Intro to Renewable Energy Final Paper

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Project Proposal

As the impending climate crisis looms, the world is rapidly transitioning to renewables. Hawaii is advantageously positioned to lead this transition. Its unique geography offers abundant solar, wind, and geothermal resources, but Hawaii currently utilizes little of what is available. Petroleum supplies 80% of the state's energy—more than any other US state. Our plan details how to make Hawaii renewable by 2053 and sustain that to 2083 and beyond.

Hawaii's tropical climate and its many beautiful landscapes make it a popular tourist destination, and tourism is its largest industry. Considering how tourism affects the population is one of the more unique factors shaping our plan. Hawaii's lopsided population distribution is another unique consideration. While the archipelago has 8 main islands and over 100 small islands, over half of Hawaii's population lives on a single island. Our plan proposes an HVDC interisland backbone to bring energy from where renewables are plentiful to population centers where demand is highest. A third unique aspect of Hawaii's energy system is its reliance on aviation. Since aviation is notoriously hard to electrify, we also focus on biofuel production to replace petroleum. Other important parts of our plan are a partially subsidized transition to 100% EVs for ground vehicles and the construction and renovation of major solar, wind, and geothermal farms.

We request a 50-year loan of 39.3 billion dollars at an interest rate of 3.3% to realize our plan. This loan covers construction, maintenance, and decommission of proposed infrastructure, with construction making up the bulk of it. Our plan staggers the construction of our plants with the increase in demand, maximizing the portion of the loan that is invested and minimizing the upfront loan amount. Under our plan, the cost per kilowatt will decrease to a third of what it is currently, from 37 cents to 13 cents. Additionally, energy cost under our plan will always stay below the current energy cost adjusted for inflation.

Hawaii is an archipelago in the Pacific Ocean. It consists of 8 main islands and over a hundred small islands. The islands are grouped into four counties: Kauai, Honolulu, Maui, and Hawaii. Most of the state's 1.4 million people live on a single island, Oahu, at 800 thousand [1]. The next most populated islands are Hawaii, at 200 thousand, and Maui, at 100 thousand. The largest industry in Hawaii is tourism, and nearly 10% of the population are tourists. Since tourism fluctuates significantly throughout the year, Hawaii's population is strongly dependent on the month of the year.

Hawaii has many promising renewable energy sources. The archipelago originated from a hot spot in the mantle: as the pacific tectonic plate moved, the location of the hot spot changed, forming the string of islands that became Hawaii [2]. Because of its volcanic origin, geothermal energy is one potential source of renewable energy for Hawaii. The state's location in the Pacific Ocean also exposes it to northeast trade winds, and its long coastlines make both onshore and offshore wind another promising resource [3]. Additionally, the state's tropical latitude brings it plenty of sunlight, so solar energy should also be explored.

Despite the potential, very little of the state's energy supply is currently renewable. In 2021, Hawaii used 102 TWh total: 30 TWh of electrical energy and 72 TWh of chemical energy [4]. The 72 TWh of chemical energy includes 22 TWh used to generate electrical energy: primarily petroleum, at 18 TWh, and coal, at 4 TWh. However, in 2022, Hawaii closed its last coal power plant, and now Hawaii only uses petroleum to generate nonrenewable power [5]. The other 8 TWh, or 26% of total electrical demand, was generated through renewables: 5.2 TWh through solar, 1.7 TWh through wind, 0.5 TWh through geothermal, and 0.3 TWh through hydroelectric sources.

Our plan will reform Hawaii's energy system. Through the construction and expansion of wind, solar, and geothermal infrastructure, policy to promote vehicle electrification, an interisland HVDC network, and replacement of vital petroleum use with biofuels, we aim to make Hawaii 100% renewable by 2053, and support 100% renewables for 20 more years.

A Close Look at Demand

Figure 1 shows power use by industry. Residential, commercial, and industrial uses make up roughly equal portions of the electric demand, while transportation accounts for most of the chemical demand. In total, residential, commercial, industrial, and transportation account for 5.77 TWh, 7.39 TWh, 8.61 TWh, and 40.75 TWh respectively [4]. Figure 2 shows energy uses within the residential sector. Heat-related uses make up about half of the demand: refrigeration, water heating, AC, and fans [6]. However, little energy is used for home heating itself: the tropical climate makes heating unnecessary, and 46% of households have no home heating at all.

Given that transportation accounts for nearly twice the demand of every other sector combined, focusing on it is imperative. Figure 3 shows demand by each form of transportation [7]. Air and ground transportation make up approximately equal portions, while marine transportation accounts for the rest, at about 10%. Notably, while electrification of ground vehicles is already underway across the world, electrification of aviation and marine transportation is difficult, necessitating biofuel and/or carbon offsetting measures.

To calculate seasonal shifts in demand, we used the Philippines as model. The Philippines are also an island state, and its latitude of 16° N is comparable to Hawaii's at 19° N. The energy use of the Philippines peaks in May at about 10% higher than mean and dips in February at about 10% below mean [8]. However, unlike Hawaii, the population of the Philippines does not shift significantly due to tourism. To correct for this factor, we adjusted the use each month by the relative number of tourist arrivals, limiting it to only affect the proportion of the population that are tourists (Equation 1). Figures 4-6 show each of those factors and the resulting corrected seasonal demand curve. The resulting curve shows that while demand still varies by about 20%, the peak demand months are shifted later into the summer when tourism is the most popular.

The demand also shifts throughout each day; Figure 7 captures this trend [9]. A primary peak occurs between 6 and 7 PM, and a secondary peak occurs between 4 and 6 AM. To normalize the daily demand, Hawaii would need to store 11% of each day's energy use (Equation 2). At the peak, power draw is over twice the base load.

Hawaii has already conducted a population forecast up to 2045 using factors such as age distribution and historical data [10]. The report suggests that Hawaii's population will continue increasing, though at an increasingly slower pace. To extend the forecast to 2073, we used a polynomial regression to capture the shape of the curve (Equation 3). The model suggests that between 2023 and 2073, the population will increase by 30%. Figures 8 and 9 show the state's forecast and our regression. Between the two dates, the energy used per capita should also change. Based on energy used per capita in the last decade, we also built an exponential model based on energy use per capita in the last 10 years (Equation 4) [11]. The model suggests that energy use per capita will increase 0.03% each year, and combining the two results suggests that the total energy use should increase by 33% by 2073. Refer to Figures 10 and 11 for the energy use per capita model and the combined result.

Current Supply Situation

Very little of Hawaii's energy supply is currently renewable. While Hawaii no longer depends on coal for energy, it still heavily relies on petroleum. In total, petroleum makes up about 80% of all energy use, the highest proportion out of all fifty states [12]. The largest petroleum plants in Hawaii are the Kahe Power Plant, at 582 MW, the Waiau Power Plant, at 457 MW, and the Kalaeloa Cogen Plant, at 220 MW [13]. While Hawaii has nearly two dozen petroleum plants, they quickly dwindle in size: these three plants account for over half of Hawaii's total petroleum electric output of 2041 MW [4]. Not only do the plants vary in age, but the units within each plant also have different ages. For example, unit 3 of the Waiau plant was constructed in 1947: now nearly 80 years old [14]. Because of varying ages and continuous maintenance, pinning down a concrete lifetime for each of Hawaii's petroleum plants is very difficult. For newer plants, like the Kalaeloa Cogen plant, we assume a lifetime of 50 years, while for the older plants, we assume that without continuous maintenance, they will have to be decommissioned within 15 years.

Hawaii does not produce petroleum itself, though it has a single crude oil refinery in Oahu, the Par Hawaii refinery [15]. Instead, Hawaii imports oil from domestic and foreign sources, primarily Libya, Argentina, and Nigeria, at 9 million, 4 million, and 3 million barrels respectively [16]. Aside from petroleum, the other fossil fuel Hawaii uses is natural gas. While, as of 2023, Hawaii no longer uses natural gas to generate electricity [12], it is still used for cooking, water heating, and other applications [16]. Natural gas is solely provided by Hawaii Gas, which generates a mix of synthetic natural gas, renewable natural gas, and hydrogen. The synthetic natural gas is produced from petroleum byproducts, while the renewable natural gas is produced from the Honouliuli Wastewater Treatment Plant.

Moving on to renewables, geothermal is often the first to come to mind, given Hawaii's volcanic origins. However, Hawaii only has a single geothermal plant, the Puna Geothermal Venture, which produces 45 MW. Several factors account for the little geothermal energy. Firstly, Native Hawaiian culture considers volcanic regions sacred [17]. Puna, for example, is the sacred home of the volcano goddess Pele. It is important to respect native Hawaiian culture especially because Hawaii's annexation was not voluntary and native Hawaiians have been historically marginalized. Another factor comes from the tendency of the current plant to release toxic gases during emergency shutdowns [18]. Exposure to hydrogen sulfide and other health concerns related to the geothermal plant have led residents to call for its closure. However, geothermal energy also presents several advantages over other energy sources. Most importantly, out of all energy sources, the cost of geothermal energy is among the least, at nearly 6 cents per KWh [19]. Given that Hawaii's electricity costs are the highest in the country, taking advantage of such a resource is essential. A factor for this low cost is geothermal plants' longevity; we modeled geothermal plants with a 50-year lifetime.

A less contentious renewable energy resource is wind. In total, wind generates 200 megawatts, with wind farms located at four major locations, as shown in Figure 12. There are two major farms in Honolulu, Kahuku and Kawailoa Wind, with a capacity of 30 and 69 megawatts respectively [20]. In Maui, there are three major farms, Auwahi Wind Energy Hybrid, Kaheawa Wind Power, and Kaheawa Wind Power II, with a capacity of 24, 30, and 21 megawatts respectively. The four major locations are located where wind speeds are highest, shown in Figure 13. While wind speeds are higher offshore, Hawaii currently has no offshore wind farms [21]. However, there are plans to produce up to 400 megawatts through an offshore wind farm. We model onshore wind turbines with a 35-year lifetime and offshore wind turbines with a 30-year lifespan.

Currently, solar is the most significant renewable energy source in Hawaii, producing 500 megawatts on average [4]. The total capacity installed is 1,811 megawatts [22], suggesting a capacity factor of about 30%. 783 MW of the total capacity is distributed, or 544 watts per capita. This is the highest amount of rooftop solar installed per person out of any state. However, there is still significant potential for additional installations: outside of central Oahu, PV penetration rate is less than 20% (refer to Figure 14) [23]. Solar in Hawaii is relatively new: about half of the total capacity was installed in 2019 or later [22]. Significant utility-scale solar projects in Hawaii include Kawailoa Solar, a 2019 62.7 MW installation, and the Waianae Solar Project, a 2017 40.3 MW farm [22]. We modeled utility scale PV with a 25-year lifespan.

The last two significant renewable energy sources in Hawaii are hydroelectric and biomass. Currently, Hawaii only has 33 megawatts of hydroelectric generators installed [4], nearly all of them run-of-the-river because of Hawaii's geography. Significant plants include the Wailuku River Hydroelectric Power Company, a 11-megawatt system, the Hawaiian Electric Waiau & Puueo Hydropower plant, a 3 MW plant, and the Makila Hydro Plant, a 500 kilowatt plant [24]. While Hawaii currently does not have any pumped-storage hydroelectricity plants, there are plans for coupling a pumped solar plant with a solar array [25]. We modeled hydroelectric plants with a 50-year lifespan.

Finally, biomass produces 47 megawatts of Hawaii's energy [4]. Historically, biomass derived from sugarcane byproducts supplied a significant portions of Hawaii's energy demand—up to half the electricity on some islands [26]. However, as sugarcane plantations shut down (refer to Figure 15), and as Hawaii's population increased, biomass derived from sugarcane became less significant in Hawaii's energy system. Today, other sources of biomass are burned to create energy. The 73-megawatt H-POWER plant in Oahu burns municipal solid waste (garbage) to produce power and reduces the amount that reaches the landfill by 90% [27]. There also existed a plant in Kapaa Quarry that burned methane from the landfill, but it was closed due to equipment failure.

A significant energy source missing from this review is nuclear. Hawaii has no nuclear power plants and has a law that prevents the construction of a nuclear power plant without two-thirds legislative approval [28]. Additionally, volcanic activity and risks of other natural disasters make construction of nuclear plants risky, and Hawaii's isolation makes disposal of nuclear waste difficult [29].

Another component in Hawaii's energy infrastructure is transmission. Hawaii operates several classes of transmission lines to efficiently transport energy from power plants to consumers [30]. The highest voltage is 138kV AC, which transports energy between substations. Those substations then step down the voltage to 46 kV, which go to local area substations. At those substations, the voltage is further stepped down to 12kV or 4kV. Finally, the lines are connected to homes and stepped down to mains voltage. Refer to Figure 16 for a map of major transmission lines in Oahu. All existing lines are AC [31], however, there have been proposals for an inter-island HVDC line. Proponents of the plan highlight that by connecting the different islands, energy can be transferred from areas with excess renewable energy to those with less, increasing redundancy [32]. However, the current need for cross-island electricity transport is not high enough to justify the high costs of the proposal.

Refer to Figure 17 for a complete map of power infrastructure in Hawaii.

Our Plan

The first major aspect of our plan is to completely electrify ground vehicles by 2050. We will incentivize the purchase of EV's with tax benefits, discounts, and monetary benefits. Specifically, we will subsidize 25% of all EV purchases. For ground vehicles that are more difficult to electrify, like busses, we plan to switch to electric hybrids. Finally, we will install 40,000 electric chargers, or about 28 electric chargers per thousand people. This number is based on the number of EVs and electric chargers in California, the state with the largest EV market share [33]. California has about 1 electric charger for thousand people, but only one in 14 cars are electric. To calculate our target, we scaled up to 100% EV and doubled the number for margin. To ensure that we arrive at 100% electric vehicles by 2050, we set milestones linearly before then: 25% by 2027, 50% by 2035, and 75% by 2043. We calculated the change in electrical demand from EVs based on this number.

The second major part of our plan is to replace all non-ground transportation petroleum supply with biofuels. As mentioned previously, aviation and marine transportation together account for 55% of transportation demand and both are very difficult to electrify because of energy density requirements. Instead, we plan to use microalgae-based biofuels to replace petroleum in these industries. One of the most significant advantages of microalgae-based biofuels is that they can replace up to 85% of the petroleum in fuel without any engine modification [34]. Thus, by 2050, engines can be expected to use 100% microalgae biofuels, removing the need for petroleum at all. Additionally, novel techniques promise to raise the EROI of microalgae-based biofuels to between 3 and 8, comparable to petroleum today [35]. We plan to scale up production of biofuel with the same schedule as EVs, and we factored in the additional electric demand using an EROI of 5. Refer to Figure 18 to see how our policies will affect the demand by sector.

The third major part of our plan are the infrastructure upgrades. As a compromise, we decided that instead of constructing more geothermal plants, we will upgrade the existing plant in Puma, increasing the mean output from 45MW to 750MW and the total capacity to 800MW. This is the upper limit of the geothermal supply in Puma according to a geothermal survey conducted by GeothermEx [36]. There will be two generations of geothermal plants, assuming a lifetime of 50 years.

We are planning to invest heavily into both onshore and offshore wind. For offshore wind, we are planning to build a 350MW, 200MW, and 450MW true output farms in southern Island of Hawaii, northern Kauai, and northern/southern Maui respectively. This will equal to 600 MW, 350 MW, and 750 MW rated capacity respectively for a capacity factor of 60%. With a lifetime of 30 years, we will need 2-3 generations of turbines to last up to 2080. For onshore wind, we are planning to build at 650 MW, 450 MW, and 250 MW true output in Honolulu, Wailuku, and Island of Hawaii respectively. This will equal to a 1300MW, 900 MW, and 500 MW rated capacity respectively for a capacity factor of 50%. With a lifetime of 35 years, we will need 2-3 generations of turbines to last up to 2080.

Because of the lower cost in installing utility-scale PV than rooftop solar, we plan to primarily focus on building more solar farms. We will install a 750 MW mean output solar farm in Southwest Oahu, or 2500 MW total capacity with a 30% capacity factor. With a 30-year lifespan, we will need 2 generations to last up to 2080. For rooftop PV, we plan to keep the current policy. We expect that from the current 300 MW, the amount of rooftop solar installed will reach 500MW by 2045 and 750MW by 2080.

The fourth part of our plan is the HVDC interisland line. The HVDC line will span the islands of Oahu, Molokai, Lanai, Maui, and the Island of Hawaii. These islands encompass nearly 95% of the population, and the last island with significant population, Kauai, will have its own dedicated grid because it is distant from the other islands [37]. Most of Hawaii's small islands are unpopulated; for those that are populated, we plan to continue using existing fossil fuel infrastructure and tap into our extensive biofuel production capacity for cost effectiveness. The line will have a capacity of 5 GW and there will be 4 primary converter stations to step down the voltage for local distribution. The HVDC line will help will redundancy and grid robustness.

Another way we provide redundancy is through the storage of energy. We introduce a vehicle-to-grid policy that will power the state when renewables are unreliable. We expect that once 100% EV, the VTG system will have the capacity of 26GWh. This is much more than the amount of storage required based on the daily use cycle, which is 11 GWh.

Refer to Figure 19 for the map of all our planned infrastructure. Refer to Figures 20 and 21 for graphs of demand and supply variation throughout the day and year. Refer to Figure 22 for a Gantt chart of each of the plants described, and Figure 23 for how supply will compare to demand for each year of the plan. Figure 24 shows the sources (petroleum and each renewable type) for each year of the plan.

We will now discuss the economics of our plan. Table 1 shows the construction, operation, and decommissioning cost per KW for each plant type [38-43]. We also included the cost of the HVDC Line, biofuel, and EV subsidies, shown in Tables 2, 3 and 4 [44-46]. We computed the cost for each of our plants' rated capacities and added up the total cost by type per year, shown in Figure 25. Then, we computed the net present value using a NYSE return of 7% (Equation 5) and added it all up to a lump sum today. We get a sum of 39.3 billion today. Then we used the lending rate of 3.3% to calculate the uniform payment (Equation 6), which ended up being about 1.6 billion per year. Finally, we can calculate the cost per KW and compare it to the current cost of energy. We get that our plan, in the beginning, will cost about 13 cents per KW compared to the current price of 37 cents per KW. The cost of our energy will always stay below the current cost of energy, even considering inflation (using 2%), shown in Figure 26. Figure 27 shows the loan value as we pay off the debt. Refer to the spreadsheet for complete calculations.

Figures

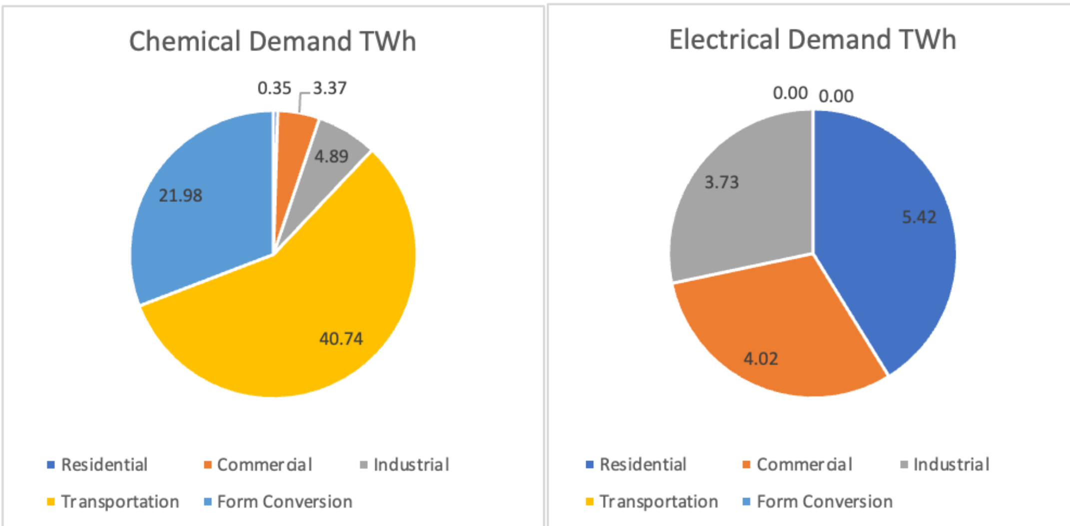

Figure 1. Total Electrical and Chemical Demand by Industry, 2021. We separated chemical and energy demand because the two forms of energy need to be treated differently (e.g. transportation, storage infrastructure, etc.). Knowing the proportion that each sector consumes tells us which sectors need to be addressed (by policy or infrastructure) the most.

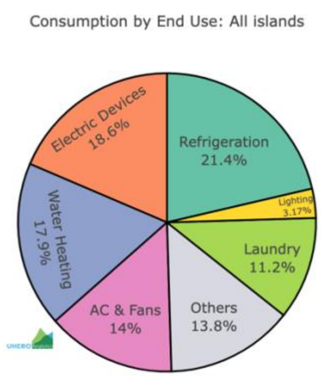

Figure 2. Residential consumption uses. This cart helps us understand the unique demands of Hawaii compared to other states. Notably, while half of the consumption is heat related (refrigeration, water heating, and AC), little is needed for home heating itself due to Hawaii's climate.

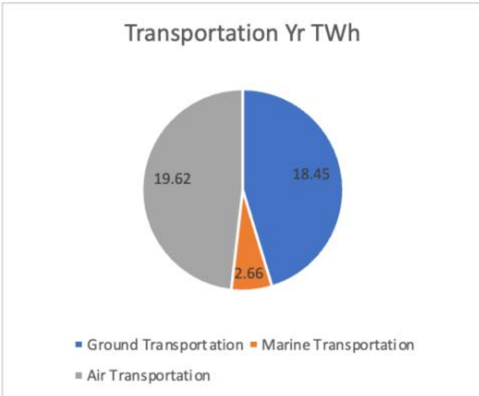

Figure 3. Transportation demand by form. Knowing the proportion that marine and air transportation accounts for is important because these two forms of transportation are difficult to electrify due to energy density requirements.

Figure 4. Visitor Arrivals by Month, 2022. Note that visitor arrivals peak in the summer months and dip in the winter. We use these values to correct the seasonal energy demand.

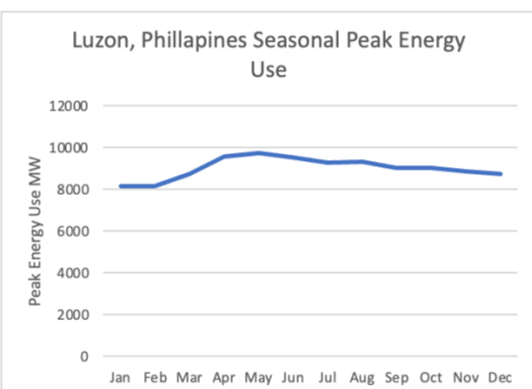

Figure 5. Energy use of Luzon, Philippines by Month. Note that the energy use peaks in late spring/early summer and dips in winter. We use the Philippines as a model for Hawaii's seasonal energy use.

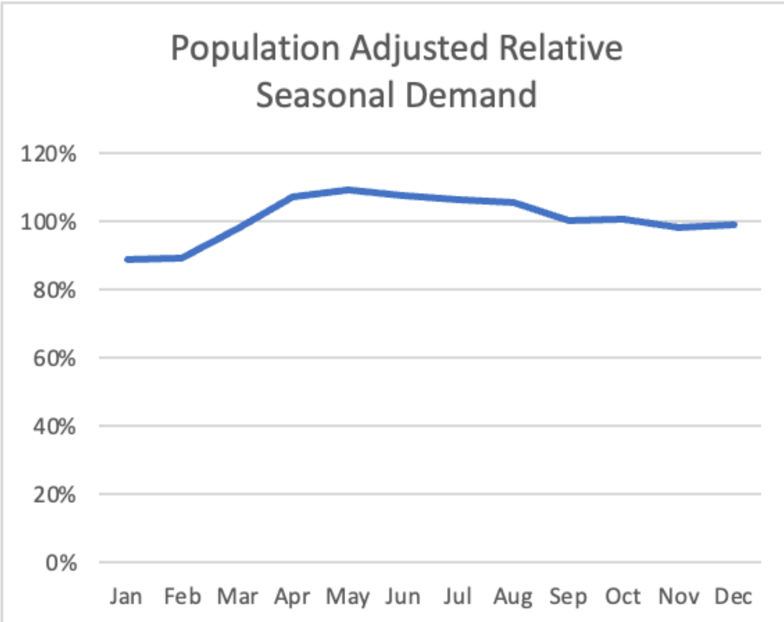

Figure 6. Population Adjusted Relative Seasonal Demand. Note that the demand varies by about 20%, dipping in the winter and peaking in the spring/summer. Consideration of population change due to tourism increases the demand in the summer by about 10%.

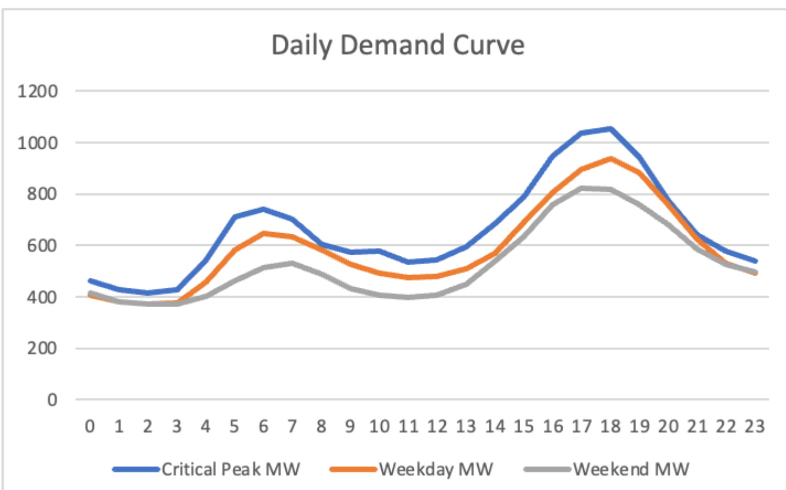

Figure 7. Daily demand curve. There is a primary peak between 6 and 7 PM and a secondary peak between 4 and 6 AM. We use this curve to compute the amount of energy that needs to be stored and to compare the daily supply curve to.

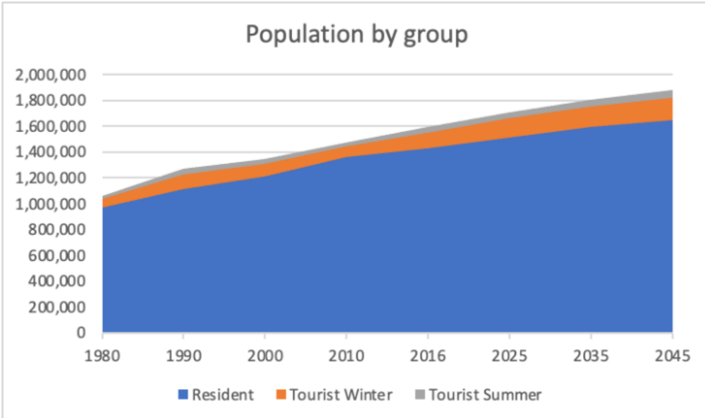

Figure 8. Resident and Tourist Population Forecast. These values are based on the survey done by Hawaii. Note the population change between the winter and the summer due to tourism, as well as the increasing but plateauing population over the years.

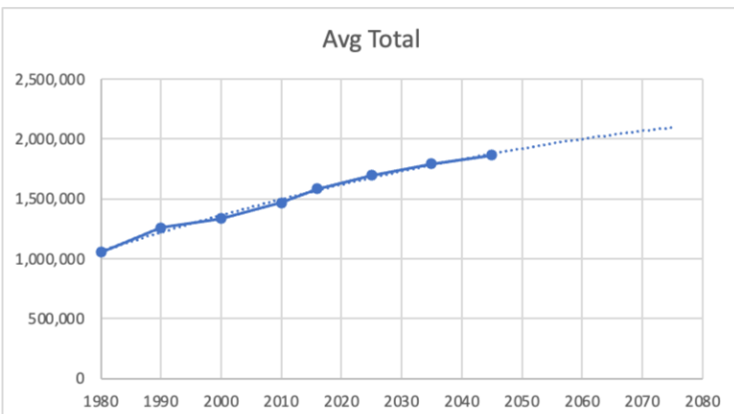

Figure 9. Total population forecast and trendline to 2073. The plotted points are based on the forecast in the previous figure and the dotted line is our polynomial regression. We derive the population in 2073 through this regression.

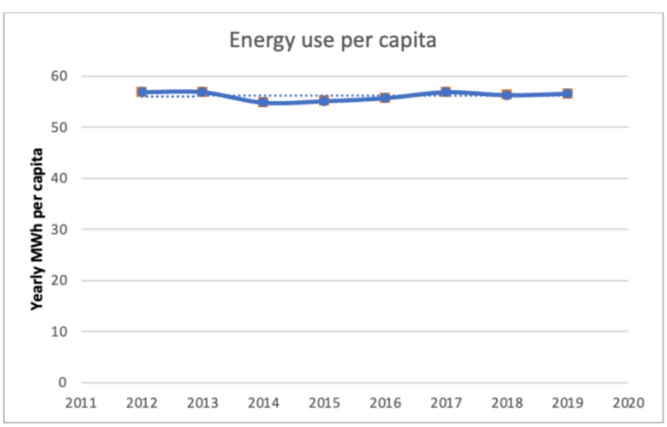

Figure 10. Energy use per capita and trendline. Plotted points are the energy use per capita in the last 10 years. The dotted line is the exponential regression we used to predict how the energy use per capita will change by 2073.

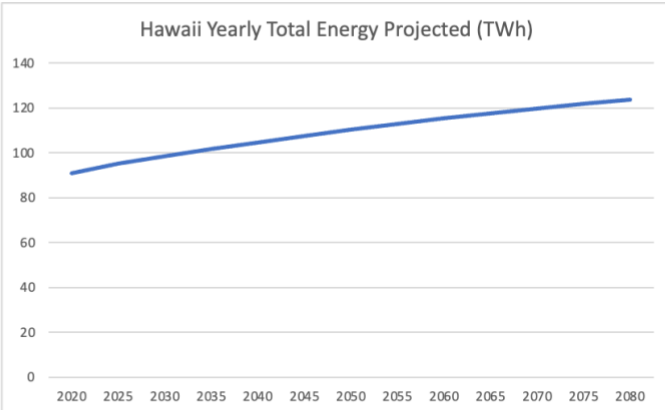

Figure 11. Total energy use projection. This graph combines the regressions within the previous two figures to create a total energy use projection. We use the 2073 value to inform the capacity required for 2073.

Figure 12. Major wind energy hot spots. This figure shows the locations of existing wind farms. We see that they are concentrated in four spots and that they are near regions of high wind speeds (refer to the next figure).

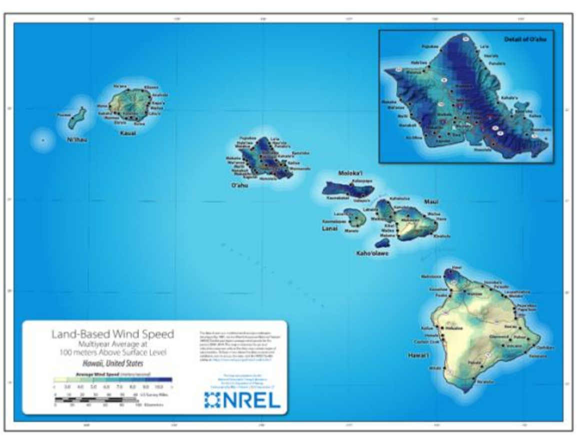

Figure 13. Land based wind speed in Hawaii. This map confirms our intuition that wind farms are clustered near high wind speed areas for maximum power output. We also use this map to place our planned onshore wind farms optimally.

Figure 3. Rooftop PV market penetration rate by census tract as of July 2017

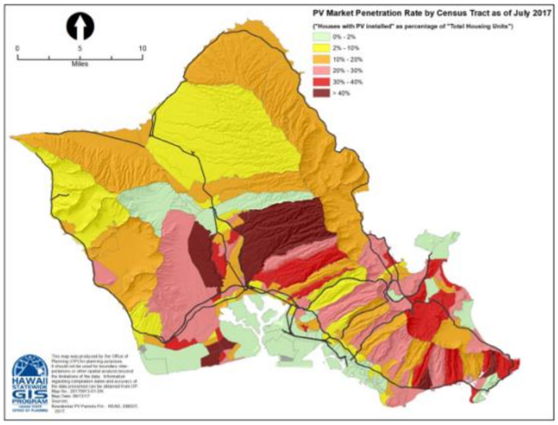

Figure 14. Rooftop PV Penetration in Oahu. This map shows that areas near central and south Oahu take advantage of rooftop solar potential the most at or beyond 30% penetration, while there is room to grow in other parts of Oahu. The map suggests that rooftop solar can potentially supply a significant portion of Hawaii's energy in the future.

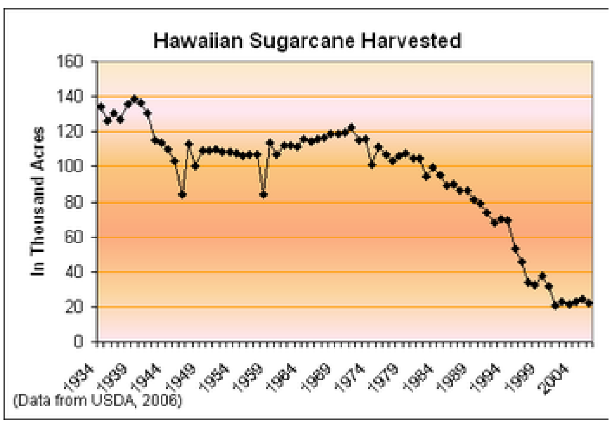

Figure 15. Historical sugarcane production of Hawaii. We see that in the past centuries, Hawaii produced significant amounts of sugarcane, but since the 70's that amount has dropped by 90%. Since sugarcane byproducts are used to produce biofuel, Hawaii cannot rely on sugarcane to produce biofuel and energy.

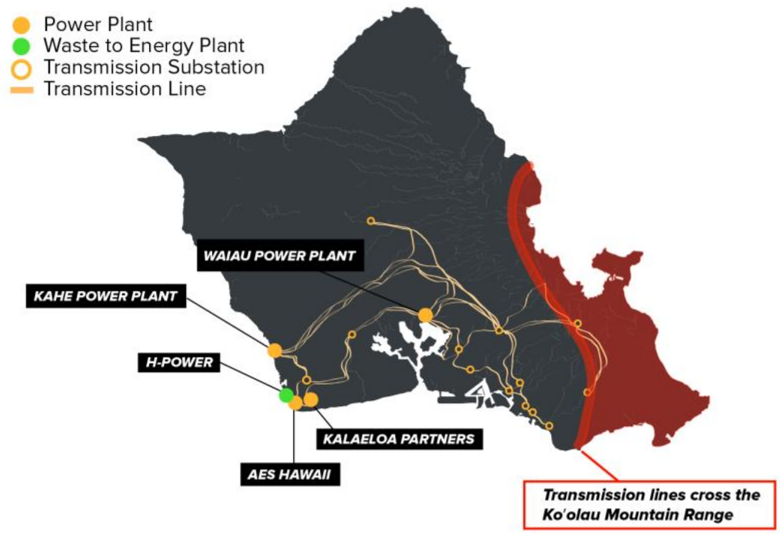

Figure 16. Transmission lines in Oahu. We see that transmission infrastructure is concentrated around southern and central Oahu, which is where the population centers are.

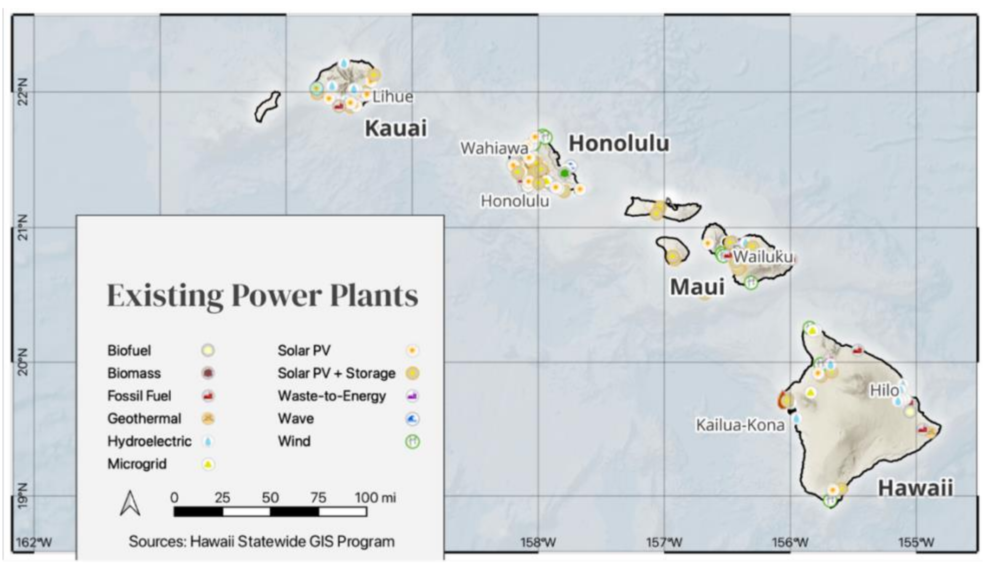

Figure 17. Complete map of power plants in Hawaii. This map shows the location of all existing power plants. We see that most power plants are located near the population center of Oahu, but all types of resources are distributed throughout the state.

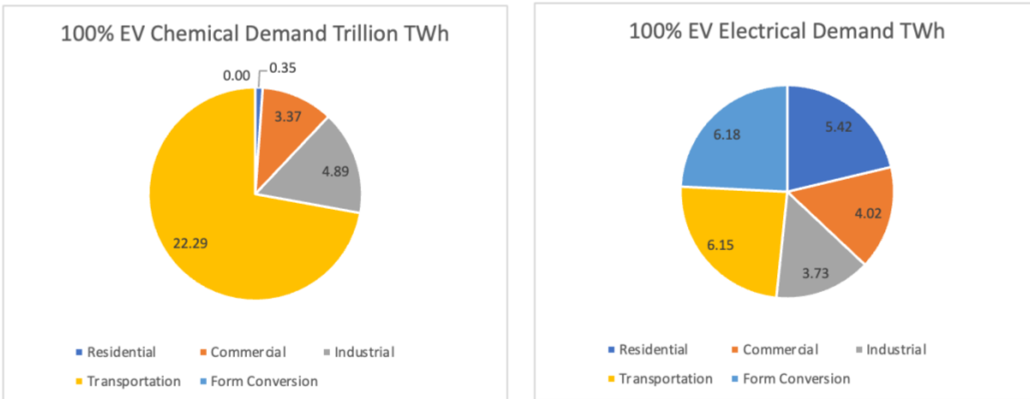

Figure 18. 2073 Demand Breakdown. Notice how form conversion (fossil fuel power plants) is no longer a part of the chemical demand, and that, rather, form conversion (as biofuel production) becomes a significant portion of the chemical demand. Additionally, transportation is halved due to EV's.

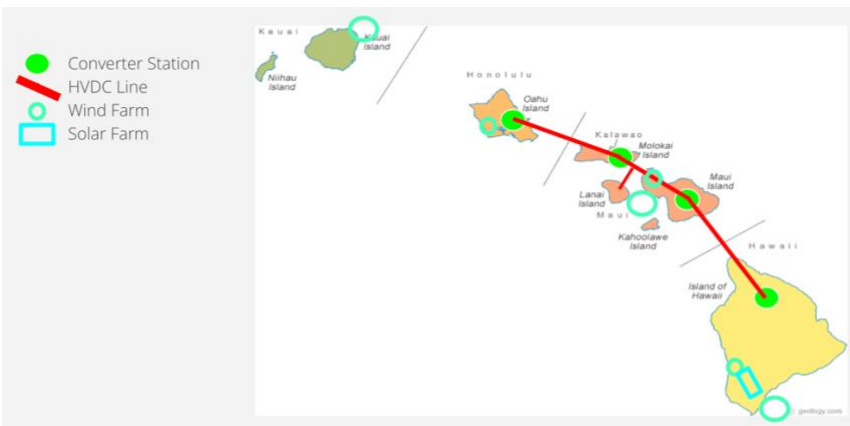

Figure 19. Complete Plant Map. This map shows the locations of the new infrastructure we plan to construct by type.

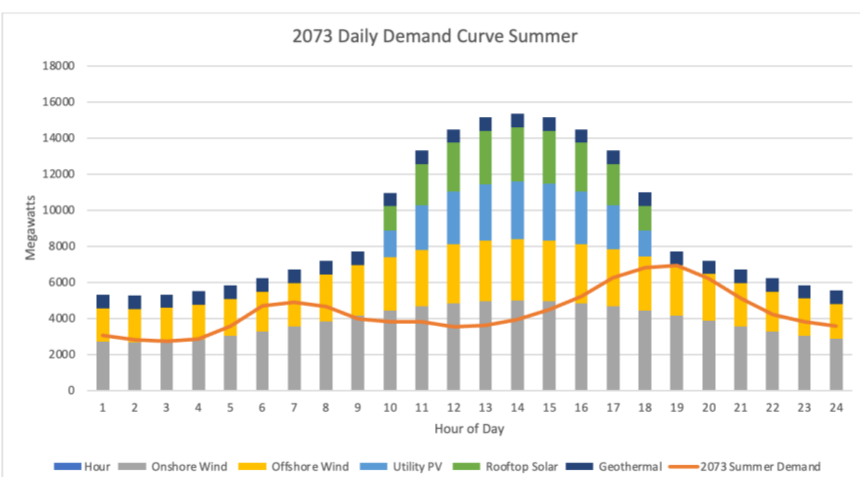

Figure 20. Daily Demand Curve Summer. Both solar and wind have a higher capacity factor during the summer, and as a result, supply is always larger than demand so storage is not necessary.

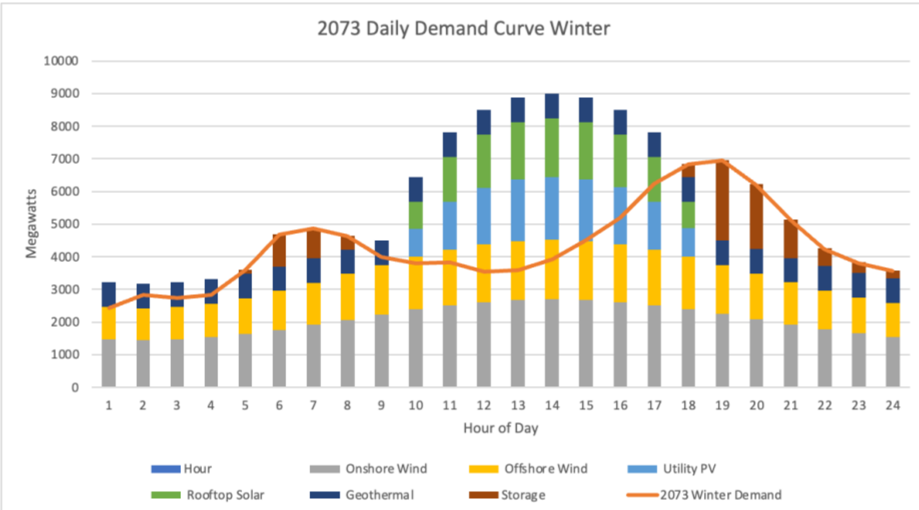

Figure 21. Daily Demand Curve Winter. During the winter, storage is required in the early morning and late afternoon. However, the total amount of energy generated is still higher than the total amount consumed, so there is enough energy to get through the day.

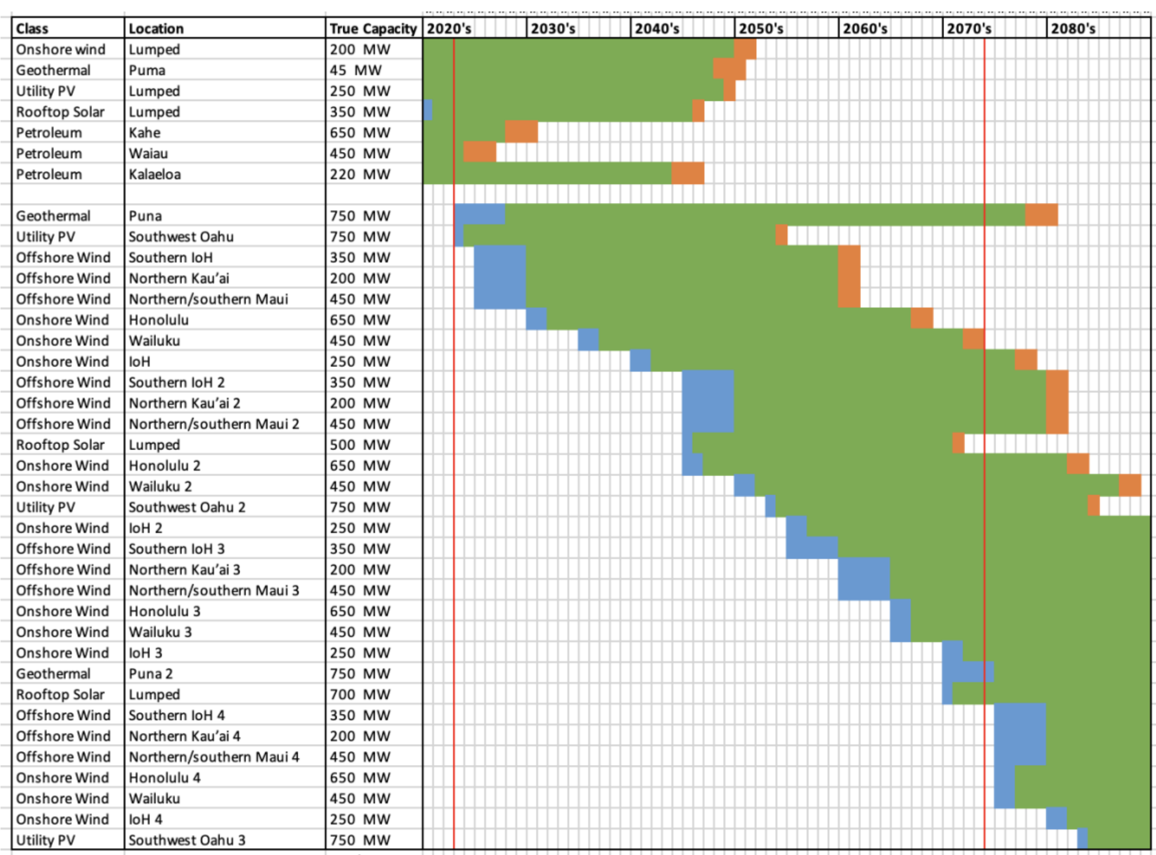

Figure 22. Gantt Chart. This chat shows the periods of construction (blue), operation (green), and decommission for each of the plants we planned. The exact periods for each stage and type of plant are shown in Table 1. Note that some plants go beyond 2073: these plants are not covered under the total costs and are merely a suggestion for an extension. Figures 23 to 25 are based off this chart.

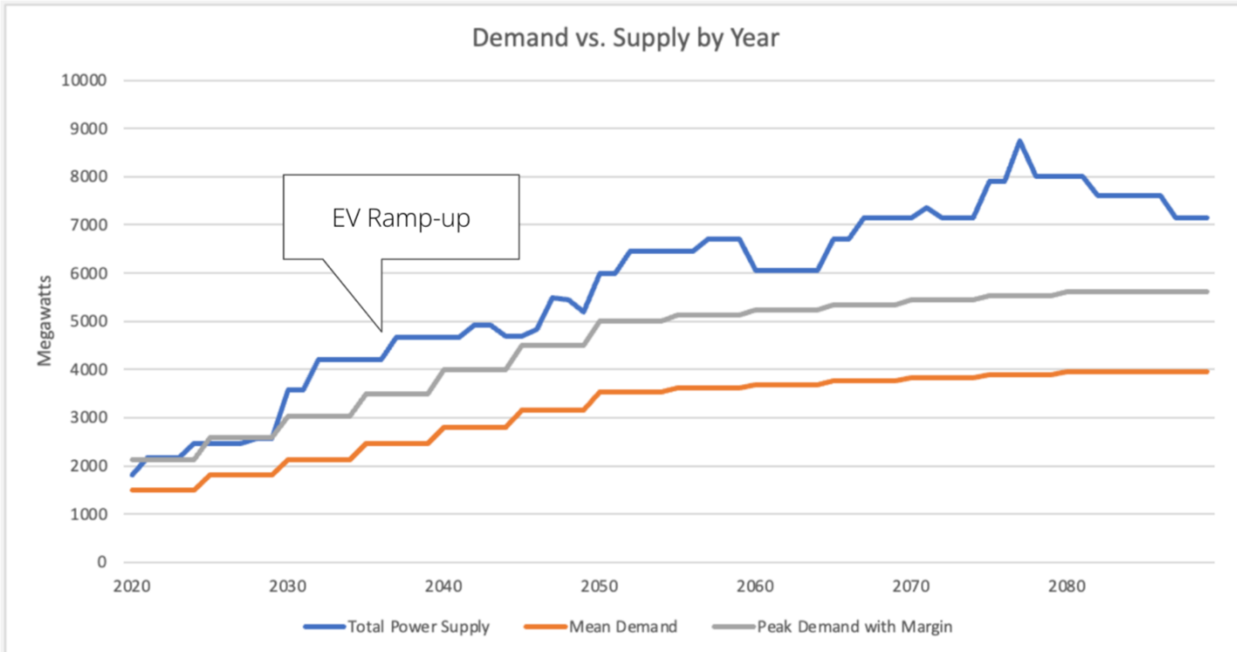

Figure 23. Demand vs. Supply by Year, with Ramp-up Region Highlighted. The total power supply (capacity factor corrected) is plotted against the year. The mean demand and the peak demand with a 25% margin are also plotted. Notice that the supply is always above the peak demand, sometimes to a significant amount. The large increase in demand from 2023 to 2050 is due to the EV ramp up period.

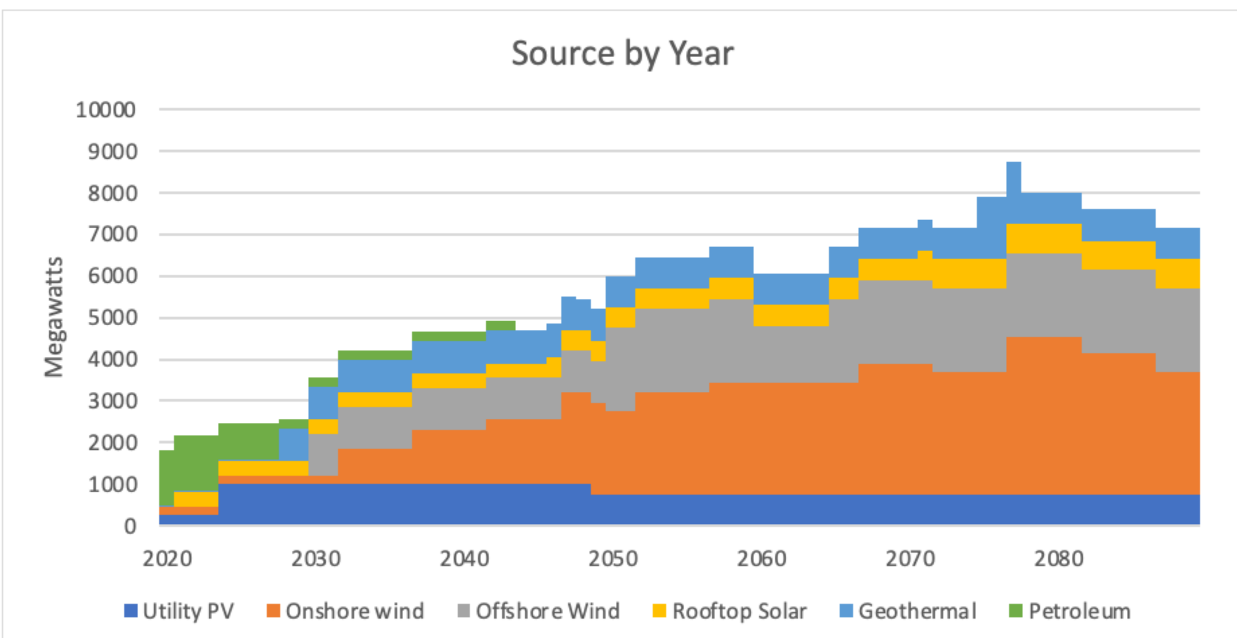

Figure 24. Source by Type per Year. This plot shows the total capacity-factor-corrected supply by year. Notice that while petroleum is significant at first, it quickly diminishes. This is partly because the largest petroleum plants in Hawaii are very old and must be decommissioned soon if not continuously maintained. Renewables, especially wind, become significant for the rest of plan's period.

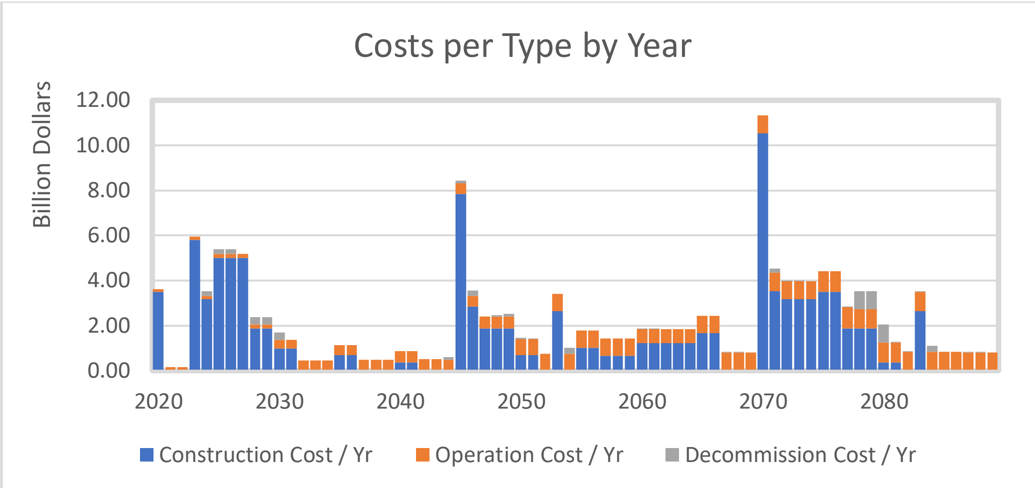

Figure 25. Costs per Type by Year. Construction is the most expensive portion of a plant's lifetime, then operation, and lastly decommission. The construction costs are spread out due to the staggering of the plants' construction times as shown in the Gantt chart.

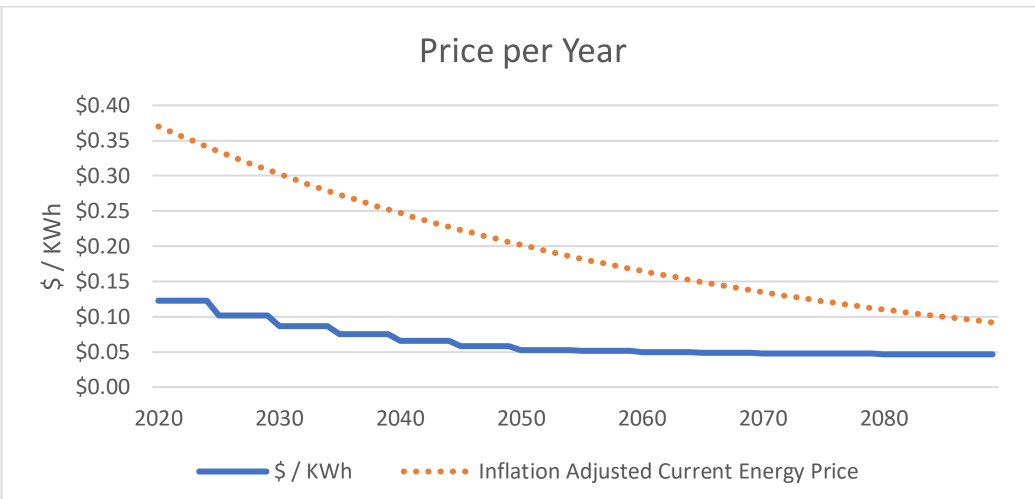

Figure 26. Energy Price Per Year Under Plan vs. Current Energy Price. The cost of energy under our plan is a third of the current cost of energy. The inflation adjusted current price is also shown and is consistently above our price. The cost of our plan decreases because while the uniform payment is always equal, the total amount of energy produced increases so the cost per amount of energy decreases.

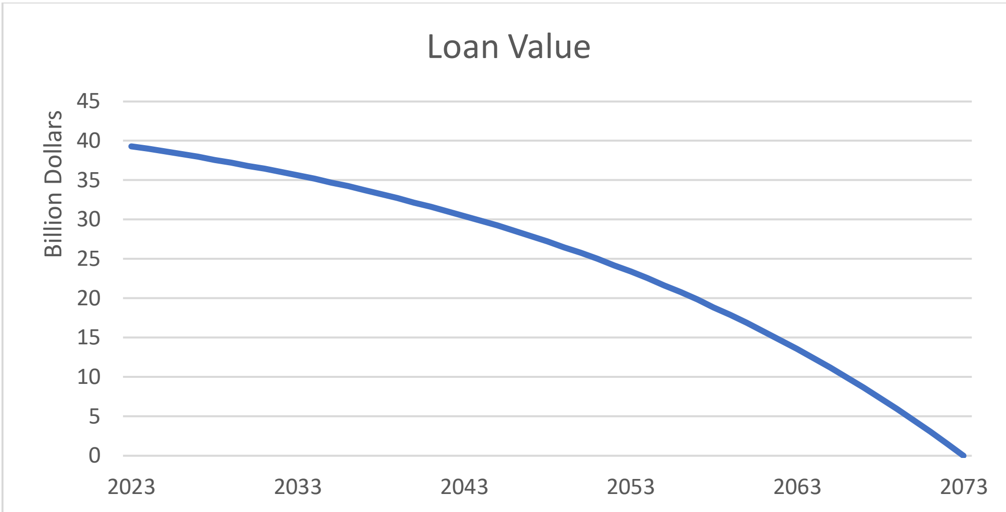

Figure 27. Loan Value by Year. We see that because the payment is always equal, earlier payments mostly interest while later payments cover the principle. However, the loan is completely paid for by 2073.

Tables

	Capacity Factor	Lifetime (Year)	Construction Time (Year)	Decommissioning Time (Year)	Construction Cost / (Year * MW)	Operation Cost / (Year * MW)	Decommission Cost / (Year * MW)
Utility PV	0.3	30	1	1	1060000	10600	100000
Onshore wind	0.5	35	2	2	750500	40000	23333.3333
Offshore Wind	0.6	30	5	2	1115400	118000	8750
Rooftop Solar	0.3	25	1	1	3000000	30000	100000
Geothermal	0.95	50	5	3	4000000	110000	1000000
Petroleum	1	50	5	3	3000000	70000	500000

Table 1. Capacity Factor, Lifetime, Construction Time, Decommissioning Time, and Cost per MW of Construction, Operation, and Decommission for each plant type. These values are used to create the Gantt chart and the cost charts. Note that construction and decommission costs are spread out over the construction time and decommission time respectively.

HVDC	
Length	240km
Converter Stations	1.2 Billion
Commission	0.25 Billion
Maintenance	0.01 Billion
Total Cost	1.46 Billion

Table 2. HVDC Economics. HVDC lines cost about 1 million per km and converter stations cost 300 million each.

Biofuel	
Capacity	41 TWH/Year
Purchase Cost	0.36 billion / year
Shipping Cost	0.2 Billion / Year
Plan longevity	20 years
Total Cost	7.6 Billion

Table 3. Biofuel Economics. Biofuel from algae costs about 3$ per gallon. We also consider shipping costs. Crude tankers carry 155 million gallons each, so we will need 8 ships/year. Costs 40 thousand per day to charter a ship.

EV Policy	
Estimated Cost per car	16250
Number of cars	500,000
Total cost	8.1 Billion

Table 4. EV. Subsidy. Costs 65 thousand per EV and 25% of cost is subsidized.

Equations

Main Spreadsheet: https://tuftscloud-my.sharepoint.com/:x:/g/personal/lqiu01_tufts_edu/EYEBZYh-eFpPjbf4EQFEzhIBmRWZbhA78h0eXiUBzRHzpA?e=daQ23a

$$D_{n,Hawaii} = \left(\frac{A_n}{A_{avg}} \cdot \frac{P_{tourist}}{P_{total}} + \frac{P_{resident}}{P_{total}}\right) \cdot D_{n,Philippines}$$

D: Relative Demand

A: Visitor Arrivals

P: Population

n: month

Equation 1. Population Adjusted Relative Demand

$$S = \frac{\sum_{n=1}^{24} |D_n - D_{avg}|}{2\sum_{n=1}^{24} D_n}$$

S: % storage needed

D: Demand

n: Hour

Equation 2. Storage Required

$$y = -54.55840x^2 + 232{,}116.03504x - 244{,}634{,}814.01970$$

y: Population

x: Year

Equation 3. Projected Population

$$y = 25.52001e^{0.00039x}$$

y: Yearly MWh per capita

x: Year

Equation 4. Energy Use Per Capita

$$V = \frac{E_{construction} + E_{operation} + E_{decommission}}{(1+r)^n}$$

E: Future Expenditure

V: NPV

n: Years into the Future

r: NYSE return rate (7%)

Equation 5. Net Present Value.

$$U = V\ \frac{r}{1-(1+r)^{-n}}$$

U: Uniform Payment

V: Loan sum

n: Years into the Future

r: Lending Rate (3.3%)

Equation 6. Uniform Payment.

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