drew considerable public protest and resulted in a temporary permit suspension. After these initial setbacks, PGV successfully drilled two production wells (KS-9 and KS-10) and one more injection well (KS-4). PGV began commercial production in 1993, producing electricity at a rate of 30 MW. PGV continued expansion through 2012, drilling at least seven additional wells (KS-11, KS-5, KS-10, KS-6, KS-13, KS-14, and KS-15), expanding its generating capacity to 38 MW (Hawai‘i Groundwater & Geothermal Resources Center 2019).

2.d. Hawai‘i Clean Energy Initiative

In rhetoric, the State of Hawai‘i is ahead of other states in the pursuit of renewable energy resources. In 2008, Hawai‘i lawmakers implemented an aggressive renewable energy strategy called the Hawai‘i Clean Energy Initiative (HCEI), which aimed to increase Hawaii’s renewable energy generation to 70% through collaboration with the U.S. Department of Energy. (U.S.

Department of Energy 2014). In 2014, Hawaiʻi Governor David Ige signed H.B. NO. 623, which further strengthened the HCEI and set a goal of achieving a 100% renewable portfolio standard (RPS) by 2045. H.B. NO 623 is the most aggressive renewable energy legislation in U.S. history, and Hawaiʻi remains the only US state to have set a concrete goal of eliminating the use of fossil fuels for electricity generation (House of Representatives 2015; Public Utilities Commission 2015).

2.e. HECO PSIP

Several resources provide information on renewable energy in Hawaiʻi, including the EIA website and energy.gov, but none of these details how the legislation in Hawaiʻi will translate into an energy generation plan. The most comprehensive resource on how these policies will be implemented in Hawaiʻi is the Power Supply Improvement Plan (PSIP), a 2,000-page document produced by the Hawaiian Electric Company (HECO). HECO provides power to 95% of Hawaiʻi residents and serves the islands of Oʻahu, Maui, Hawaiʻi Island, Lanaʻi, and Molokaʻi (Hawaiian Electric 2016b). The PSIP is a series of plans and reports that projects Hawaiʻi's future energy needs, estimates the local cost of energy resources, and simulates the effectiveness of various combinations of resources to meet the projected future demand. The PSIP is designed to be a flexible, "working" document. As stated by HECO in the PSIP Executive Summary:

> We operate in an increasingly dynamic environment. Technology, prices, policies, and regulations rapidly change. Our action plans are designed to continue to make strong progress on Hawaiʻi's renewable energy goals while preserving flexibility for multiple long-term energy pathways. The Hawaiian Electric Companies are committed to performing energy planning on a continuous basis. This flexibility will allow us to integrate

> emerging and breakthrough technologies while adjusting to these changing circumstances (Hawaiian Electric Company Inc. 2016c, ES-7)

HECO submitted an updated PSIP to the Public Utilities Commission (PUC) in August 2014 in response to the HCEI.

The depth of analysis in the PSIP and, more importantly, the duration and severity of its review process, lend this document some credibility as a source for information on renewable energy in Hawai‘i. The PSIP review process took nearly 3 years and involved some 20 different governmental bodies and private organizations (Appendix A). The organizations involved were diverse. Many, like the Sierra Club and Ulupono Initiative, LLC, advocated sustainable and environmentally friendly policies. Others, like the Hawai‘i Department of Business, Economic Development, and Tourism (DBEDT), reviewed the PSIP in terms of its potential economic impact. Many organizations on the review committee submitted lengthy, comprehensive critiques of the PSIP, which HECO was required to address by law (Public Utilities Commission 2015). The original PSIP was rejected by the PUC. HECO was required to submit a revised PSIP in December 2016, which the PUC approved. The approved PSIP is available on HECO’s website at https://www.hawaiianelectric.com/about-us/our-vision-and-commitment.

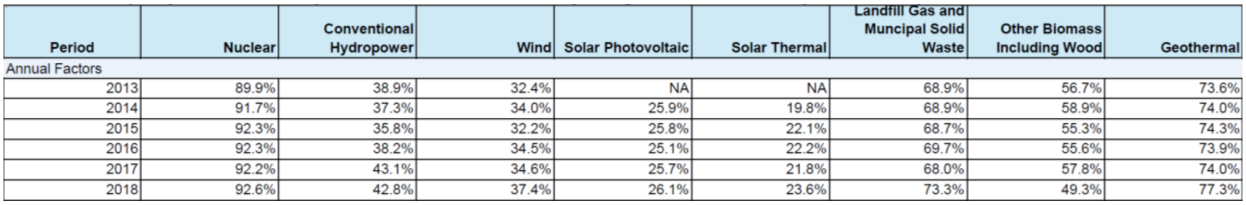
3. Renewable energy comparisons – wind, solar, & geothermal

3.a. Renewable energy cost analysis

Many of the energy generation enhancements projected in the December 2016 PSIP became outdated as soon as the document was published (Hawaiian Electric Company Inc. 2016c, ES-7), but the usefulness of this document goes beyond the specific roadmaps it provides. The December 2016 PSIP is particularly useful for examining the costs of renewable energy resources. HECO contracted the National Renewable Energy Laboratory (NREL) to examine its cost assumptions in the 2014 PSIP. The NREL reports included in the 2016 PSIP provide reliable estimates of the cost of renewable energy resources in Hawai‘i by year through 2045. The cost estimates are given in nominal dollars assuming a 1.8% annual inflation. The values reflect the overnight cost of building a power plant of a given installed capacity (Hawaiian Electric Company Inc. 2016c, F).

3.a.i. Power plant capacity factor & baseload energy

Capacity factor is one of the best measures of the reliability of a power plant. The maximum generating capacity of a power plant is its maximum output rate (commonly referred to as “nameplate capacity” and expressed in MW). The capacity factor is the ratio of the actual output of the power plant and its maximum generating capacity, thus, is basically a measure of how often a power plant is running at peak output. Capacity factor is usually expressed as a percentage and is measured annually. Even the most reliable power plants do not produce electricity at maximum output all the time. This is due to many factors, including maintenance and personnel issues, fuel availability, and even curtailment as a result of low demand. Renewable energy resources generally have lower capacity factors than power plants that use fossil or nuclear fuel. Table 1 shows annual capacity factors for the major utility scale renewable energy resources in the United States.



Period	Nuclear	Conventional Hydropower	Wind	Solar Photovoltaic	Solar Thermal	Landfill Gas and Muncipal Solid Waste	Other Biomass Including Wood	Geothermal
Annual Factors								
2013	89.9%	38.9%	32.4%	NA	NA	68.9%	56.7%	73.6%
2014	91.7%	37.3%	34.0%	25.9%	19.8%	68.9%	58.9%	74.0%
2015	92.3%	35.8%	32.2%	25.8%	22.1%	68.7%	55.3%	74.3%
2016	92.3%	38.2%	34.5%	25.1%	22.2%	69.7%	55.6%	73.9%
2017	92.2%	43.1%	34.6%	25.7%	21.8%	68.0%	57.8%	74.0%
2018	92.6%	42.8%	37.4%	26.1%	23.6%	73.3%	49.3%	77.3%

Table 1: Excerpt from Table 6.7.B. Capacity Factors for Utility Scale Generators Not Primarily Using Fossil Fuels, January 2013-January 2019, Electric Power Monthly, March 2019, produced by the U.S. Energy Information Administration

Perhaps the greatest challenge in renewable energy generation is related to baseload energy. Baseload energy is the minimum sustained output of a power plant over a given period and is a good measure of a resource's dependability. Energy professionals must carefully manage electricity grids to ensure that the energy being supplied to the grid exactly matches the energy being taken out of the grid. Understanding a power plant's baseload capacity allows energy professionals to accurately forecast a grid's energy-generating requirements. Poor planning can lead to redundant generating capacity and curtailment of productive resources, which consumers pay for in their electricity bills. Renewable energy resources that depend on sun and wind have baseload capacities of zero: at some point in each day or throughout each year, they will not produce any electricity. In contrast, geothermal resources tend to have high capacity factors and stable baseload capacities. In the fifteen years prior to its closing, PGV's capacity factor and annual output generally increased (Fig. 6).

3.a.ii. Energy storage

Energy storage plays a critical, and expensive, role in the current plans to achieve a 100% RPS in Hawai‘i. Energy storage systems allow load shifting – "absorbing and storing renewable energy when that generation exceeds customer demand and releasing that energy later (typically several hours) when energy demand is high and renewable output is low" (Hawaiian Electric Company Inc. 2016c, G1). Load shifting is a necessity when using renewable energy resources with low baseload capacity. Energy storage systems can take several forms, including flywheels, pumped hydroelectric reservoirs, and batteries. Flywheels are rotating mechanical devices that store energy in the form of angular momentum (Energy Storage Association, 2019). Pumped hydroelectric storage systems pump water to a high elevation reservoir, converting electrical energy to gravitational potential energy. Batteries store chemical potential energy. Hydrogen fuel cells are special types of batteries that store chemical energy by separating O_2 and H_2 through electrolysis. Hydrogen fuel cells are inefficient when compared to other chemical batteries (U.S. Dept. of Energy 2006).

The most efficient batteries today are lithium ion batteries. They have a fast charge rate, a fast discharge rate, and they lose their energy storage capacity more slowly than other chemical batteries (U.S. Dept. of Energy, Office of Energy Efficiency & Renewable Energy 2017). Lithium ion batteries also have high energy density, which equates to low land use. One PSIP model calls for a 1200 MWh lithium ion battery storage system on Oʻahu in 2030 (Hawaiian Electric Company Inc. 2016c, 4-5). This battery storage system would have a discharge rate of 300 MW for a total discharge time of 4 hours. The projected cost of a 4-hour load shifting battery storage system in 2030 is $250 per kWh (Hawaiian Electric Company Inc. 2016c, 4-5). Assuming a steady decline in the cost of battery storage, the total cost of this energy storage facility is projected to be $300 million.

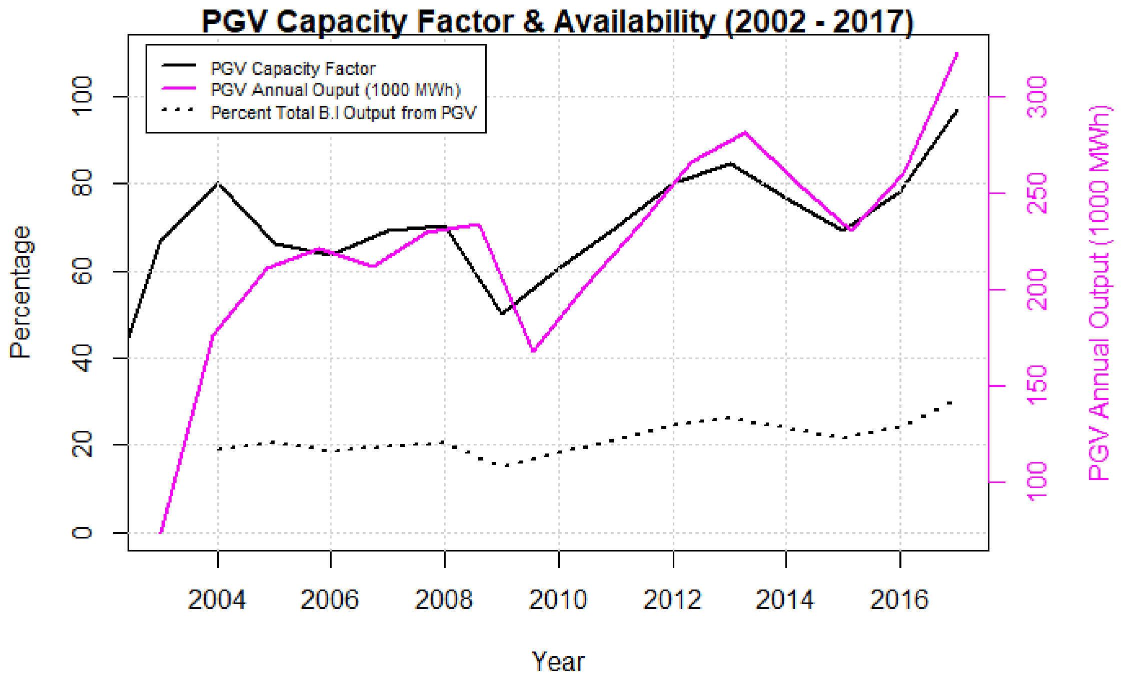


Figure 6: Puna Geothermal Venture's annual capacity factor and total annual output from 2004 to 2016. Since geothermal resources provide baseload energy, they can be curtailed when other renewables are producing more electricity and "turned back on" when needed. The changes in the plot correspond to changes in the amount of power HELCO purchased from PGV. The chart shows that dependence on PGV increased throughout this period, and that PGV generally met more of Hawai'i Island's electricity needs each year. The data is taken from RPS reports from the PUC website at http://puc.hawaii.gov/reports/energy-reports/renewable-portfolio-standards-rps-annual-reports/

3.a.iii. PSIP cost analysis

The intent of the subsequent analysis is not to oversimplify a complex problem but rather to aid in a more objective, complete understanding of the benefits and disadvantages of the major renewable energy resources used in Hawaiʻi. Table 2 compares the cost to create wind and solar resources with annual energy outputs, capacity factors, and baseload capacities like those of PGV. While this comparison highlights the cost benefits of geothermal compared to other renewables, it is not entirely realistic since it is unlikely that geothermal resources will be able to completely replace other renewables in Hawaiʻi. Energy generation is becoming increasingly decentralized. Even today, the electricity grid in Hawaiʻi is a complex system of central power plants, wind farms, commercial solar farms, a geothermal operation, and thousands of residential PV systems. This trend towards decentralized energy generation will likely continue, so a more realistic viewpoint should support a diverse renewable energy portfolio that maximizes all available resources.

Puna Geothermal Venture generated 322,609 MWh in 2017 (Hawaiian Electric Company Inc. 2016a). PGV has an installed capacity of 38 MW, or the capacity to produce 322,880 MWh per year. In 2017, PGV had an annual capacity factor of 97%. Utility scale solar farms in Hawaiʻi have capacity factors ranging from 20-25% (State of Hawaiʻi DBEDT 2016). Wind farms in Hawaiʻi have capacity factors ranging from 35-45% (State of Hawaiʻi DBEDT 2016). Energy storage requirements for wind and solar farms will vary depending on the specific use (load shifting, grid stabilization, emergency reserves, etc.), but will likely range from 25-75% (Hawaiian Electric Company Inc. 2016c, G13). Technically, a wind or solar resource would need to have the capacity to store 100% of its peak daily output to match PGV's capacity factor. Table 2 shows that the stable baseload capacity and high capacity factor of geothermal resources make them an extremely competitive renewable energy resource in Hawaiʻi when compared to wind and solar.

Resource		Utility Scale Solar	Onshore Wind	PGV
Capacity factor		20-25%	35-45%	97%
Installed capacity to match PGV 2017 output (322,609 MWh)		147-184 MW	82-105 MW	38 MW
Cost per installed kW ($/kW)		$2,057	$2,867	$11,302
Plant construction cost		$302,379,000 – 378,488,000	$235,094,000 – 301,035,000	$429,476,000
Energy storage cost ($/kWh)		$ 250		N/A
Daily kWh storage at 25%		220,965 kWh		
25% energy storage cost		$55,241,267		
Daily kWh storage at 50%		441,930 kWh		
50% energy storage cost		$110,482,534		
Daily kWh storage at 75%		662,895 kWh		
75% energy storage cost		$165,723,801		
Fixed Annual O&M costs ($/kW)		$31.80	$43.38	$202.97
Total Annual O&M Cost		$4,674,600 – 5,851,200	$3,557,160 – 4,554,900	$7,712,860
Total Capital Cost	25% storage	$357,620,267 – 433,729,267	$290,335,267 – 356,276,267	**$429,476,000**
	50% storage	$412,861,534 – 488,970,534	$345,576,534 – 411,517,534	
	75% storage	$468,111,801 – **544,211,801**	$400,817,801 – **466,758,801**	

Table 2: The costs are those projected for the year 2030, when battery storage systems costs are expected to be extremely competitive. All costs are Hawaiʻi-specific nominal costs in US dollars. Projected costs are taken from the 2016 PSIP for the islands of Maui and Hawaiʻi Island, due to their increased geothermal resource potential. Data were taken from PSIP Tables F-14, F-16, and F-20, and Hawaiʻi State 2017 Energy Facts & Figures.

3.a.iv. Renewable energy subsidization & price parity

Subsidies have been an important component of the renewable energy industry's recent growth. Subsidies are a form of financial aid that governments can offer institutions, economic sectors, or individuals who meet certain conditions. Subsidies have been shown to be extremely effective in Hawaiʻi. For example, the Net Energy Metering Program was an incentive that allowed Hawaiʻi residents with rooftop solar systems to feed excess energy from their systems into the electricity grid and gain "credit" when their system's energy input exceeded their home energy expenditures (Hawaiian Electric Company Inc. 2019a). The program was active from 2001 – 2015 and is credited for dramatically increasing the number of residential rooftop solar systems in Hawaiʻi (Hawaiian Electric Company Inc. 2019a).

Though renewable energy subsidies are clearly a powerful tool, they are subject to flaws in implementation and even abuses. In Hawaiʻi, these programs seem to favor wind and solar development and often exclude geothermal development. There are several federal and state incentives for renewable energy development in Hawaiʻi; the largest is the Hawaiʻi Renewable Energy Technology Income Tax Credit (RETITC) (Hawaii State Energy Office 2019). According to Pacific Business News, Hawaiʻi residents claimed $673.3 million in RETITC from 2011 – 2016 (Mai 2018). Geothermal energy resources are ineligible for this tax incentive (Hawaii State Energy Office 2019). In 2009, the Honolulu City Council passed a 100% property tax exemption for alternative energy resources (City Council, City and County of Honolulu 2009). Geothermal resources are excluded from this incentive as well. Clearly, much of the recent rapid growth of the solar industry in Hawaiʻi has been funded by taxpayers.

In stark contrast, Hawaiʻi's single geothermal plant has been a significant source of revenue for the state through royalties and property taxes. From 2007 to 2018, the State of Hawaiʻi received $24.7 million in royalties from PGV (State of Hawaiʻi Dept. of Land & Natural Resources 2019). Twenty percent of those royalties, or approximately $5 million, went to the Office of Hawaiian Affairs. Subsidies can clearly alter renewable energy markets and the perceptions of consumers.

3.b. Renewable energy land use analysis

Geothermal has the lowest land use of all non-nuclear, non-hydrocarbon renewable energy resources. Land use is an important issue in Hawaiʻi, and renewable energy resources vary widely in their land use requirements. Wind resources occupy 30 – 113 acres per MW (Denholm et al. 2009). Solar resources occupy 5 – 10 acres per MW (Ong et al. 2013). The entire PGV facility sits on a 45-acre parcel (Fig. 8). PGV occupies approximately 1 acre per MW. Geothermal power plants in general occupy 1 – 8 acres per MW (U.S. Dept. of Energy Efficiency & Renewable Energy 2019b). In order to match PGVs 2017 annual output, a wind farm would need to have an installed capacity of 82 -105 MW and would occupy 2,500 - 12,000 acres. A solar farm would need to have an installed capacity of 147 – 184 MW and would occupy 700 – 1900 acres (Table 2).

Even the most optimistic renewable energy plans for Hawai‘i demand significant portions of land or sea. The PSIP details several different plans to reach 100% RPS by 2045. The plans calling for the fewest solar and wind resources on O‘ahu are the E3 RESOLVE plans that utilize liquid natural gas (LNG) (Hawaiian Electric Company Inc. 2016c, Table 4-1). The language in the PSIP suggests the E3 RESOLVE plan with LNG and generation modernization is preferable though slightly more expensive (Hawaiian Electric Company Inc. 2016c, 4-10). This plan calls for 364 MW of wind and 1904 MW of solar on O‘ahu (Hawaiian Electric Company Inc. 2016c, Table 4-1). Assuming solar and wind capacity factors and land use requirements do not improve substantially, renewable energy resources on O‘ahu are projected to require 32 square miles of land or sea at best (Fig. 7).

$$364\,MW\,of\,wind\ \approx 10{,}920 - 41{,}132\,acres \approx 17 - 64\,mi^2$$

$$1904\,MW\,of\,PV\ \approx 9{,}520 - 19{,}040\,acres \approx 15 - 30\,mi^2$$

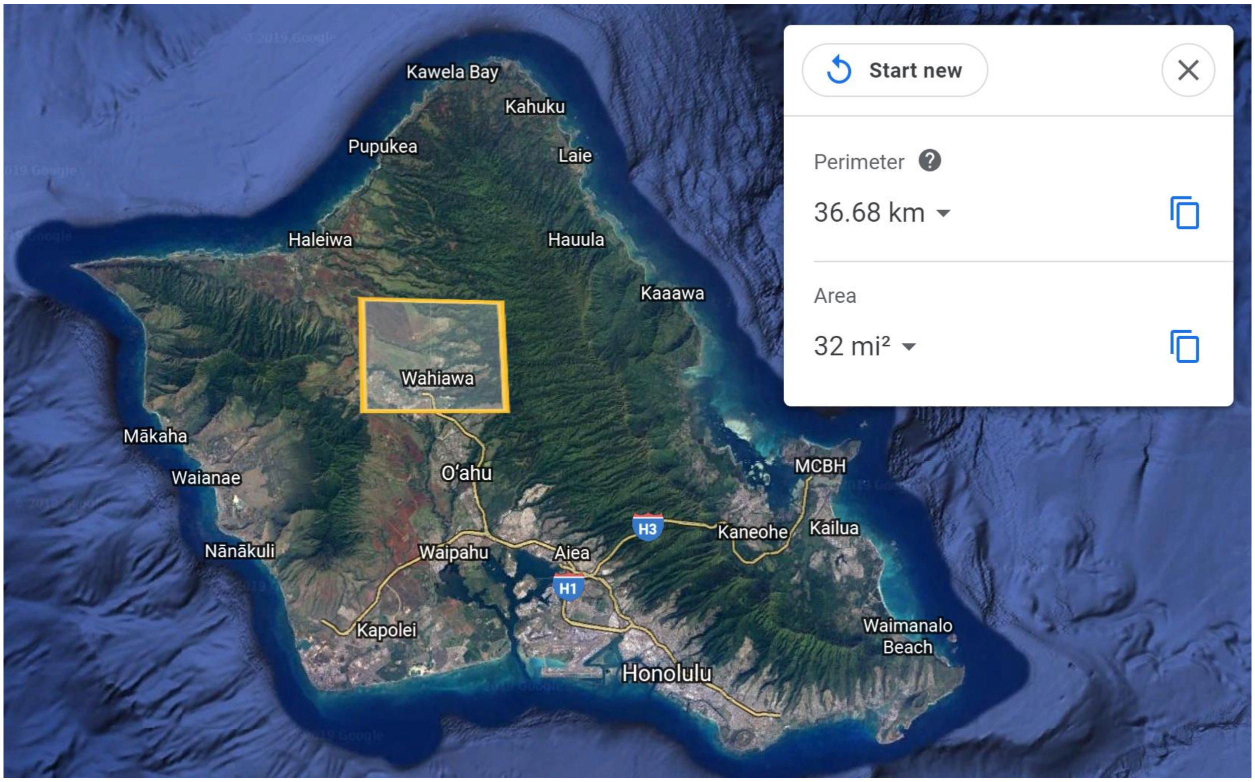


Figure 7: Google Earth screenshot of the island of Oʻahu with conservative projections of wind and solar resource land requirements. According to the PSIP E3 plan with liquid natural gas and generation modernization, Oʻahu can expect 364 MW of wind and 1904 MW of solar, which approximates to 30-90 square miles of land or sea (PSIP Book 1, Table 4-1).

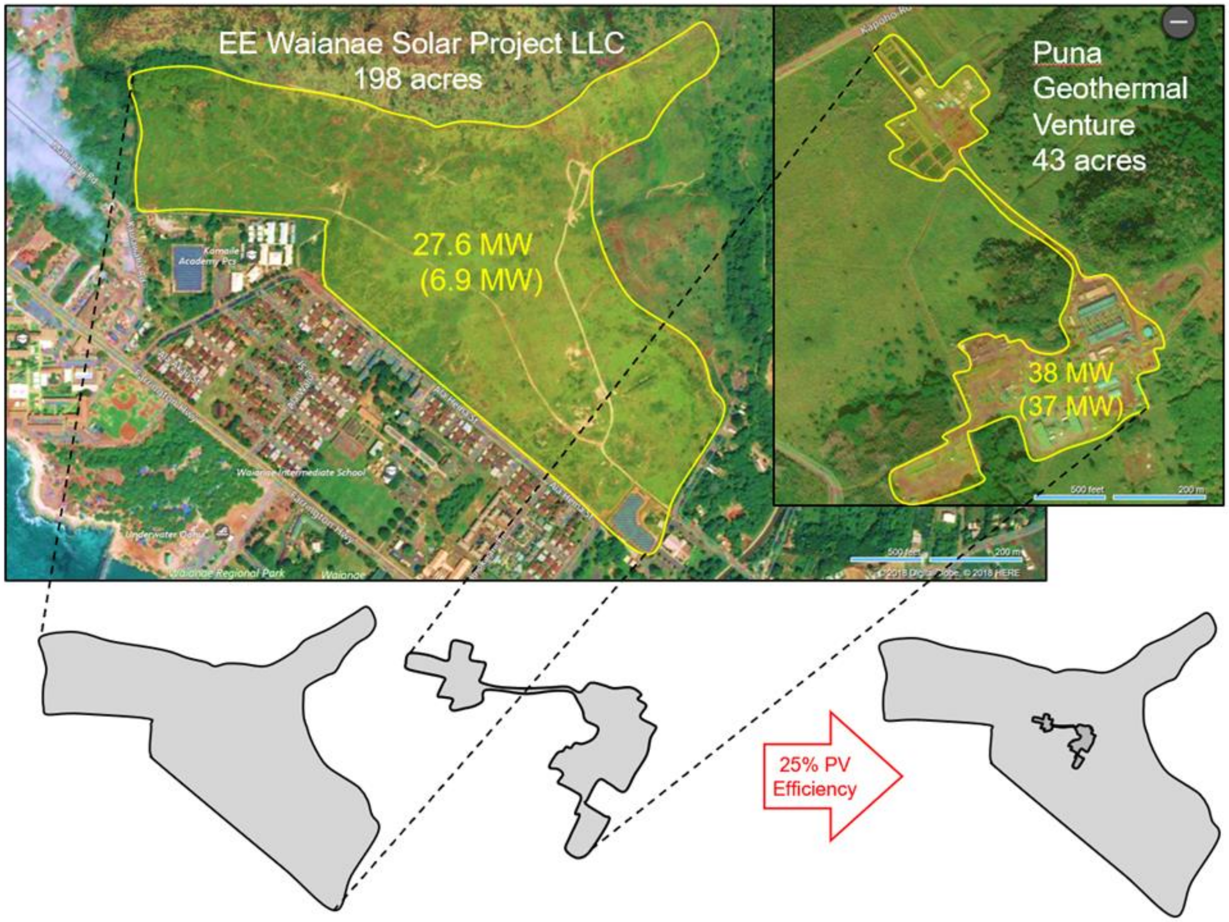


Figure 8: EE Wai‘anae Solar Project LLC is Hawai‘i’s largest solar farm. It has an installed capacity of 27.6 MW and occupies 198 acres (Mykleseth 2017). PGV has a higher nameplate capacity, higher capacity factor, and a smaller footprint. A solar farm would need to occupy 700-1900 acres to match PGV’s annual output in 2017. Images were taken from Google Earth. Scale bars are shown for accuracy. The plant outlines are proportionally scaled.

3.c. Renewable energy hazards

3.c.i. Solar hazards

Solar panel construction is an energy intensive process that requires mining and the use of large volumes of hazardous chemicals. Solar panel manufacturers make solar-grade silicon from 99.9% pure quartz (Fthenakis et al. 2011). The quartz is harvested from open pit mines, dredging or fracking, each of which requires disturbing large swaths of land. This fact is not often quantified or considered when comparing renewable energy resources. Manufacturers purify quartz into metal-grade silicon (which is suitable for use in electronics) by heating it with wood chips (carbon) in a large reactor. This process requires 10 – 12 MWh of electricity per ton of quartz (Norwegian University of Science and Technology 2018). Solar panel manufacturers purify the silicon further through one of two methods: the Siemens method or the fluidized bed reactor method (FBR) (Silicon Products Group 2019). The Siemens method accounts for ~90% of solar grade silicon production in the US and involves introducing silane- or trichlorosilane-gas into a heated reactor (PVEducation.org 2019). The purified solar-grade silicon deposits on heated polysilicon rods (PVEducation.org 2019). The International Energy Agency (IEA) completed a detailed, multiyear study analyzing total resource requirements for solar panel construction (Fthenakis et al. 2011). The study found that a single 243 cm^2 solar wafer required 2.8 MJ or 0.77 kWh of energy and 8.9 grams of hazardous chemicals, to include sodium hydroxide, hydrofluoric acid, hydrochloric acid, nitric acid, phosphoryl chloride and hydrogen chloride (Fthenakis et al. 2011, Table 5.1.5). Assuming 90% of a solar farm’s land area is covered with solar panels, the construction of a 200-acre solar farm like EE Waiʻanae Solar Project LLC would require approximately 25,000 MWh of energy and 80,000 gallons of hazardous chemicals. PGV would have to generate electricity at peak capacity for nearly a month to produce the energy needed to manufacture the solar panels for a 200-acre solar farm. It would take EE Waiʻanae Solar Project LLC more than 5 months to generate 25,000 MWh of electricity.

3.c.ii. Wind hazards

Wind energy development can also have negative environmental impacts. A single 2 MW wind turbine requires around 700 metric tons (t) of concrete in the foundation (Martínez et al. 2009). Concrete production is known to produce CO_2 through the conversion of calcite to lime ($CaCO_3 \rightarrow CaO + CO_2$) (Hasanbeigi et al. 2012). In fact, concrete production worldwide is believed to account for about 5% of anthropogenic CO_2 emissions (Hasanbeigi et al. 2012). The production of one ton of cement releases an estimated 0.73–0.99 t of CO_2 (Hasanbeigi et al. 2012). The construction of a single 2 MW wind turbine, therefore, releases 500 – 700 t of CO_2. The PSIP E3 RESOLVE plan with LNG for Oʻahu calls for 364 MW of installed wind capacity by 2045 (Hawaiian Electric Company Inc. 2016c, Table 4-1). The installation of 364 MW of wind energy could produce 91,000 – 127,400 t of CO_2, which is roughly equivalent to the amount of CO_2 emitted by 20,000 passenger cars in one year (U.S. EPA 2018). Wind turbines could also pose some significant ecological threats. In Denmark, some estimates report 30,000 birds are killed by wind turbines every year (MacKay 2013). Offshore wind facilities also have potential to disturb marine habitats through processes that are not well understood (Soukissian et al. 2017). The December 2016 version of the PSIP calls for 300 MW of offshore wind, which would require between 14 and 53 square miles of sea floor (Hawaiian Electric Company Inc. 2016c, Table 4-1). Wind turbines are even associated with adverse health effects in humans related to noise emissions (Jeffery et al. 2013). Several studies have linked noise emissions from wind farms to increases in sleep loss and many of its associated side effects (Jeffery et al. 2013). Many of these negative impacts are relatively small. For example, many more birds are killed by house cats and window collisions than wind turbines (MacKay 2013). Taken together, however, these negative impacts help to demonstrate that no renewable energy resource is without its foibles.

3.c.iii. Geothermal hazards

Geothermal power is not without its drawbacks, either. Hydrogen sulfide (H_2S) emissions have been the most significant hazard associated with geothermal power in Hawai‘i. Hydrogen sulfide gas is a colorless gas associated with sulfate reduction in decaying organic matter. Hydrogen sulfide has a distinct odor of rotten eggs that can be detected by the human nose at concentrations as low as 0.01 – 1.5 parts per million (ppm) (U.S. Department of Labor 2019). The mechanisms that produce hydrogen sulfide in volcanic systems are not well understood but are believed to be a biproduct of the interaction of sea water and basalt at high temperatures (Vetter et al. 2010). Hydrogen sulfide is extremely toxic at concentrations above 100 ppm and can be a powerful irritant at concentrations above 10 ppm (U.S. Department of Labor 2019). Hydrogen sulfide is quickly converted to sulfur dioxide (SO_2) in the atmosphere, which can cause low pH ("acid") rain and other environmental hazards (Kagel et al. 2005). Despite these hazards, emissions from geothermal power plants are generally low, particularly from binary plants like PGV. In fact, one US government-sponsored study by the Geothermal Energy Association in 2005 found that binary geothermal plants produced negligible emissions (Table 3). The relationship between geothermal H_2S emission and adverse health effects in Hawai'i is unclear. Hawai‘i Island residents have higher rates of respiratory illnesses than residents of other islands, but there is no definitive link between these health issues and H_2S exposure (Healthcare Association of Hawai‘i 2015, Adler et al. 2013).

The Clean Air Act of 1970 and the Hawai‘i Department of Health (DOH) mandate the monitoring of PGV's gas emissions and set an ambient air quality standard for hydrogen sulfide of 25 parts per billion (ppb) in any one-hour period (Hawaii Dept. of Health 2013). This standard is approximately three orders of magnitude lower than the daily exposure limits established by the Occupational Safety & Health Administration (OSHA) (U.S. Department of Labor 2019). Monitoring PGV's emissions occurs through three air quality stations positioned around PGV (the data from these stations is open to the public at http://72.253.107.171/pgv/pgv.asp). One study from the University of Hawaiʻi at Hilo analyzed air quality data from these stations taken in 2005 and from 2007 to 2012 and found that hydrogen sulfide concentrations did not exceed 23.0 ppb, well below the standards for toxicity and even acute exposure (Meder 2013).

lbs per megawatt hour	Nitrogen Oxides	Sulfur Dioxide	Carbon Dioxide	Particulate Matter
Coal	4.31	10.39	2191	2.23
Coal, life cycle emissions	7.38	14.8	not available	20.3
Oil	4	12	1672	not available
Natural Gas	2.96	0.22	1212	0.14
EPA Listing Average of all US Power Plants	2.96	6.04	1392.5	not available
Geothermal (flash)	0	0.35	60	0
Geothermal (binary and flash/binary)	0	0	0	negligible
Geothermal (Geysers steam)	0.00104	0.000215	88.8	negligible

Table 3: Summary of average air emissions of geothermal and equivalent fossil fuel plants in pounds per megawatt hour. (Kagel et al. 2005)

In addition to the low emissions associated with normal operations at PGV, large volumes of hydrogen sulfide have been released through controlled and uncontrolled venting. An uncontrolled venting is a "blowout". Blowouts are abnormal occurrences in which a well or a pipe carrying hydrothermal fluid ruptures unexpectedly and releases pressurized gases and fluids. PGV has reported several blowouts throughout its operation (U.S. EPA, 2000). As of 2013, the DOH had recorded six incidents during which PGV H_2S emissions exceeded the DOH standard (Adler et al. 2013). Some of these events released large volumes of hydrogen sulfide and other gases into the atmosphere. The EPA estimates that one event in 1991 released 2,247 lbs. (~1 t) of hydrogen sulfide into the atmosphere over a period of 31 hours (U.S. EPA 2000, Geothermal Public Health Assessment Study Group 2013). Although this quantity may seem large, the USGS estimates that nearby Kīlauea Volcano releases 2,000 t of sulfur dioxide gas every day (U.S. Geological Survey 2000).

4. Renewable Energy Future for Hawai‘i

4.a. PSIP renewable energy projections

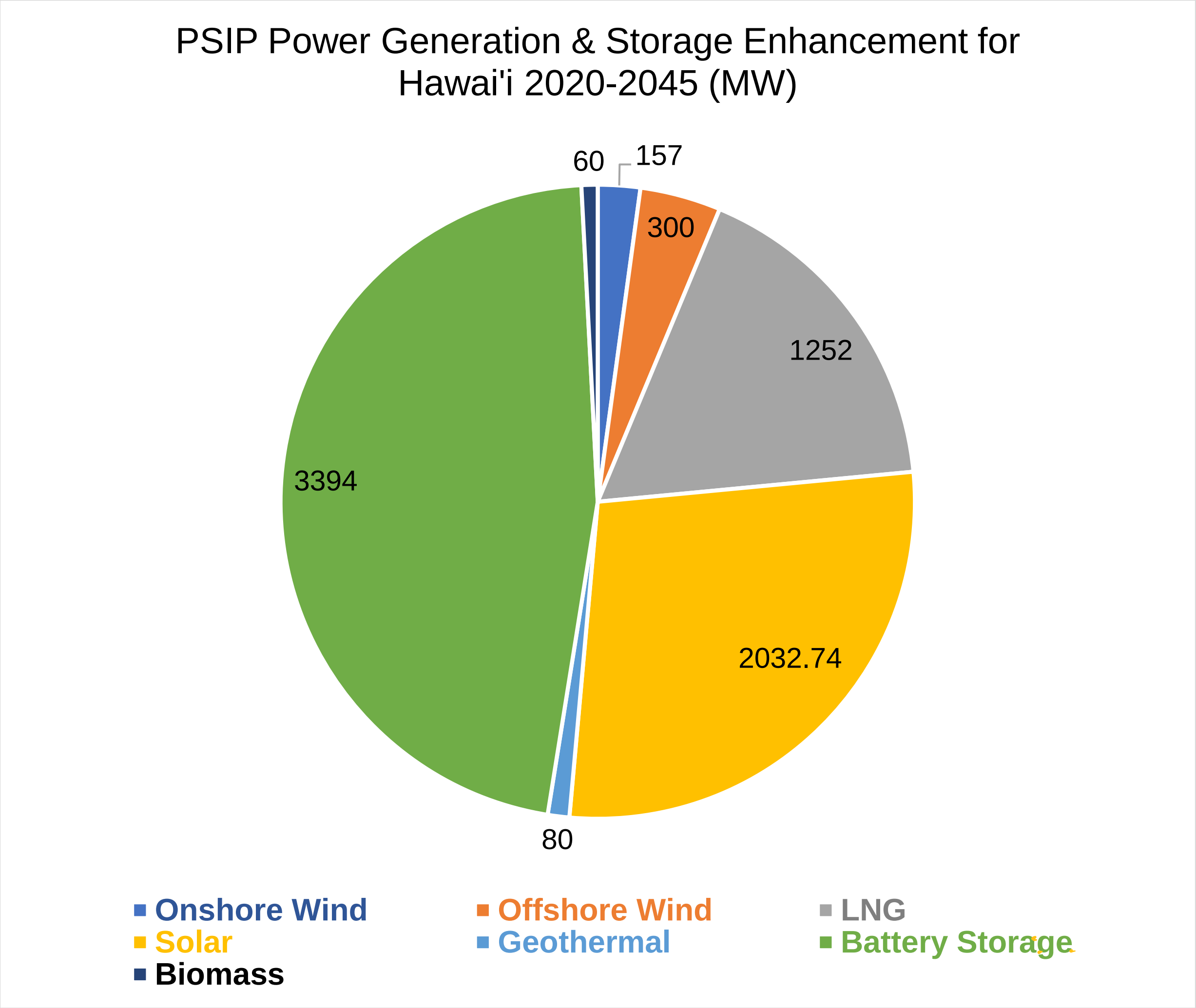


Figure 9: This figure summarizes the distribution of energy generation and energy storage enhancements projected for Hawai‘i as described in portions of the December 2016 Power Supply Improvement Plan (PSIP). The PSIP contains multiple plans for each island. This figure displays data from the E3 Plan with Liquid Natural Gas (LNG) and Generation Modernization for O‘ahu, the E3 Plan with LNG for Maui, the April PSIP for Moloka‘i, the April PSIP for Lana‘i, and the E3 Plan with LNG for Hawai‘i Island. HECO has since updated the PSIP to dramatically reduce the amount of LNG power generation. The power generating capacity lost by this change is expected to be filled by additional solar and wind resources with battery storage.

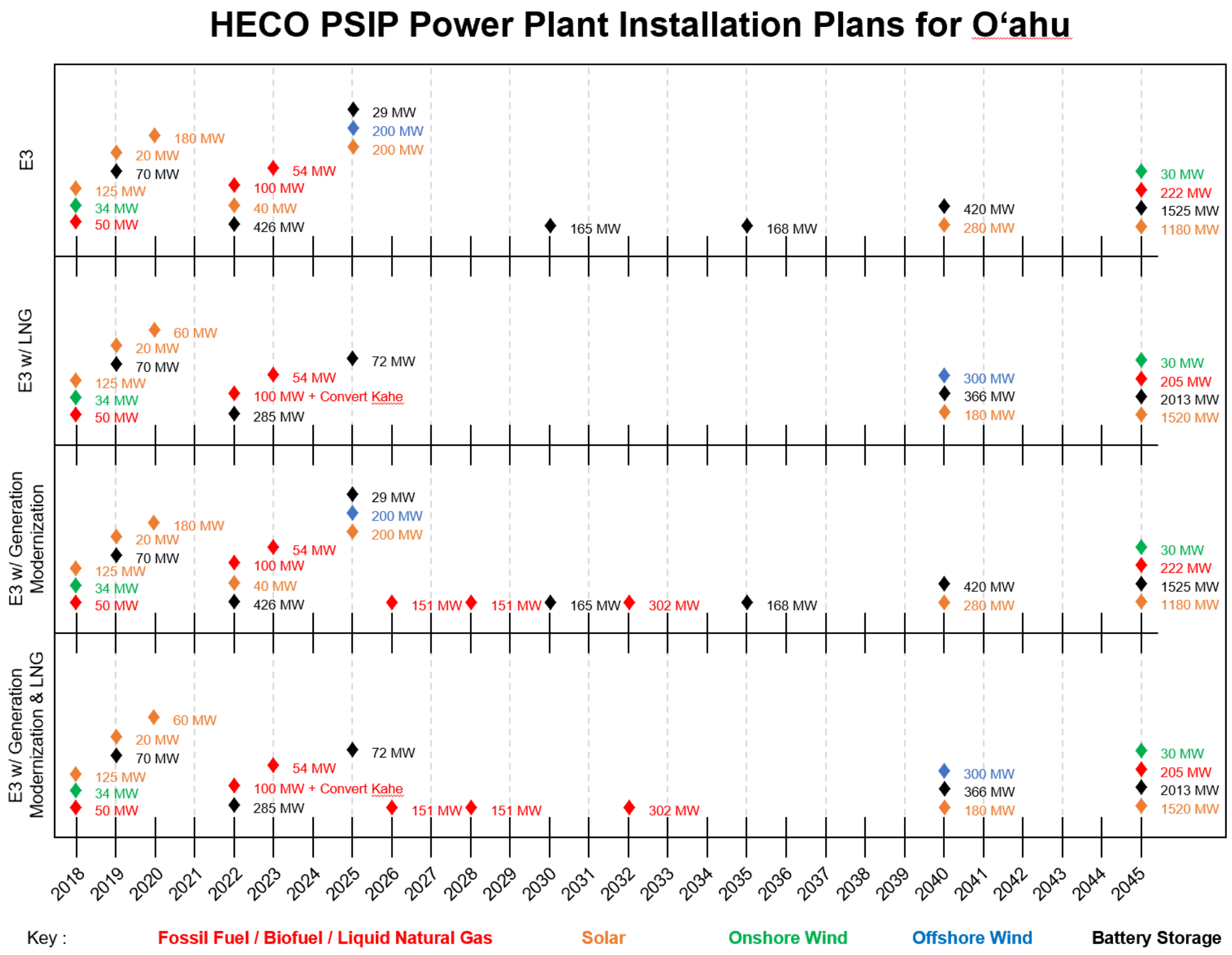


Figure 10: O‘ahu PSIP Projections. This figure summarizes the results of the E3 RESOLVE modeling for the island of O‘ahu. LNG, biofuels, and fossil fuels are grouped together to highlight wind and solar resources. It should be noted that all plans involve biofuels or liquid natural gas. The largest difference between the plans involves the conversion of the Kahe Power Plant from fossil fuel to LNG in 2022. This conversion is only required in the E3 plans with LNG. Each of the six Kahe generators are gradually retired.

4.b. Geothermal resource potential in Hawai‘i – Play Fairways Analysis

The extent of Hawai‘i’s geothermal resource potential remains largely uncharacterized, and, given the limited funding and relatively high cost of geothermal exploration, there have been few efforts to change this. The initial phases of geothermal exploration have the highest financial risk since geothermal resources can be pinpointed only through drilling (World Bank 2012). The ongoing three-phase Hawai‘i Play Fairway study, funded by the U.S. Department of Energy Geothermal Technologies Office (award DE-EE0006729) to the University of Hawai‘i at Mānoa, Hawai‘i Groundwater and Geothermal Resource Center, aimed to better characterize geothermal resource potential in Hawai‘i. The first phase of the project focused on identifying, compiling, and ranking existing geologic, groundwater, and geophysical datasets relevant to subsurface heat, fluid, and permeability. The team developed a statistical methodology to integrate these data into a resource probability map. This analysis identified 10 locations for geothermal exploration throughout Hawai‘i. Phase two of the project involved the collection of new groundwater data in 10 locations across the state and new geophysical data on Lana‘i, Maui, and central Hawai‘i Island, as well as modeling of topographically induced stress to better characterize subsurface permeability. The Play Fairway team is currently in phase three of the project, which has a goal of obtaining scientific data from a test well. The results of the Play Fairway Analysis have provided a major step forward for the State of Hawai‘i through providing an updated resource assessment, a roadmap for additional exploration activities, and the identification of target sites for drilling.

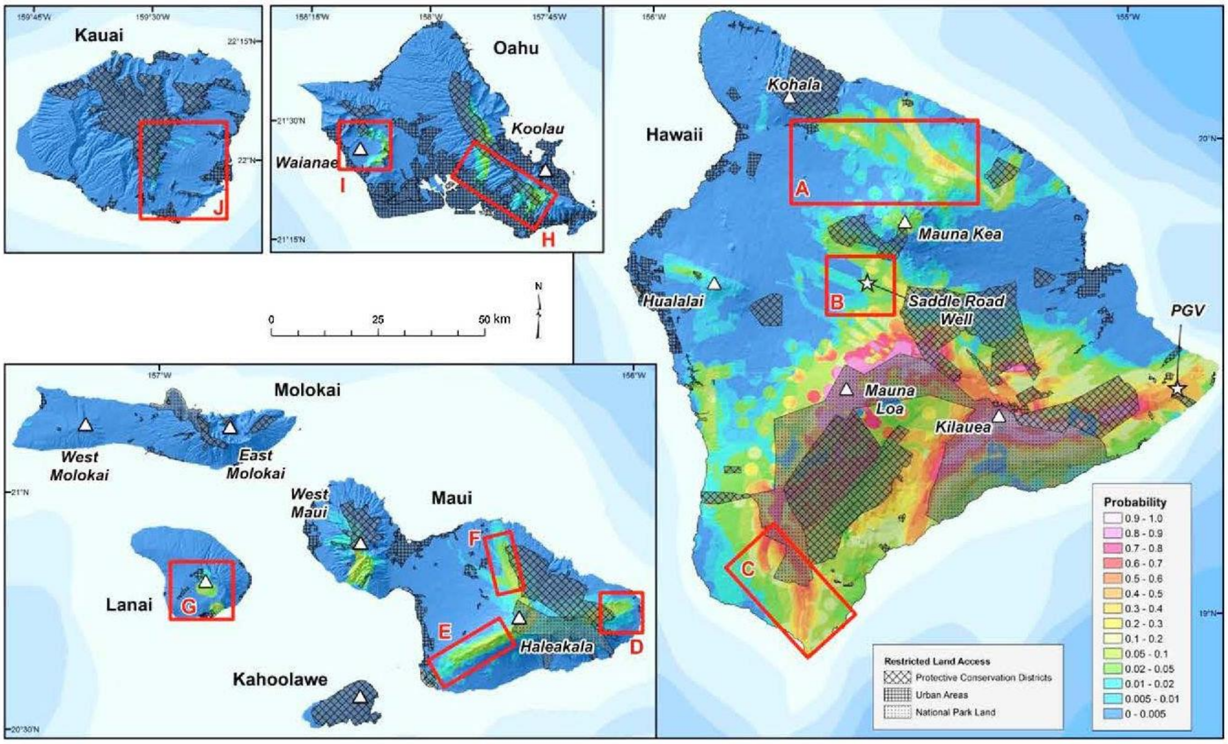


Figure 11. Results of the DOE Phase 1 geothermal play fairway probability analysis for the State of Hawaii. Probabilities of a geothermal resource are colored. Areas with restricted land access are shown in stippled and crosshatch patterns (e.g., National Park lands, protective conservation districts, and urban areas). Red boxes outline areas proposed for Phase 2 study. White triangles indicate the calderas of the main shield volcanoes. White stars mark the locations of the Saddle Road well and PGV. (Lautze et al. 2015)

5. Conclusion

Geothermal is an underexplored and underutilized renewable energy resource in Hawai‘i. Facts show that it is a clean, affordable technology that uses land more efficiently than wind and solar resources and provides baseload power. Cost projections for geothermal power plants in Hawai‘i are competitive with other renewables, especially when considering the necessity of battery storage for intermittent resources. Geothermal resources in Hawai‘i have been a source of revenue, whereas solar resources have been heavily subsidized at taxpayer expense. Hazards associated with geothermal are limited. Uncontrolled, largescale hydrogen sulfide emissions are infrequent, and have never been definitively linked to adverse health effects in the population. Geothermal energy has massive potential to enable Hawai‘i to achieve its bold renewable energy goals, yet the distribution and quality of geothermal resources across most of the state remain unknown. Furthermore, apart from the Hawai‘i Play Fairway Project, there appears to be little effort to change this. These potentially vast stores of energy beneath our feet warrant thorough exploration and fair consideration.

Renewable energy development is a critical and timely issue. Per capita, Hawai‘i residents live energy-intensive lives, as do most Americans. Without a dramatic change in average lifestyle, Hawai‘i will need to maximize the use of every available renewable energy resource. Hawai‘i cannot afford to squander energy by favoring resources whose hazards are less obvious. Unfortunately, no renewable energy resource is perfect: Wind, solar, and geothermal resources all have drawbacks, and renewable energy resources touted as panaceas should be viewed with skepticism. To choose one resource over another is to trade one package of advantages and disadvantages for another. Hawai‘i residents, communities, and policymakers must work together to create shared understanding about renewable energy and collectively decide which advantages have primacy and which disadvantages they are willing to accept. In closing, as stated by the late Dr. David JC McKay in his book “Sustainable Energy – without the hot air,”

> To achieve our goal of getting off fossil fuels, these reductions in demand and increases in supply must be big. Don’t be distracted by the myth that “every little helps.” If everyone does a little, we’ll achieve only a little. We must do a lot.

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7. Appendix A (PSIP Docket Participants)

Instructions to access docket online:

1) Go to https://dms.puc.hawaii.gov/dms/
2) Enter docket 2014-0183 into the “Docket Quick Link” box on the left side of the screen

Appendix A (PSIP
Docket Participants).c