MSc Program
Environmental Technology & International Affairs

ENERGY INDEPENDENCE TROUGH RENEWABLE ENERGIES
-
Hawaii's challenge to become a clean energy leader!

A Master's Thesis submitted for the degree of
"Master of Science"

supervised by
Univ.-Prof. Dr.-Ing. Günther Brauner

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Affidavit

I, **Anna Maria Pölzl**, hereby declare

1. that I am the sole author of the present Master's Thesis, "ENERGY INDEPENDENCE TROUGH RENEWABLE ENERGIE. - Hawaii's challenge to become a clean energy leader!", 59 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted this Master's Thesis as an examination paper in any form in Austria or abroad.

Vienna, 28.05.2019

Anna Pölzl

Signature

Abstract

The state of Hawaii is among the most remote places of the world. With a rich abundance of the natural resources they need in order to produce electricity without burning fossil fuels, they are highly dependent on petrol imports from the main land of the United States of America. Contradictorily enough, this also leads to outstandingly high energy prices even though Hawaii has a very low energy use compared to U.S. average energy consumption. This master thesis examines why it is of such importance for the Island State to become energy independent. Whilst doing so, the thesis examines the main implemented renewable energy technologies harvesting solar and wind energy. Furthermore, the measures taken to increase energy efficiency are described. Using landmarking cases and events the thesis estimated the further potential of the technologies investigated. Throughout this detailed investigation of Hawaii's situation, main challenges are identified, and recommendations to further push their goal of becoming independent from oil imports, are given. The thesis concludes that the island state has had a great start departing towards 100% renewable electricity production, coming with the benefits of international attention and the opportunity to become a green energy role model. In order to achieve their goal until 2045 policy makers, the research community, social advocates, and important influencers do not only have to keep up their good work but also still need to increase their effort. The need of a common strategy and raising awareness is evident.

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List of abbreviations

BESS	battery energy storage system
CGS	Customer Grid supply
CSS	Customer Self supply
DoD	Department of Defense
DON	Department of the Navy
DR	demand response
EEPS	Energy Efficiency Portfolio Standard
EIA	Energy Information Administration
EPC	Energy Performance Contracting
ESPC	energy saving performance contract
FIT	Feed-In-Tariff
GDP	gross domestic product
GSP	gross state product
GWh	gigawatt hours
HCEI	Hawaii Clean Energy Initiative
HECO	Hawaiian Electric Company
HELCO	Hawaii Electric Light Company
HNEI	Hawaii Natural Energy Institute
HSEO	Hawaii State Energy Office
IRR	internal rate of return
KIUC	Kauai Island Utility Cooperative
kW	kilowatt
kWh	kilowatt hour
MECO	Maui Electric Company
MSW	municipal solid waste
MW	megawatt
NEM	net energy metering
PCPI	per capita personal income
PGV	Puna Geothermal Venture
PUC	Public Utilities Commission
PV	photo voltaic

RE	renewable energy
RES	renewable energy sources
RET	renewable energy technologies
RPS	Renewable Portfolio Standard
SDG	Sustainable Development Goals
ST	solar thermal
USGBC	U.S. Green Building Council

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1. Introduction

"E-Komo Mai"

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"Welcome to my home! While you are here, we are going to treat you like family!"

- Hawaiian saying

This Hawaiian saying captures the spirit and the mentality of the Hawaiian culture very well. People living on these islands are blessed with sun, oceans, plants and animals of all kinds. Biodiversity and rich fauna and flora provide them with their basic needs and also attract tourists from all over the world. They know how lucky they have been to land on this paradise on earth. This is also how they know how important it is to keep this place as beautiful as it is and to protect it. The 'Aloha Spirit' is reflected in the hospitality of the people, their open-minded culture but also in their expectation of encountering the same respect for their home from visitors. Welcome to my home, and whilst you are here, treat it with respect.

The following two chapters will evaluate the importance of transitioning to renewable energies in Hawaii and further state the aim of this thesis.

1.1. Reasons and motivation to shift to Renewable Energy

Hawaii is located in the middle of the Pacific Ocean and is the most recent State to have joined the Unites States of America. This makes it the only State of the U.S. entirely made up of islands and also with a unique location, far outside of North America. The sensitive position of Hawaii contains multiple factors pressuring the everyday life of this group of islands. The typical effects of climate change such as rising air and ocean temperatures, shifting rainfall patterns, rising sea levels and changing ocean chemistry will heavily affect people and ecosystems in Hawaii. Especially the rising sea level will increase coastal erosions, which will have negative impacts on agriculture, coastal infrastructure and coastal ecosystems. This poses a huge threat to the living standards on the Islands, as **Hawaii is extremely dependent** on imported food, material, and fuel. The damage of coastal infrastructure through the increase in sea level and in heights of waves, will challenge existing harbors and airports and their ability to keep supplying habitants and tourists with their basic needs from the mainland. Transporting fossil fuel from the continent North America, to Hawaii is yet another tactic that comes with very risky side effects, such as heavy pollution of the ocean and coastal areas through oil spills, in case of emergencies. The generation of electricity with nonrenewable fuel sources, including their delivery leads to a quasi **100 % dependency of the Hawaii to the mainland**.

The most reviewed possibility to increase energy security, energy independence, and at the same time protect the environment, human health and fight climate change is shifting from fossil fuels to renewable resources in the production of energy. Implementing the technology of Renewable Energies (RE) kills two birds with one stone. Firstly, it gives the state the chance to take responsibility and contribute to the global combat of climate change. Secondly, it leads to independence in electricity generation from the main land. Renewable energy production has way fewer emissions then burning fossil fuels and also comes with the benefit of access to affordable, reliable, sustainable and modern energy for everybody.

All these factors put together – true energy security, energy independence, affordable energy, the threats of climate change, and the protection of their environment – were reason enough for the State of Hawaii to part on the journey of a complete transition to renewable energies. In order to comply with their values and be environmentally "pono" (a Hawaiian word commonly rendered as "righteousness") the State of Hawaii with *Governor David Ige* passed the Law to become 100 % renewable until 2045. This means that they want to eliminate all fossil fuels for electricity generation until 2045. Hence, they want to become energy independent with RE.

This transition has already transformed Hawaii into one of the world's leading test beds for energy innovation. The uniquely isolated island setting has attracted entrepreneurs from around the world, seeking to develop, test and improve emerging strategies and technologies before going to market. Whilst leveraging state funding with federal and private sources, the island state is sustainably implementing an innovation ecosystem to branch the development of clean energy solutions. One of the positive side-effects that comes along with this transition is the creation of high-wage jobs and economic opportunities for the people of Hawaii.[1]

1.2. Content and aim of thesis

This Thesis is a case study that will investigate *how the state of Hawaii wants to achieve its goal of becoming 100 % renewable in the electricity production.* It will more closely investigate on the potentials of photovoltaic (PV) and wind energy generation. The aim is to identify the true potentials of these two technologies, as well as the main drivers and challenges of the transition. Not only in a technical but also in an economic and regulatory and social manor. It is important to state that this paper only focuses on the generation of electricity and not the transition to renewable energies in the transportation sector. In order to achieve Hawaii's goal, there are many different technologies using renewable resources that are being implemented. This thesis will mention them but only go into more detail with solar energy and wind energy. The following table shows an "In and Out analysis" summing up the topics that will and won't be part of this thesis.

Table 1. In and Out Analysis

In	**Out**
Electricity production with renewable energy sources	Energy Use
Focus: PV, Wind Energy and	Empirical data about all Islands of Hawaii
energy efficiency	Biomass plants

[1] State of Hawaii and Public Utilities Commission, "RPS 2018 Legislative Report," 7.

Financial tools implemented	
Cases to describe potential of RE in focus	Only mentioned: Geothermal power
Potential of focused RET	Mobility and Electric Vehicles
Forecasted development of energy prices	Hydro power
Subventions, authorization process for plant building	Exact technical description of grid
Need for grid improvement	

The methodological framework of this thesis was drafted during a research trip to Hawaii and further adjusted throughout the working process. Representatives of the blue planet foundation and the Hawaii Natural Energy Institute were interviewed in order to collect up to date data and insights. Local electricity sites were visited, and the environment was closely investigated. A detailed literature review comparing relevant academic studies and papers as well as gathered information from national institutions further helped to make a valid estimation of potentials and deliver beneficial results.

Firstly, the thesis will give a clear understanding of the task Hawaii has set for itself, including agreed goals and developed actions. This will be accompanied by an overview of the current status the State has achieved so far. Secondly, the technologies of photovoltaic and wind and their potentials will be investigated in more detail in order to identify their true ability to generate electricity and its future prospects. Most of the reference data was taken from Oahu and Maui and Kauai in attempt to capture a broad range of occurrences. Oahu and Maui and Kauai are the three islands with the biggest efforts already taken in order to achieve the goal of the State. So as to cover both technical and policy topics there will be a close investigation into the financial and governmental regulations that support the implementation of renewable energies. Lastly, an identification of the main drivers and possible obstacles will be discussed in order to give guidance for further proceedings. The conclusion will give a realistic forecast of how and if Hawaii will be able to achieve its goal.

The ambitious target in combination with the very short time frame has already attracted wide interest, not only within other States of North America but also in the energy sector globally. This great interest attracted by Hawaii is also given the unique and remote location of the Islands of Hawaii. **This case study should give guidance to other states and markets to learn from the experiences and practices**, in order to avoid difficulties in implementing processes and adapting to their own circumstances in electricity production from 100 % renewable energy technologies and becoming energy independent.

2. Zero fossil fuels on Hawaii

The following chapters will give an overview about the economic, political and social situation of the United States and of course in particular of the State Hawaii. It will also describe the journey Hawaii has made so far including major steps and changes and giving an estimation of where they stand, on their way to 100 % RE in electricity generation.

2.1. Country and State overview

To give a comprehensive understanding about Hawaii's situation and strength to tackle the challenge of electricity transmission, these next two subchapters will give an overview of the geographical, social and economic overview of the United Stated and Hawaii.

2.1.1. Unites States

The United States of America are the world's third-largest country by size and by population. It has a total area of 9,833,517 km^2 consists of 50 States, one of them being Hawaii. When it comes to natural resources the US has coal reserves of 491 billion short tons, which makes up 27% of the world's total reserves. The total population of the US is 329,256,465 people (2018) with a population growth rate of 0,8% (2018). The US has the most technologically powerful economy in the world, with a per capita GDP of $59,500. It is a common habit that in the US, private individuals and firms make most of the decisions. The federal and state governments buy needed goods and services mostly in the private marketplace. Imported oil accounts for more than 50% of consumption in the whole country, hence the overall health of the economy is majorly impacted by oil.[2]

100 % of the entire population of the United States has access to electricity (2016) with a total electricity consumption of 3,902 TWh per year.

[2] Central Intelligence Agency, "The World Factbook - Central Intelligence Agency, North America - United States."

This makes the US the world's second biggest consumer after China. The following figure shows the composition of total energy produced.[3]

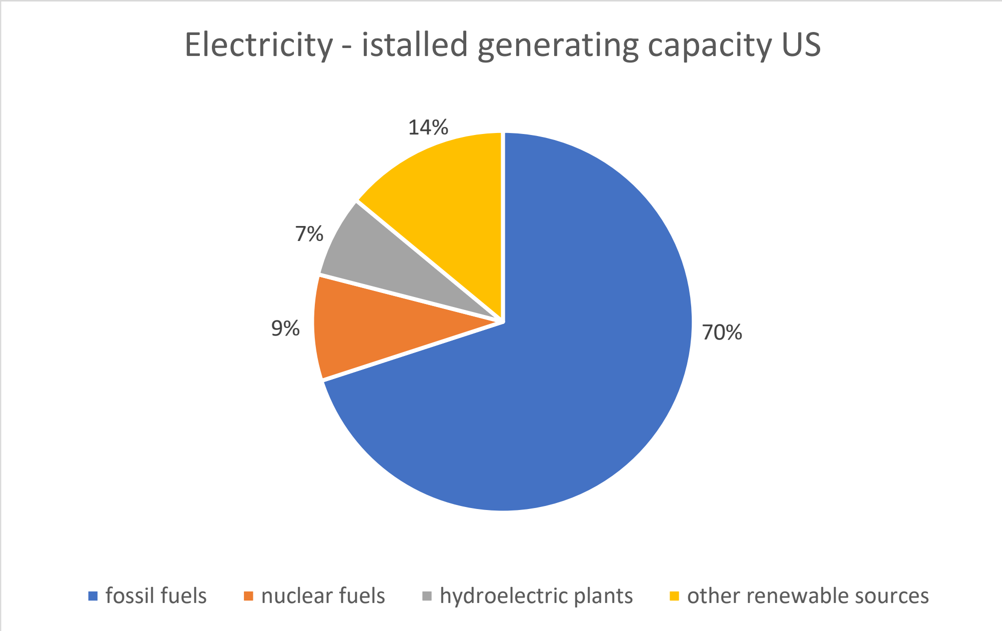

Figure 1. US Electricity capacity

The total carbon dioxide emissions from energy consumption were 5,242 billion megatons in 2017, which makes the states the second largest emitter of CO_2 in the world, again one rank after China. The gap to rank number one is a big one, as China emits 11,670 billion megatons yearly. Still, this large number of emissions in the states reflects the impact of electricity generation from burning fossil fuels. Other environmental challenges faced by the US are air pollution – also related to burning fossil fuels -, water pollution from runoff of pesticides and fertilizers, limited natural freshwater resources in many western parts of the country, deforestation, mining, desertification, species conservation and invasive species. [4]

US Action - Renewable portfolio standard (RPS)

In order to promote the implementation and sales of renewable energies from electricity to increase desired social and environmental effects, a common instrument used in many States of the United States, is the Renewable Portfolio

[3] Central Intelligence Agency.
[4] Central Intelligence Agency.

Standard (RPS). It is a "quantity-based" policy instrument to endorse States to commit to a minimum amount of electricity sold, from a specific technology. These technologies are typically focusing on electricity production from either wind, geothermal heat, ocean energy, hydropower, sun (both PV and solar thermal heat) etc.[5] The RPS does not only promote RE production but is also aimed at encouraging local energy production. These policies are actively renewed by the States and help driving the nationwide market for renewable energies which has the size of 64 billion US-Dollars.[6] Figure 2 shows which States of the US have already legally committed to a certain RPS. Also committing voluntary to a certain RPS Standard is possible.

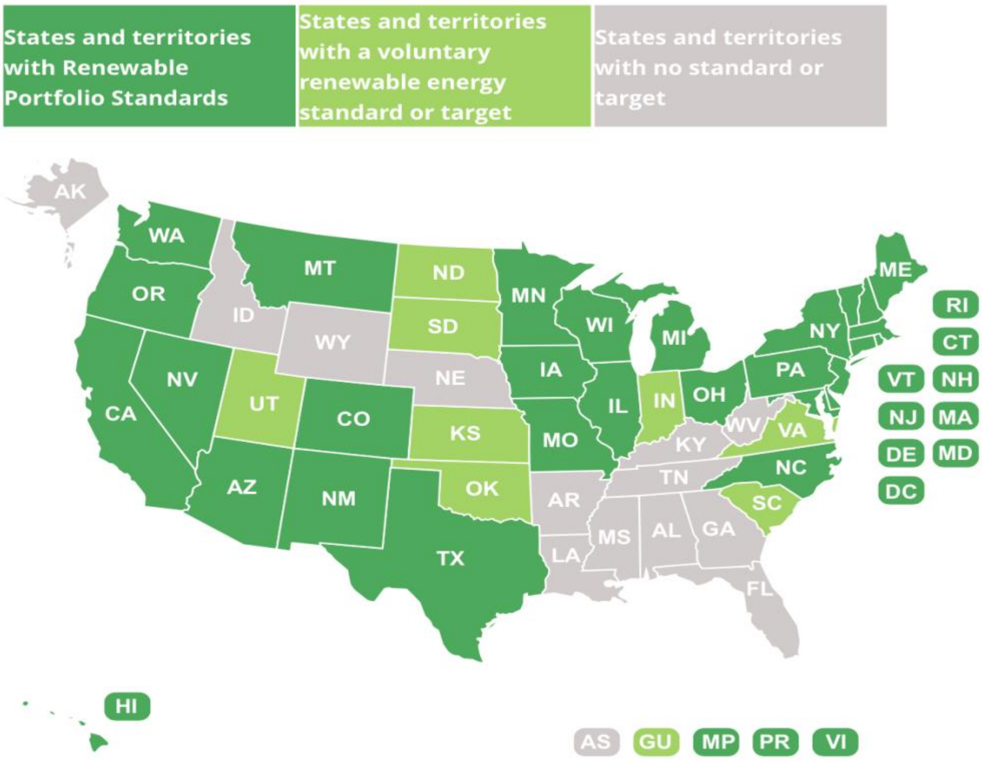

Figure 2. RPS State wise[7]

In total 33 of the 50 US states have set a legally binding goal for themselves. Only three of which have committed to 100 % RE. These beings:

[5] Jaccard, "Renewable Portfolio Standard," 413.
[6] National Conference of State Legislatures, "State Renewable Portfolio Standards and Goals."
[7] National Conference of State Legislatures.

the **State of California** with an interim target of 60 % by 2030 and finally 100 % by 2045,

Washington D.C. with an interim target of 20 % by 2020 and reaching 100 % by 2032 already. And of course

the **State of Hawaii** with their goal of 100 % RE by 2045.[8]

2.1.2. Hawaii

Figure 3. Map of Hawaii

Hawaii used to be an independent nation before it was annexed by the United States in 1898 hence, it is the youngest of the 50 US States. It consists of eight sizable Islands and many smaller ones.[9] In total, the islands make up 28,311 km^2 of surface area. Hawaii Island, in this thesis referred to as 'Big Island', has twice the size of all other islands put together. The distance to the mainland is about 3,600 km, far away from the continental land mass and quasi surrounded by the Pacific "Ring of Fire". This makes Hawaii the vulcanic most active zones on earth, accommodating Mauna Loa, the largest volcano on earth. Almost 90 % of the world's earthquakes and around 75 % of the world's volcanoes occur within the Ring of Fire.[10] In terms of population the Island of Oahu is the biggest, with 953,207 people living there. It also accommodates Honolulu, the largest city and county in Hawaii. Kauai is the smallest sizeable island with 66,921 people living on the "Garden Island".[11] In total the "Aloha-State" has 1,42 million inhabitants

[8] National Conference of State Legislatures.
[9] World Population Review, "Hawaii Population 2019 (Demographics, Maps, Graphs)."
[10] Central Intelligence Agency, "The World Factbook - Central Intelligence Agency, North America - United States."
[11] US Census Bureau Applications Development and Services Division, "US Census Bureau."

(2018) which divided by the total surface area (28,311 km^2) gives us an average population density of ~ 50 people per square kilometer. Despite the fact that the population was strongly increasing in the past decade, the current growth rate is at -0.08%. Most Hawaii residents (75 % of total inhabitants) only speak English, although Hawaiian is also an official language in the state of Hawaii.[12]

Economically Hawaii's GDP represents 0.45 % of US GDP which makes it the 39th largest state economy in the nation in 2016.[13] In 2017 the GDP was $88,447.9 million. The State had a per capita personal income (PCPI) of $54,565 in 2018, which ranked it at place 16th and is at 102 percent of the national average in the United States. This PCPI reflects an increase of around 3 percent from 2017. In comparison to that the 2008 PCPI was at $42,160. In total this annual the 2008-2018 compound annual growth rate of PCPI was 2.6 percent being only a little lower than the 2.8 percent national compound annual growth rate. The largest industries in the Island State are finance, insurance, real estate, rental and leasing.[14]

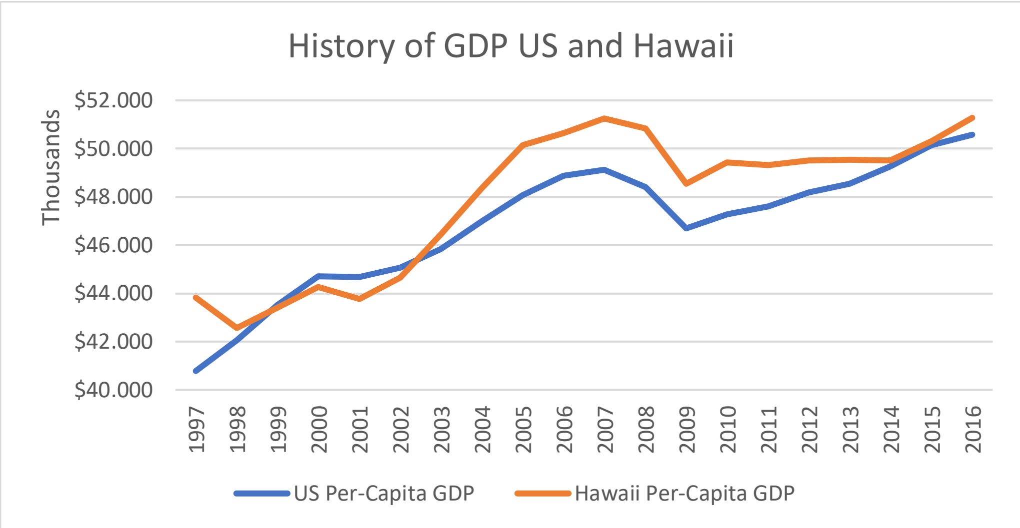

Figure 4. GDP US and Hawaii[15]

Looking at Figure 4, it can be detected that Hawaii's GDP has developed similar to the average nationwide GDP of the US. With exception of the slump in 2008,

[12] World Population Review, "Hawaii Population 2019 (Demographics, Maps, Graphs)."
[13] Department of Numbers, "Hawaii GDP and Per-Capita GDP."
[14] U.S. Department of Commerce, "Hawaii," 1.
[15] Department of Numbers, "Hawaii GDP and Per-Capita GDP."

which can be attributed to the financial crisis, an overall uptrend can be observed.

2.2. Hawaii's Energy Market – a story of dependence

Following Joelle Simonpietri, an independent advisor to strategic investors in renewable fuels projects and technologies that integrate food, feed, fuel, fiber, and waste conversions, Hawaii is *"the only place in the world where you have access to every form of renewable energy, and you are in the dollar and the US legal system."*[16]

In 2008 Petroleum imports to Hawaii made up about 80 % of the energy supply for Hawaii's main utility. This made Hawaii the most oil dependent State of the U.S.[17] In terms of alternative energy, biomass and solar hot water heating represented the biggest portion, even though they still represented only 1.63 % (biomass) and 1.38 % (solar thermal) of total primary energy consumption. Having the lowest per capita consumption, it is controversial that Hawaii at the same time also had the highest electricity costs in the whole United States. According to the Energy Information Administration (EIA), Hawaii had the highest electricity price in the country at 18.7 ¢/kWh (kilowatt hour) compared to a national average of 8.8 ¢/kWh. In economics, oil prices strongly decelerate the growth of the gross state product (GSP).[18] The following figure made by the State of Hawaii Department of Business, Economic Development & Tourism shows a comprehensive comparison of Hawaii's gasoline price in comparison to U.S. average gasoline price per gallon from 2006 until 2019.

[16] Carlton, "Energy (A Special Report)."
[17] Carlton.
[18] U.S. Department of Energy, "Assessment of Dependence of State of Hawaii on Oil," iii.

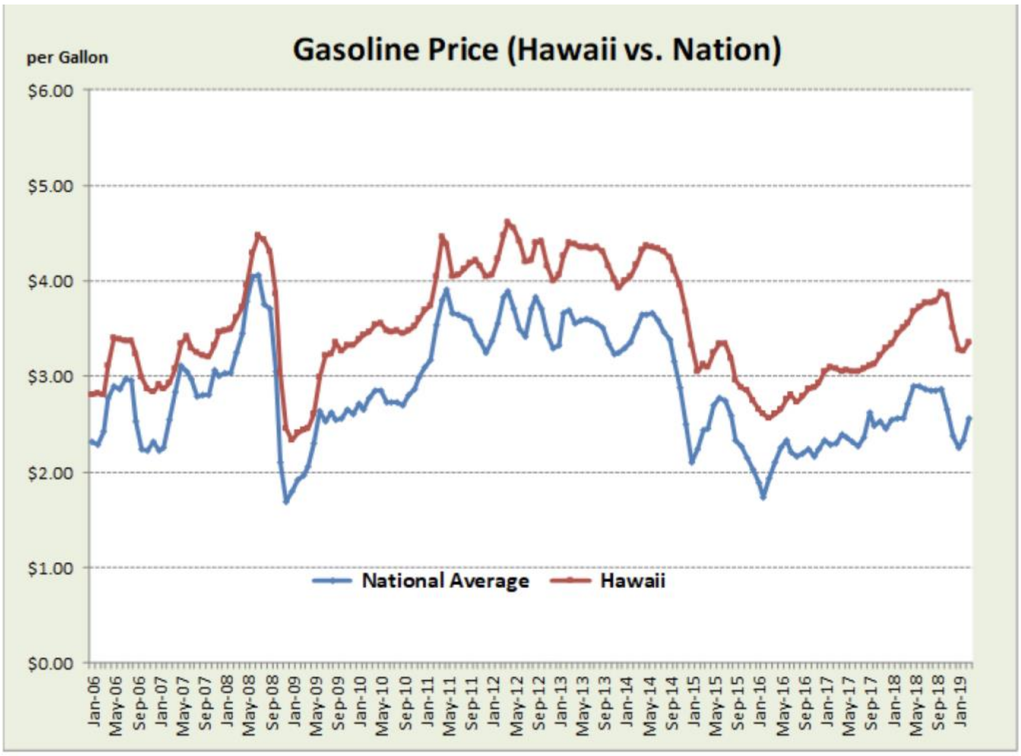

Figure 5. Gasoline Price Hawaii vs. Nation[19]

The transportation sector is definitely the biggest consumer of total energy on Hawaii. This includes ground transportation as well as inter island connections, which are mainly provided by planes. The other half of total energy is consumed mostly in the industrial sector, followed by the commercial sector. As the transportation sector mainly uses petrol the renewable energy goal set for Hawaii in the first step mainly concerns the transition to RE in electricity production. In the latter three sectors mentioned.

[19] Department of Business, Economic Development and Tourism, "Energy Dashboard."

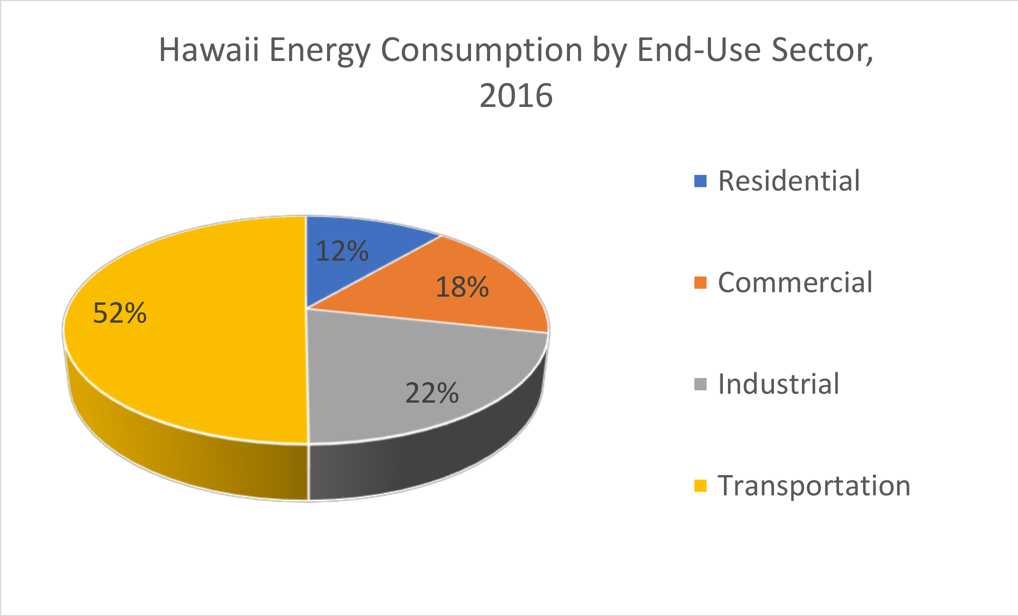

Figure 6. Energy Use per sector Hawaii[20]

As already mentioned, the major part, in particular two thirds, of all petroleum used in Hawaii is consumed by the transportation sector. Electricity power sector uses about one fourth and the rest of it is used to make petroleum products. The huge amount of petrol used in transportation is due to many military installations and commercial airlines. In 2008, most crude oil was imported from Russia and other Pacific Rim producers, as well as from Africa and the Middle East. The Crude oil is later refined in one of two refineries located in Honolulu, Oahu. Before the start of the state's transformation, electricity was mostly produced with petroleum-fired power plants.[21]

The Electricity in Hawaii is mainly supplied by the Hawaiian Electric Companies - Hawaiian Electric (HECO), Hawaii Electric Light (HELCO) and Maui Electric (MECO). In this thesis all three companies together are referred to as HECO. They provide electricity for 95 % of residents of the State of Hawaii being responsible for the islands of Oahu, Maui, Molokai, Lanai and Big Island.[22] Only Kauai has its own electric supplier, the Kauai Island Utility Cooperative (KIUC). As the Name already stated in the name, on Kauai the

[20] Energy Information Administration, "Hawaii - State Energy Profile Overview - U.S. Energy Information Administration (EIA)."
[21] U.S. Department of Energy, "Assessment of Dependence of State of Hawaii on Oil," 6.
[22] Hawaiian Electric Company, "Power Facts."

‘Cooperative’ is controlled, and operated by 24.000 member-owners, contributing equity capital, and shares serving 33.000 electric accounts on the island of Kauai.[23] All islands of the State of Hawaii have their own separate electricity grid. They are not interconnected undersea, just like there are no pipelines connecting the islands. Hence, each island must generate its own electricity. The isolated island grids are, next to the imported petroleum and the combined dependency, a major contributor the high electricity prices on Hawaii.

2.3. Actions to promote RE on Hawaii

The first time this dependency challenge was tackled seriously was in 2008, in form of a partnership between the state of Hawaii and the Hawaiian Electric Company. Later this developed into the famous ‘Act 97’ of 2015 where Hawaii finally committed to 100 % RE until 2045. The following two chapters will go into detail about the main actions and ongoing strategies.

2.3.1. Hawaii Clean Energy Initiative (HCEI)

In January of 2008, former Governor Linda Lingle announced that a state-federal partnership developed plans in order to derive 70 % of its energy from renewable sources by 2030.[24] The partnership between the US Department of Energy and the state of Hawaii is called Hawaii Clean Energy Initiative (HCEI) and aims at implementing new technologies using renewable sources, improving energy efficiency in order to reduce the energy use and kick of a new set of actions.[25] Signatories are the Governor of the State of Hawaii (at that time Linda Lingle), the State of Hawaii Department of Business, Economic Development and Tourism, the State of Hawaii Consumer Advocate and the Hawaiian Electric companies.[26] This is the first time where all parties officially committed to (1) accelerate the addition of new, clean energy resources on all islands. It is stated

[23] Kauai Island Utility Cooperative, “Kauai Island Utility Cooperative.”
[24] Carlton, “Energy (A Special Report).”
[25] U.S. Energy Information Administration, “Hawaii - State Energy Profile Analysis - U.S. Energy Information Administration (EIA).”
[26] State of Hawaii and Hawaiian Electric Companies, “Energy Agreement Among the State of Hawaii, Division of Consumer Advocacy of the Department of Commerce and Consumer Affairs, and Hawaiian Electric Companies,” 1.

that this (2) transition will officially require to move irreversibly away from fossil fuels in the generation of electricity as well as in the transport sector. Signatories pledge to (3) focus on a communal approach, transparent and truthful about the public and private investments necessary. The HCEI is also aimed at a new system of regulations (4) to transform Hawaii's major utilities from a traditional sales-based approach to an energy-service provider to truly serve the public.[27] This HCEI is still known as Hawaii's overall energy transformation agenda and refers to the entire body of laws, regulations and rules that define pace and scope of the desired transition. It also refers to various energy stakeholders who also have committed to drive this change on a technological, social educational and financial level.[28]

This Agreement draws the kick off of Hawaii's journey and set the basic steps in order to achieve this goal. Taken from the agreement, the following is a list most important strategies that were agreed on and still influence the energy transition of the Island-State, with special focus on renewable energy commitments, wind energy and energy efficiency commitments.[29]:

Renewable Energy commitments – Hawaii Electricity companies commit to:

- **streamline power purchase agreements**. These will still have to be approved by the Public Utilities Commission (PUC)
- The **transition to** Biofuels won't slow down the transition to non-fuel RE projects
- The transformation will go on **without lowering standards or service reliability**

Signatories agree that the **RPS is an effective structure** to fulfill the obligation of adding RE, of Hawaiian Electric companies. The agreement states the **increase of the RPS from 20 % to 25 % by 2020 and to 40 %**

[27] State of Hawaii and Hawaiian Electric Companies, 2.
[28] Cole and Glick, "Hawaii's Progress and Lessons Learned in Reaching a 100% Renewable Portfolio Standard," 3.
[29] State of Hawaii and Hawaiian Electric Companies, "Energy Agreement Among the State of Hawaii, Division of Consumer Advocacy of the Department of Commerce and Consumer Affairs, and Hawaiian Electric Companies."

by 2030. Energy savings from energy efficiency, demand response and renewable displacement are not counting toward RPS goals but towards the achievement of specially set HCEI goals.

Big Wind – Another goal under the agreement is to **combine wind potential across state.** This will require undersee electricity connections/ cable systems from Lanai or Molokai to Oahu in order to access wind energy from neighboring islands. The plan is to integrate up to 400 MW of wind power into the electrical system of Oahu. This integration was planned to happen through linking the rural islands of Lanai and Molokai, through undersea cables to the urban island of Oahu.[30] Wind energy was appealing means of reaching RPS due to the steady "trade winds" Hawaii is fortunate to have.[31]

Decoupling revenues from sales – this measure shall stop the encouragement of increased electricity sales. Rates shall be based on a system with independent measures to track costs of providing electric service and monitor these carefully in order to determine the Rates Payers costs for the service. The PUC can review the decoupling mechanism at any time and can unilaterally discontinue.

Feed-in tariff – is set in order to standardize and ensure a transparent market for power rates, terms and conditions for each type or RE. The feed-in tariffs are set to **cover the developer's costs including a reasonable profit**.

Energy Efficiency – Parties of the HCEI agree to support the achievement of **increasing energy efficiency statewide**. The Legislature adopted HB 1464 in 2009, required PUC to create Energy- Efficiency Portfolio Standards (EEPS) – intended to be the energy efficiency counterpart to the RPS, setting goals to increase energy efficiency[32] – in order to increase cost-effective energy efficiency programs and technologies. In total these standards shall achieve **30 % of electricity sales to come from RE until 2030** or in different measures a reduction of 4,300 GWh by 2030.[33] The government also afforded the PUC flexibility to adjust to energy-efficiency

[30] Coffman and Bernstein, "Linking Hawaii's Islands with Wind Energy," 2.
[31] Coffman and Bernstein, 4.
[32] Pintz and Morita, *Clean Energy from the Earth, Wind and Sun*, 41.
[33] Hawaii State Energy Office and Department of Business, Economic Development & Tourism, "Energy Resources Coordinator's Report on the Status and Progress of Clean Energy Initiatives and the Energy Security Special Fund," 4.

programs and technologies and to promote incentives as well as establish penalties based on performance in achieving EEPS.[34]

Greening Transportation – The key strategy here is to aggressively **support alternative fuels** (most of all electricity) in order to reach the goal of 70 % RE in Transportation by 2030.

Lifeline Rates – these are designed to **cap rates** in order to make sure to **still provide electricity to people who are unable to pay the full cost** of it.

'Pay as you save' – This program makes it possible for ratepayers to **'rent' a solar heating system**. The utility pays for the installation and the ratepayer repairs in form of maintenance costs of the installation. Once the installation is repaired the savings accrue entirely to the ratepayer.

Photovoltaic Host Program – Hawaiian Electric companies can **'rent' Roof** space to install PV Systems. The site owner can choose whether to receive a rental payment or use a portion of the energy granted. Owner of the PV installation can be the utility, the site owner but also a third party.

Advanced Metering Infrastructure – programs in order to **promote the installation of advanced meters** in order to give customers greater control of their electricity use.

The Update Report of the CCRI Western Conference in 2017 states, that in practice most action has been taken in the electricity sector, whereas the goals set in the transportation sector remained unrealized.[35] The positive achievements of the goals set by the HCEI in the electricity sector were paving the way to commit to 100 % RPS in 2015.

2.3.2. Committing to 100 % renewable energy

"Hawaii is sending a signal to the world that 100 percent renewable energy isn't just a vision, it's a commitment." – Henk Rogers, president of Blue Planet Foundation.

[34] Cole and Glick, "Hawaii's Progress and Lessons Learned in Reaching a 100% Renewable Portfolio Standard," 4.

With Governor David Ige signing the famous Act 97 in 2015, Hawaii officially became the first state in the nation to adopt a 100 percent renewable energy requirement. A great factor of facilitation to achieve this commitment, is the fact that with Governor Ige from the Democratic Party, this was already the third administration in favor of RE, after Governor Neil Abercrombie governing from 2010 to 2014 from the Democratic Party and prior Governor Linda C. Lingle governing from 2002 to 2010 from the Republican Party.[36] With this new set RPS commitment of 100 % Hawaii has made a great progress ever since first adapting legally binding RPS goals in 2004 and was also the first State of the U.S. making this ambitious commitment.[37]

In 2001 the State already establishes voluntary targets to get started in implementing RE. With the legal commitment Hawaii's PUC now has to evaluate and if necessary, renew the RPS every five years. In this matter the PUC relies on the information taken from annual reports provided by the electric utilities. This report has to then be published and presented to the government. The following table 2 shows the targets set in 2001 in comparison with the upgraded targets set in 2015[38]:

Table 2. RPS targets Hawaii

	targets set in 2001	**targets set in 2015**
2010	10 %	10 %
2015	15 %	15 %
2020	**20 %**	**30 %**
2030	-	40 %
2040	-	70 %
2045	-	100 %

Ever since the initial creation of the RPS by Act 272, the interim target could already be increased by 10% thanks to the fast and progressive implementation

[36] National Governors Association, "Hawaii."
[37] State of Hawaii and Public Utilities Commission, "RPS 2018 Legislative Report," 4.
[38] State of Hawaii and Public Utilities Commission, 12.

of RE on the islands of Hawaii. This thesis will investigate on the latest status and the achievability of these interim targets set. Act 99 requires the University of Hawaii to establish a goal of becoming a net zero user of energy and Act 100 obliges the PUC to implement community based renewable energy programs. Both of these Acts were also passed in 2015 and marked this year as regulation kick off. In addition, Act 100 aims at setting forth a system in which the individual electricity ratepayers can buy shares in a community solar project and use this solar power to offset their electric bill. This gives people living in multi-unit homes the possibility to take part in RE-projects.[39]

An Update in 2018 of the State Energy office allocated the priorities of measures, in order to achieve the Strategic Goals, as follows[40]:

1. **Promote Energy Efficiency**
2. **Diversify Energy Portfolio**
3. **Establish a Grid for the 21st Century**
4. **Accelerate Clean Transportation**

2.3.3. Financial Tools (PV, Wind and efficiency)

Initial subsidies and tax credits are crucial to the quest of pursuing a renewable energy strategy in an oil dependent state like Hawaii. As with most subsidies, which are actually meant to tilt economics of a market toward a public policy goal, they typically lead to achieving numerical goals as set by the HCEI, but often had a distorting effect on further strategic decision-making for ongoing projects and the future of the transition.[41] Also in Hawaii these distortions weren't escaped.

[39] Cole and Glick, "Hawaii's Progress and Lessons Learned in Reaching a 100% Renewable Portfolio Standard," 8.
[40] Hawaii State Energy Office and Department of Business, Economic Development & Tourism, "Energy Resources Coordinator's Report on the Status and Progress of Clean Energy Initiatives and the Energy Security Special Fund," 4.
[41] Pintz and Morita, *Clean Energy from the Earth, Wind and Sun*, 147.

2.3.3.1. Tools for Photovoltaic

Most subsidies on customer side were installed aiming at PV-Installations. This makes Hawaii's solar PV Tax credit system and similar mechanisms the most effective policies implemented, reflected in the growth rate of PV installations. In 2003 Hawaii adopted two such tax credits, upon other mechanisms. One for individuals and one on corporate level. Both regulations gave a 35 % tax credit for the up-front costs of renewable energy technology, including PV. Additionally, there is also the Federal Residential Renewable Energy Tax Credit covering 30 % of the cost of PV systems capped at $ 5000 per system. Early controversies occurred due to the difference between legislative intent and implementation. Legislation didn't clearly define what a "system" is and missed out on restricting the number of "systems" per roof. The cap of $ 5000 per "system" was herewith eliminated, as many households claimed tax credits for multiple systems on a single property. Addressing this inaccuracy new administrative rules were released in 2012.[42]

One financial tool commonly used for is the feed-in-tariff (FIT). The FIT is a guaranteed tariff rate, utilities pay to prosumers (private power producers and consumers) for the generation of RE for a specified period of time. This rate demonstrates a certain security for investors when planning such RE projects as PV installations. RPS together with FIT is proven to be a successful combination of tools, especially on Hawaii. Hawaii's FIT is designed to provide a 20-year contracted for PV systems up to 5 megawatt (MW), with a rate based on the size of the installation. The most relevant size of systems of typical households in Hawaii is 20 kilowatt (kW). For this size the FIT was initially set to $ 0.218/kWh assuming that PV providers will receive the 35% state renewable energy tax credit. As Hawaii's electric rates turned out to be substantially higher than the FIT rates, most households were rather choosing net energy metering (NEM), as it was providing a better return.[43] Now, in 2019 FIT, created with a goal of establishing market mechanisms for customers and relative simple

[42] Coffman et al., "A Policy Analysis of Hawaii's Solar Tax Credit," 1036.
[43] Coffman et al., 1037.

compensation mechanisms, programs are closed to new applicants and are no longer in action.[44]

Customer to the NEM receive credit for their energy produced by their PV installation, that is not used for themselves. In Hawaii the credits were granted at a retail rate and could only rollover month-to-month. The NEM applies to systems up to 100 kW for HECO and 50 kW for KIUC.[45] Although the NEM in Hawaii is closed for new applicants just like the FIT, HECO claims it as a "huge success". The program was already installed by the electric company in 2001 and over 60,000 households installed their PV-systems under the NEM in the HECO, HELCO and MECO service territories.[46]

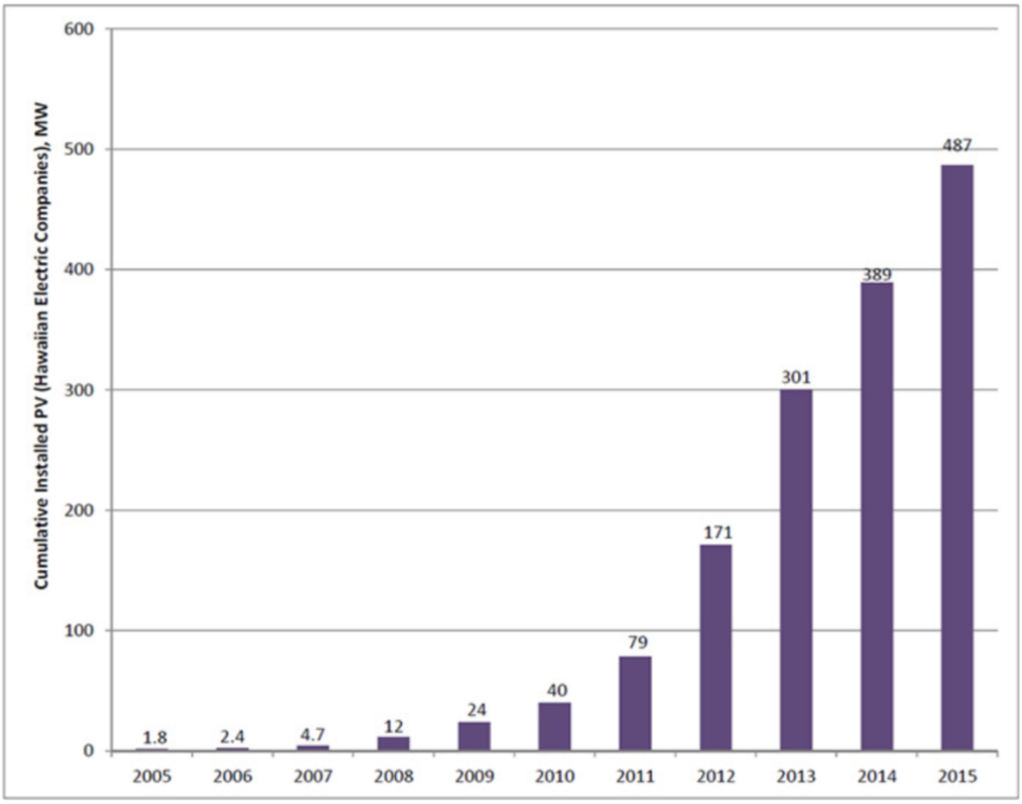

Figure 7. PV Installed under NEM in HECO territory[47]

When the NEM was first designed in 2001, it was supposed to be applied to 0,5 % of peak demand. In 2008, the capacity limit was raised to 15 % of peak

[44] Hawaiian Electric Companies, "Feed-In Tariff Program."
[45] Coffman et al., "A Policy Analysis of Hawaii's Solar Tax Credit," 1037.
[46] Hawaiian Electric Companies, "Net Energy Metering."
[47] Hawaiian Electric Companies.

load per distribution circuit. This limit was raised in order to give an incentive for early adoption and to be cautious of potential impacts on grid stability. For 2013, HECO gave PV capacity approval for circuits up to 100 % of daytime minimum load.[48] As seen in the figure 7, this resulted in a rapid increase in PV installations, and led to a queue of wide over thousand customers awaiting NEM interconnection approval. When evidence that large-scale distributed PV does not have a negative impact to system reliability of the PUC grew, the threshold again was raised to 250 % of daytime minimum load. With the NEM and the FIT installed the estimated payback period for investing in PV was at a statewide average of 6 years. The internal rate of return (IRR) was estimated to 16 % not including the statewide tax credit for PV.[49] In capacity installed from NEM is at 462 MW, which accounts for 75 % of total generated capacity installed. Closing the NEM program in October 2015 has posed a great challenge to policy makers and resulted in difficulties to the transition to new market options set forth by the PUC.[50] In retrospective NEM was successful in creating a local market for distributed generation but in the end, regulators found themselves in the uncomfortable position closing a program of huge popularity among the solar industry and its customers, which makes it hard to start a discussion on future successors to the program avoiding a prejudice of being pro-utility and anti-solar or anti-renewable.

3.3.3.2. Tools for wind energy

Wind energy is counted as one of the most doable RES for electricity based on its favorable cost and carbon neutrality. However, the development and installation of wind farms and require site-specific technical and economic resources. The biggest target group for subsidies and tax credits concerning wind energy are, unlike with PV installation, States. To encourage wind energy all

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[48] Coffman et al., "A Policy Analysis of Hawaii's Solar Tax Credit," 1038.
[49] Coffman et al., 1038.
[50] Cole and Glick, "Hawaii's Progress and Lessons Learned in Reaching a 100% Renewable Portfolio Standard," 11.

over the United States, there is a Federal Production Tax Credit of 2.3 cents/kWh for the first 10 years of operation.[51]

3.3.3.3. Tools for efficiency

As already mentioned, one goal set by the HCEI is an EEPS of 30 % by 2030. In 2016, the U.S. Department of Energy supported the state of Hawaii with awarding it with the energy saving performance contract (ESPC). This is a contract to retrofit 12 of the state's airports and consists of 158 million U.S. dollars.[52]

2.4. Status of the transition

Following the latest RPS report, which was published in the end of 2018, fulfilling the 5-year reporting duty of the PUC, statewide renewable generation totaled 27.6 % of utility sales by the end of 2017. Remembering the goals for RPS in 2015, of achieving RPS of 15 % the table 3 below shows that the RPS could exceed the 2015 RPS goals. To achieve this goal KIUC was developing utility scale solar and storage projects on a large scale. Statewide Hawaii is not far from achieving its 2030 RPS.[53]

Table 3. RPS achievements Hawaii 2007-2017[54]

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
HECO	4.3%	4.8%	5.1%	4.7%	6.7%	7.6%	11.7%	15.2%	17.2%	19.4%	20.8%
HELCO	33.8%	35.4%	33.7%	34.6%	41.1%	46.7%	48.1%	47.4%	48.7%	54.2%	56.6%
MECO	15.4%	13.9%	13.9%	15.3%	17.1%	20.8%	29.1%	33.7%	35.4%	36.9%	34.2%
HECO Cos.	*9.1%*	*9.4%*	*9.5%*	*9.5%*	*12.0%*	*13.9%*	*18.2%*	*21.3%*	*23.2%*	*25.8%*	*26.8%*
KIUC	5.7%	8.2%	9.2%	8.9%	10.5%	11.0%	13.8%	17.5%	27.3%	41.7%	44.4%
Statewide	**8.9%**	**9.4%**	**9.5%**	**9.5%**	**11.9%**	**13.7%**	**18.0%**	**21.1%**	**23.4%**	**26.6%**	**27.6%**

The effectiveness of Act 97 in 2015 is reflected most significantly at KIUC. They reached an increase by 14 percentage points extending their RPS from 27 % to

[51] Coffman and Bernstein, "Linking Hawaii's Islands with Wind Energy," 2.
[52] Coggin, "3 Ways Hawaii Is Becoming More Energy Efficient."
[53] State of Hawaii and Public Utilities Commission, "RPS 2018 Legislative Report," 6.
[54] State of Hawaii and Public Utilities Commission, 6.

42 % from 2015 to 2016. The table also shows that KIUC already exceeded its goal of RPS 30% until 2030 in 2016.

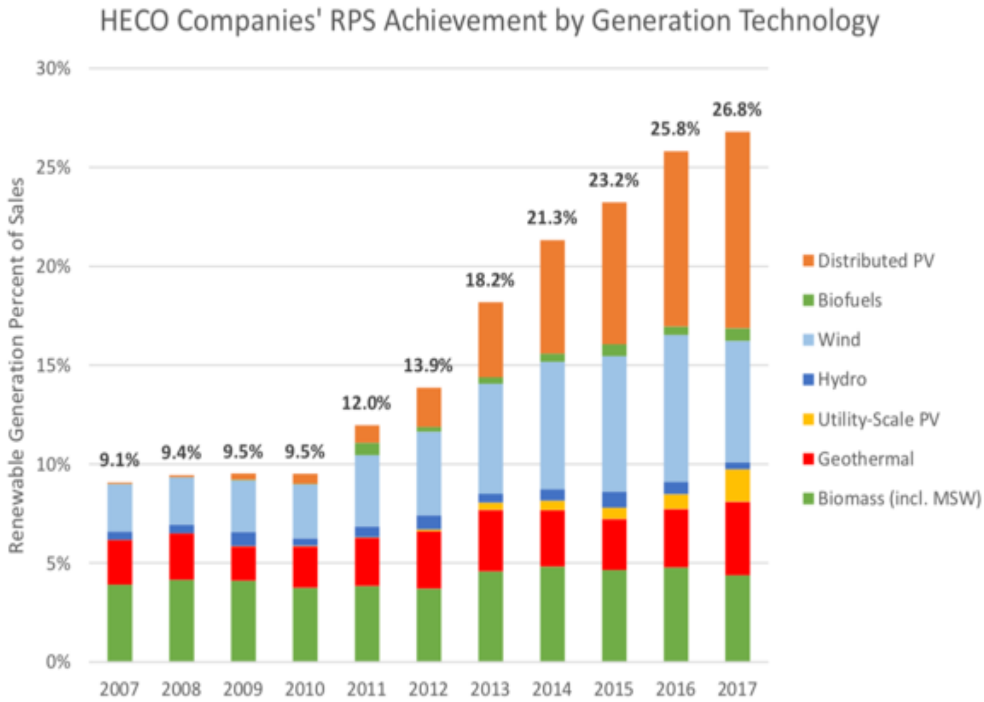

Figure 8. HECO Generation Technology[55]

The fig. 8 shows the mix of electricity generation by all HECO Companies put together. To reach their RPS the HECO has the advantage to draw back on a wide variation of RE technologies and herewith reaching an energy mix that results in flexibility and generation security. On an island basis, the island of Hawaii, also referred to as Big Island is leading the way with an RPS of 54 %. This is strongly supported by the availability of geothermal resources.[56] The generation through geothermal energy is expected to be largely minimized in recent years as an effect of the eruption of the volcano Kilauea on Big Island in 2018. The outbreak shut down the Puna Geothermal Venture (PGV) power plant and it has yet to be determined when or if it is going to be opened again. Following expert's opinion, the reopening of the PGV plant at the moment seems

[55] State of Hawaii and Public Utilities Commission, 7.
[56] Cole and Glick, "Hawaii's Progress and Lessons Learned in Reaching a 100% Renewable Portfolio Standard," 6.

rather unlikely due to a strong public opposition of the people living on Big Island.

In contrast to that the fig. 9, which shows the KIUC generation technologies, shows that on Kauai neither wind energy nor geothermal energy or biofuel are implemented in electricity generation. The overall strongest RE nationwide is distributed PV followed by wind energy in the HECO area and Hydropower on the Island of Kauai. Utility-Scale PV is far more represented through KIUC than by HECO. Whilst Biomass including municipal solid waste covers the baseload of the Island of Maui, Oahu, Lanai and Molokai at least since 2007 it has only been newly installed on Kauai. The installation of Biomass and the increase in solar generation are the two main drivers to serve KIUC's electricity ratepayer accounts in improving RPS percentage. Not shown in either of these charts is the energy consumption reduction due to energy efficiency measures. Due to the significant impact of this measures on the RPS 100 %-Journey, this will be examined in chapter 3.3. of this paper.

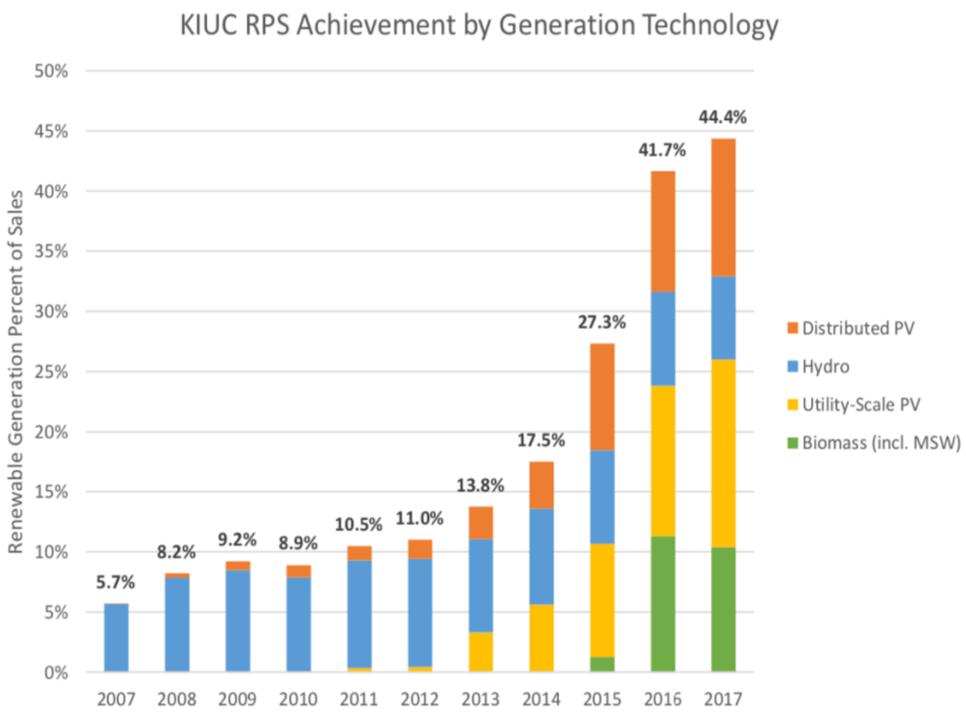

Figure 9. KIUC Generation Technology[57]

[57] State of Hawaii and Public Utilities Commission, "RPS 2018 Legislative Report," 8.

3. Potential ≠ Potential

Potential ≠ Potential. As stated already in this thesis, due to the unique geographical situation of Hawaii, it is 'blessed' with abundant resources for producing renewable energies. This is thanks to the special location in the zone of trade winds, many hours of sun in a yearly average and geothermal potential all over the place. These factors put together would make an energy transition seem easy. But why isn't it sufficient to 'just' switch to solar and wind energy with a dash of geothermal power? The potential concerning geographical properties is referred to as *ecologic potential*. Potential that is determined by the threshold of natural abundant resources. It is easy to mix up the ecological potential, with the *theoretical potential,* which describes the physically usable potential. Again, not to be mistaken with the *technical potential*. The technical potential takes into account the technical data, such as for example the efficiency of a certain technology or additional the framework settings like restricted zones (e.g. airports, harbors). Another distinction has to be made to the *economic potential.* Production costs of RE technologies, amortizations of plant construction and costs for grid integration are the major characteristics influencing this kind of potential. Subtracting all these factors from the theoretical potential, or in case of our example, the ecologic potential, leaves us with the *feasible potential*. The small part of potential that projects should be planned after, bearing in mind that the biggest challenge, social acceptance, has yet to be taken into account.[58]

Research has shown that in Hawaii the gap between ecologic and feasible potential is of substantial size. The following chapters describe the major impacts reducing the potentials of wind and solar energy, which have a considerable impact on the importance of energy efficiency measures in the island state.

[58] Brauner, *Systemeffizienz bei regenerativer Stromerzeugung*, 19, 20.

3.1. Solar Energy

Solar radiation is a clean and abundant source of energy. As seen in the rapid growth of electricity generated from distributed PV and Utility-Scale PV, it quickly became the number one attributor to RE in Hawaii. With an ongoing improvement in technology, increasing public acceptance and most importantly decreasing costs, solar energy will surely keep on playing a relevant role of future energy systems all over the world. [59] The share of Hawaii's residential energy use (12 % of total energy consumed in Hawaii) and the share of commercial energy use (18 %) are the ones that can be easily supplied with PV and solar thermal (ST) collectors. Due to their modularity they gain interest in urban areas and are the driving force of increasing decentral electricity and thermal energy production, which does not come without challenges. To measure solar potential some methodologies are rendered more appropriate than others. A straightforward solar potential estimate by simple generalist methods is a standard practice for small scale rooftop installations. When it comes to measuring the potential of complete urban environments data like shadowing events etc. make potential analyses more complex. To achieve higher reliability, vertical structures such as building facades are included in the estimation. By gradually excluding certain zones the ecologic potential is here calculated.[60]

In 2005, solar of either variety did only exist in a small amount in Hawaii. In 2008 when HCEI was first put in action, potential was already evident. Specialists used to consistently merge solar and wind technologies in one pot. Due to the unstable nature of solar availability the solution was to balance demand with liquid fuels. Further, PV solar technology was majorly discussed with a focus on utility-scale projects.[61] Looking at Figure 5, it becomes evident that this early assumption did undermine the success of rooftop PV in private settings. The implementation and speed growth of PV installations in Hawaii is seen as a huge success, all over the world. Back then the state's midrange scenario, set in 2008, aimed at 377 MW of solar power by 2030. The goal was

[59] Freitas et al., "Modelling Solar Potential in the Urban Environment," 916.
[60] Freitas et al., 916.
[61] Pintz and Morita, *Clean Energy from the Earth, Wind and Sun*, 75.

set with PV systems accounting for 207 MW. The great success of Hawaii is proven through the fact that in 2018, 700 MW (with 90 % of it as PV) have already been installed. This makes PV currently the most successful measure of all implemented and is the main reason Hawaii could draw this much international attention towards the state. In 2018, Hawaii ranked first in the United States in solar power per household. The explosive increase has several reasons supporting it. One of them being a whole package of programs like tax credits, low interest loans etc. coming generous state and federal subsidies earlier described in chapter 2.3.3.1. Also, the price of solar panels and other components fell sharply due to low cost imports from China. Balance of system costs, that refer to all components necessary to install the panels and connect them to the grid, decreased significantly. Inverter prices were decreasing by 7 % yearly since 2005 and installation costs have fallen 15 %. Keeping in mind the success of NEM, described in Chapter 2.3.3.1. that also encouraged homeowners to install rooftop systems. At state everyone in five households, has a rooftop panel.[62] Even with limiting net metering in 2015 PV and solar still continued to grow (fig. 10). With or without the NEM incentive rooftop panels just make sense to many homeowners.

The State also pursues utility-scale PV projects which will probably lead to an ongoing increase in solar energy. KIUC partnered with a SolarCity (a utility-scale PV plant operated by Tesla). SolarCity sells power to KIUC at 13,9 cents per kWh so KIUC can provide customers with clean energy. In addition, KIUC developed an energy storage system together with the AES Corporation. The storage system sells power to KIUC at 11 cents per kWh. HECO has a similar project together with EE Waianae Solar. The utility is able buy electricity from the solar farm at about 14.5 cents per kWh.[63]

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[62] Pasquier, Rogers, and Siccardo, "Hawaii's Quest to Become a Low-Carbon Leader," 1.
[63] Hawaii State Energy Office, Department of Business, Economic Development & Tourism, and Hawaii State Energy Office, "Hawaii Energy Facts & Figures," 32.

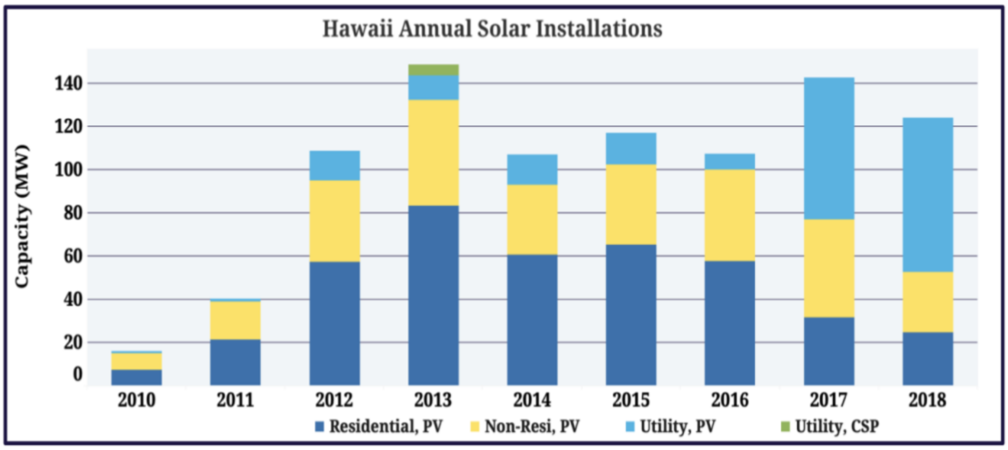

Figure 10. Annual Solar Installations Hawaii[64]

Looking at the latest update of Hawaii's solar market data from the 13th of March 2019, we find that when it comes to newly installed PV, the PV at utility scale has picked up quite significantly since 2016 and is the leading force of pushing PV installations. The estimated growth over the next 5 years is 1,107 MW statewide with a total investment of $ 2.99 billion in 2019. The investment in 2018 was $ 191.74 million. The in-state investment in solar has a positive effect on local companies and creates a wide variety of jobs. In 2019, a total of 2,120 solar jobs exist and 134 solar companies. There is enough solar power installed to provide electricity for 243,000 average homes.[65] Increasing utility-scale PV is the state's way of combating the conflicting business models of private rooftop PV and utility scale PV. They also see the advantage that whilst distributed solar, where excess energy is fed back into the grid, leads to a more uncontrolled and unscheduled grid load. Utility-scale solar systems can be better to controlled or curtail by the system operator.[66]

Following the Hawaii Natural Energy Institute (HNEI), Solar Energy will continue grow with a forecast of 994 MW growth by 2021. The success of the PV continues to rely on changes of support policies and continually

[64] Solar Energy Industries Association, "Solar Spotlight Hawaii," 1.
[65] Solar Energy Industries Association, 1.
[66] Cole and Glick, "Hawaii's Progress and Lessons Learned in Reaching a 100% Renewable Portfolio Standard," 20.

decreasing cost reduction of the modules due to economy of scale, efficiency improvement and production optimization.[67]

3.1.1. Interconnection and PV a challenge

Increasing Rooftop PV also comes along with new problems. High penetration levels of intermittent renewable energy sources in distribution systems may pose a threat to networks in terms of stability. Also, the decentralized feed can create major grid management problems. The interconnection process posed a persistent source of friction and controversy for the growing quantity of customers requesting PC and electric utilities concerned about keeping a safe and reliable electricity system. In attempted to avoid potential network instability HECO's approach to installation of new household PV systems is very cautious in some of its service areas. Distributed generation systems are required to comply with strict technical and regulatory frameworks so keep efficient operation going and a sage service of the overall network.[68] One acute backlog started in September 2013. To comply with the mentioned strict technical and regulatory frameworks and protecting the overall grid services, HECO announced changes to the interconnection process with no real prior stakeholder engagement and feedback. The changes included measures to facilitate interconnection of PV installations below 10 kW but unfortunately also delayed interconnection on a growing number of circuits with high levels of PV pending results from technical studies. They also changed the process of interconnection and required new applicants to receive interconnection approvals before installing systems and receiving county electrical permits. This change was already put in process without informing customers adequately. This resulted in an interconnection queue over the next year, with confused and angry customers due to the lack of information, clear timelines or guidance on the new technical requirements. In autumn 2014, when HECO initiated a program to "Clear the Queue". By the time interconnection queue had already grown to

[67] Busquet and Kobayashi, "Modelling Daily PV Performance as a Function of Irradiation, Ambient Temperature, Soiling, Wind Speed, and Aging - Applied to PV Modules Operating in Maui," 3401.

[68] Singh et al., "Grid Interconnection of Renewable Energy Sources at the Distribution Level With Power-Quality Improvement Features," 307.

5,476 customers. Ultimately the program was successful with the utility eliminating this backlog of customers two years later, by the end of 2016.[69]

This rapid increase of customer-side generation poses a great threat and challenge to utilities not only concerning their business model but also affecting the grid. Utilities cannot plan for balancing demand only based on modifying the fleet of central station generation. The conventional Hawaii Integrated Resource Planning model is inadequate for this new mode of decentral electricity generation. The market requires new distribution planning, innovative regulators environment and the ability to quickly respond to new challenges to adapt and overcome them. This will probably need grid updates as well, but the first step would need to be setting a clear vision of KIUC and HECO for the future design of the grid, so the grid can fully integrate the full range of renewables whilst still empowering consumers to manage their energy future. More localized grid controls are a must in this progress.[70]

3.1.2. Storage and PV an opportunity

With energy provided by fossil fuels, power plant operational plans could exactly be organized following the forecasted network load. Conventional coal or petrol power plants are inflexible when it comes to the production of energy. During the night, where not much energy is needed, they are not turned down, but often surplus energy is used to pump water into water storage. This energy is usually used to cover peak load demand the next day. Water storage plants are therefore used as short time storage. In contrast to that, electricity produced from PV or wind energy achieve less full load hours than conventional plants but, at high productivity and under technology friendly conditions, reach a higher performance per unit of energy. In this nature it so often happens that wind or PV plants produce more energy over a longer period of time, followed by a period of low to no energy production, in which the technologies are unable to cover demand. [71] Power output of PV can change by up to 80 % in a matter of

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[69] Cole and Glick, "Hawaii's Progress and Lessons Learned in Reaching a 100% Renewable Portfolio Standard," 10.
[70] Cole and Glick, 68.
[71] Brauner, *Systemeffizienz bei regenerativer Stromerzeugung*, 81.

seconds due to the passing of clouds, for example. This increases the need for highly dispatchable and fast-responding technologies to cover demand during such disturbances and also to avoid strong fluctuations in voltage. Main drivers of daily performance of PV especially in Hawaii are irradiation, ambient temperature, soiling, wind speed and aging of the module. A study using an empirical model on the island of Maui in order to predict the daily PV energy production showed that there is only a low impact of ambient temperature and wind speed with less than 5 % impact on the daily performance. Soiling also only impacts production by 5-8 % but has a limited impact thanks to Hawaii typical regular rainfall. Nevertheless, degradation play an important role on the daily output of PV systems.[72] Fluctuations are decreasing efficiency of voltage lines. Dispatchable energy storage could accommodate the integration of large-scale solar generation and due to catching fluctuations increase the operational efficiency across the entire electric grid system. [73] Battery energy storage systems (BESS) could also improve the economics of distributed PV generation by minimizing the need for cycle traditional generation assets and maximizing asset utilization of existing utility power generation by allowing the coupled PV and BESS to provide frequency and voltage regulation. [74] While, as further described in chapter 3.3., efficiency is important regarding the overall electricity output, it is essential to maintain a high PV module performance over its lifetime. To identify economic potential and predict the return of investment of PV systems, it is essential to assess long-term performance in Hawaii.[75]

The BESS is a battery containing bidirectional converters that are able to absorb or inject active and reactive power at designated set point. For completeness and comprehension, the next table 4 sums up all requirements and aims for BESS on Hawaii.

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[72] Busquet and Kobayashi, "Modelling Daily PV Performance as a Function of Irradiation, Ambient Temperature, Soiling, Wind Speed, and Aging - Applied to PV Modules Operating in Maui," 3405.
[73] Hill et al., "Battery Energy Storage for Enabling Integration of Distributed Solar Power Generation," 851.
[74] Hill et al., 857.
[75] Busquet and Kobayashi, "Modelling Daily PV Performance as a Function of Irradiation, Ambient Temperature, Soiling, Wind Speed, and Aging - Applied to PV Modules Operating in Maui," 3401.

Table 4. BESS aims and requirements[76]

Battery Energy Storage System Requirements
BESS to stabilizing the power system
BESS to reduce fluctuations in the power system in response to high level of integration of variable energy sources (PV & Wind)
Optimal size of BESS for short-term power dispatch to maximize energy harvested
Optimal BESS and power levels for peak load shaving applications
BESS for reducing transmission and distribution losses
BESS for leveling utility load
BESS to regulate active and reactive power according to State of Charge limits
BESS to send control signals into the switches using a current control loop

Whereas pump water storage does not play an important role in Hawaii alternative battery storage has set foot in Hawaii. The state of Hawaii has recognized the need for storage technologies in order to continue the expansion of distributes solar as well as with utility-scale renewable generation. As they have not yet been fully deployed this poses a future challenge and also opportunity to Hawaii. To respond to the need of increasing BESS usage in Hawaii the utilities have designed a customer self-supply (CSS) program and a Customer Grid-Supply (CGS) program. As the names of the programs already suggest the CSS is designed for private rooftop solar installations that are not designed to export any electricity to the grid. Under the CGS, customers receive a PUC-approved credit for electricity. They can send their excess energy to the grid and are billed at the retail rate for electricity they use from the grid, in case their private system does not produce energy system.[77] So far, the market reaction to both of these programs was diverse. As the CGS program was fully subscribed by the end of 2016, the CSS remained the only one open for subscription. The biggest obstacle for customers to subscribe to the CSS are mostly the requirement for a private storage system, which comes with high

[76] Reihani et al., "Energy Management at the Distribution Grid Using a Battery Energy Storage System (BESS)," 338.
[77] Hawaiian Electric Companies, "Customer Renewable Programs."

implementation costs and the need for a sufficient space. More challenges, that potential customers have stated, are the fulfillment of all certification requirements in order to install new equipment (such as the battery). Problems arose concerning the interpretation of tariff language on technical requirements for "inadvertent export" and county permitting requirements to approve installations of energy storage systems. Until May 2017, only 57 self-supply systems have been approved for installation by the utility and received all subsequent permits to start operating. Nearly 700 systems were approved by the utility for interconnection but are still pending further approvals, especially the ones from county permitting agencies.[78]

This bottleneck has to be removed in order to push distributed PV to a constant increase in implementation. One the bright side market development of energy storage systems has shown a constant decrease in retail prices of about 20 % per year. HECO forecasts that battery costs will decline more than 50 % in the next 15 years.[79]

3.2. Wind Energy

Table 5 shows a complete list of all wind farms either under operation or proposed and under development on all of the islands of Hawaii. In total there are 205.4 MW total wind capacity installed. With two additional wind farms in a development phase and additional capacity of 70.8 MW this will lead to a total wind capacity installed of 275.4 MW.

Table 5. Wind Energy Statewide Hawaii[80]

Island	Location	Project Status	Capacity
Maui	Ulupalakua	Existing/Operational	21 MW
Hawaii	Upolu Point	Existing/Operational	10.56 MW
Maui	Kaheawa	Existing/Operational	30 MW

[78] Cole and Glick, "Hawaii's Progress and Lessons Learned in Reaching a 100% Renewable Portfolio Standard," 12.
[79] Blue Planet Foundation, "Energy Report Card," 31.
[80] Hawaii State Energy Office, "Hawaii Renewable Energy Projects Directory."

Maui	Kaheawa	Existing/Operational	21 MW + 10 MW BESS
Oahu	Kahuku	Existing/Operational	30 MW
Oahu	Kawailoa / Haleiwa	Existing/Operational	69 MW
Hawaii	Lalamilo	Existing/Operational	3.3 MW
Oahu	Kahuku	Proposed	24 MW
Hawaii	North Kohala	Existing/Operational	100 kW
Hawaii	Ka Lae (South Point)	Existing/Operational	20.5 MW
Oahu	Waianae	Proposed	46.8 MW

3.2.1. BIG WIND a threat

Looking back at chapter 2.3.1., where the goals of HCEI were investigated, it is noticeable that the total of 275.4 MW is just a little more than half of the wind capacity that was initially aimed at. The project called "Big Wind" should have contributed about 400 MW electricity to Hawaii's energy supply through 174 windmills.

The project was initially designed to supply mainly the Island of Oahu with renewable energy. Oahu has the highest electricity consumption of all Hawaii Islands, but not enough feasible potential to supply itself. That's why developers and decision makers were planning on installing the wind farms needed on Lanai and later extended the area of installation to also Molokai. The wind energy harvested on Lanai and Molokai should have been transported to the Island of Oahu via marine cables. These cables did not exist before and should have been built specifically for this project. Back in 2008, the idea of building marine cables was generally considered to be challenging but still technically feasible. For what it is worth, the Big Wind proposal was a conceptual revolution that gave energy planners statewide the confidence to move forward with a large-scale renewable energy strategy.[81] When completed the project would have provided 14 % of Oahu's power needs. Word spread fast as people living on the islands of Molokai and Lanai learned about the 174 windmills on their islands, producing electricity for energy use on Oahu. The proposed wind farms would have involved a relatively small project footprint and no direct threat to existing land uses, but many residents still view them as threats to their lifestyle and character of their islands. In an attempt to combat the strong public opposition and still be able to realize the project HECO and the government proposed benefit packages for residents. These compensatory benefits ranged from commitment of 1 % of wind revenues to a local development fund, to concessionary power tariffs for Lanai and Molokai residents. The benefits could not convince residents to agree on the further development of the big wind projects and the project was stopped.[82] Experts today say that the ongoing could have risked the whole kick off of the energy transition as this project could have destroyed the public mood on all islands of Hawaii.

3.2.2. The Nene Goose on Kauai a weakness

Looking at Table 5 one also notices that there is no wind energy harvested from the island of Kauai. KIUC does only rely on generating electricity from distributed PV, Hydro plants, utility-scale PV and Biomass plants. Looking at Figure 11. there is clear evidence that unused wind energy potential does exist around and on the Island of Kauai.

[81] Pintz and Morita, *Clean Energy from the Earth, Wind and Sun*, 42.
[82] Pintz and Morita, 73.

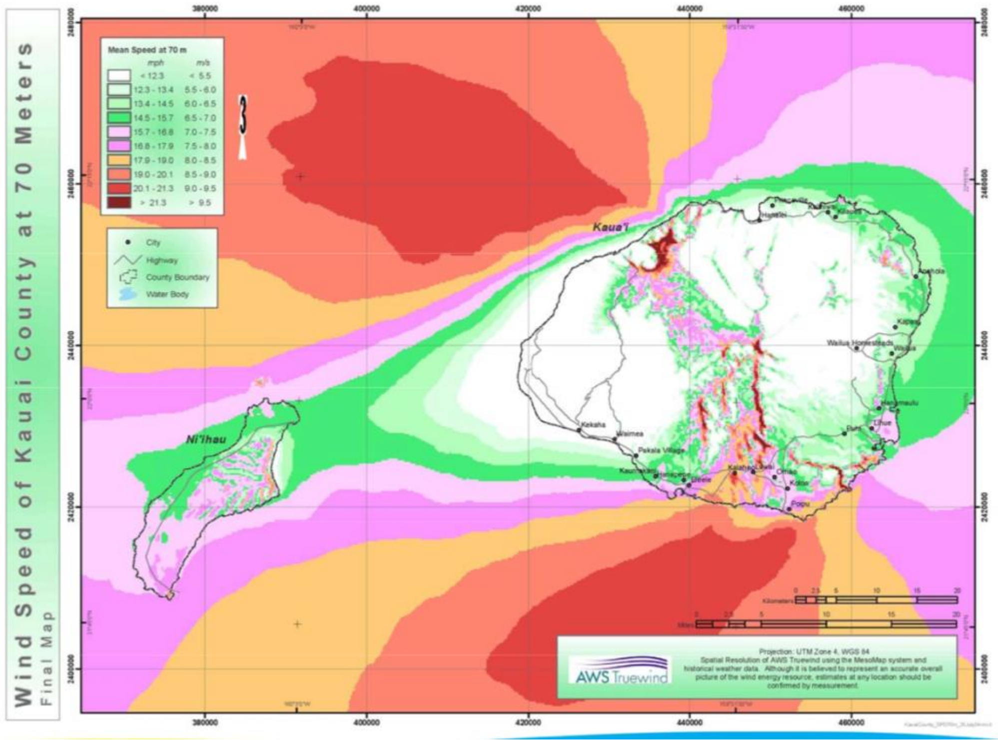

Figure 11. Wind potential Kauai at 70 Meters[83]

As described in the introduction, the Island of Kauai is also commonly known as the “Garden Island”. This is because of its large amounts of untouched vegetation and its little population. The residents of Kauai pride themselves on keeping the islands lack of economic and tourist development and natural feel. As KIUC is owned by people living on Hawaii, the interests of them minimizing the amount of industrial sized power plants are strongly supported by their local utility. This is also the reason why wind farms are facing strong public opposition. Triggered by the protection of the so-called *Nene Goose,* the community of Hawaii opposed the installation of wind farms. Given their success on implementing RE so far, it seems like this is not a problem. What remains unclear is if they will still reach 100 % RPS without the permission of further wind farms.

[83] First Wind, “Kauai Wind Power,” 7.

3.2.3. Offshore Wind an opportunity

A detailed study from a corporation between the General Electric Company and the HNEI in 2010, found out that 400 MW of off-island wind energy and 100 MW of on-island wind energy can be integrated into the Oahu electrical system, whilst maintaining system reliability. Together with 100 MW of solar PV, the study stated, that this would substitute the need of burning approximately 2.8 million barrels of low sulfur fuel oil and 132,000 tons of coal each year could. This combined supply from wind and PV would have covered just over 25 % of Oahu's projected electricity demand.[84]

Nine years later, looking at Table 5, shows that there are still no off-shore wind installations anywhere close to the Islands of Hawaii yet. Again, it is proven that the potential does not automatically have to be a feasible potential. In Hawaii's special case this is due to a stakeholder involved of significant power and influence in the Unites States of America, the U.S. Military.

Figure 12 plots a map from the Outer Continental Shelf of Oahu. This Map was created throughout a compatibility assessment of a portion of outer continental shelf around Oahu and reflects the requirements of Navy and Marine Corps missions conducted in the air, on the surface and below the surface of these waters. This assessment was conducted by the Department of the Navy (DON). Together the U.S. Marine Corps and the Department of the Navy have expertise related to U.S. military installations and training. As all branches of the military are present on Oahu, this includes radar restricted areas, airspace and training areas. These branches are in constant coordination with the U.S. Department of Defense (DoD) on renewable energy project compatibility through the DoD siting Clearinghouse in the Office of the Deputy Undersecretary of Defense for Installations and Environment.[85] The Map can also be found in a bigger size Appendix I for closer investigation.

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[84] Hawai'i Natural Energy Institute, "Hawai'i Distributed Energy Resource Technologies for Energy Security," 3.

[85] U.S. Department of Energy, "Hawai'i Clean Energy Final Programmatic Environmental Impact Statement (Final PEIS)," 13.

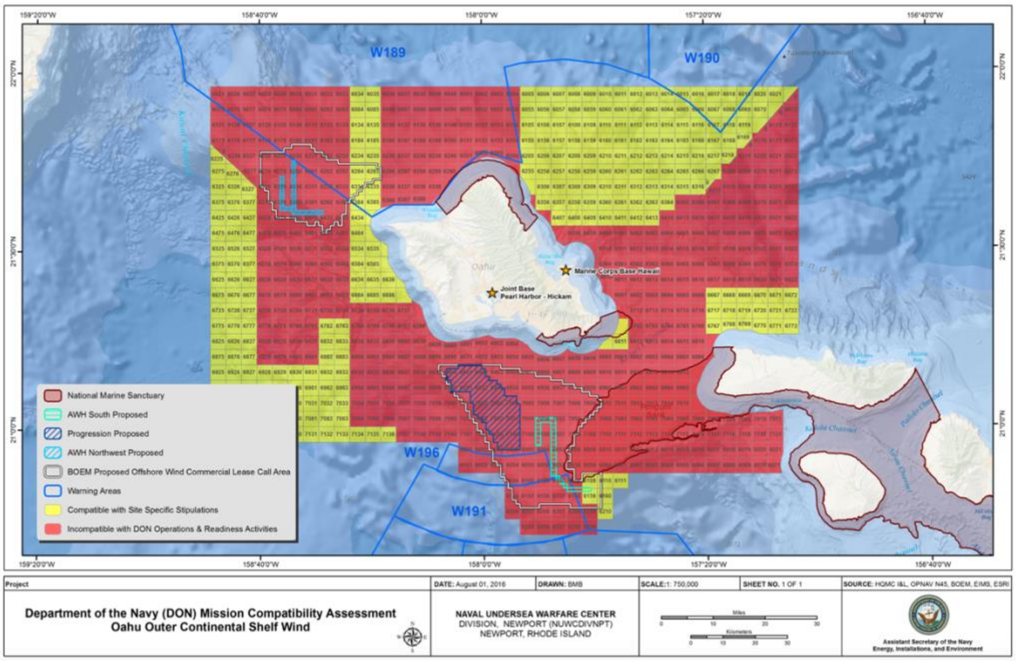

Figure 12. Compatibility Assessment Oahu Outer Continental Shelf Wind[86]

The small turquoise, blue and light blue dashed areas, on the map called *"AWH South Proposed"*, *"AWH Northwest Proposed"* and *"Progression Proposed"*, mark location where Offshore Wind projects were proposed. These locations were proposed after investigating the wind potential around Oahu and already taken into considering National Marine Sanctuaries. After also respecting not only National Marine Sanctuaries, but zones of importance to military and naval action, the DON marked concerned areas that would be compatible for an Offshore Installation with specific stipulations in yellow and areas that are completely incompatible with DON Operations & Readiness Activities in red. Unfortunately, almost the entire part of the AWH Northwest, the AWH South and the Progression area are in the red zone, hence there are incompatible with the DON requirements. This challenge has not been tackled yet, as there are no plans and strategies set in order to (a) find new locations that also fit or (b) try to negotiate with involved stakeholders, if possible.

[86] U.S. Navy Energy, Environment and Climate Change, "Department of the Navy Hawaii Offshore Wind Compatibility."

3.3. Efficiency

As already described in chapter 2.3.2. of this thesis, in December 2018 the Hawaii State Energy Office (HSEO) declared the promotion of energy efficiency as their number one strategic goal. Increasing energy efficiency is the cheapest and easiest form of clean energy worldwide. Although the incentives set from the State of a Hawaii and from federal level to install PV in commercial and residential buildings are important to reach Hawaii's long-term goals, reducing the energy consumption with increasing energy efficiency efforts are a more sensible and effective short-term measures to reduce the dependence on fossil fuels. When looking at it from the economical perspective, energy savings through building equipment and retro-fits is more cost-effective than installing renewable energy sources. On the Islands where air condition and cooling are one of the biggest energy consumers all year round, equipping buildings to be more efficient is essentially important.[87]

[87] Yalcintas and Kaya, "Conservation vs. Renewable Energy," 3269.

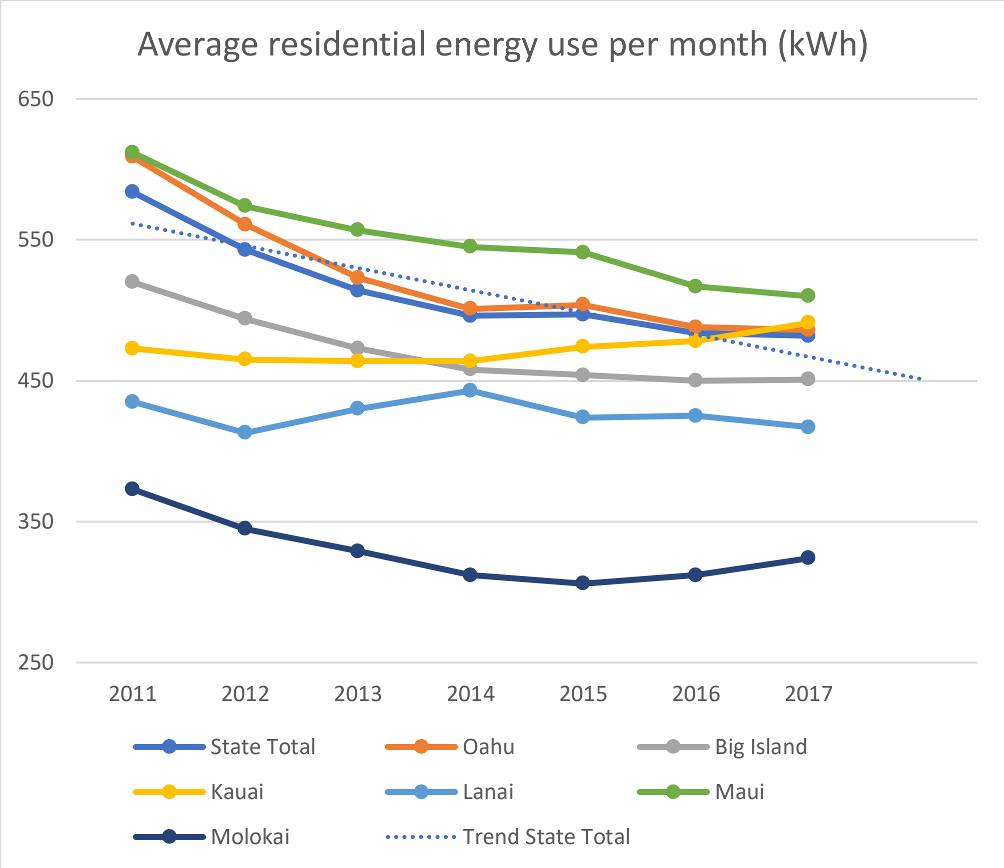

Figure 13. Average residential energy use per month (kWh)[88]

Looking at fig. 13 makes it clear that since 2011 the state wide energy consumption is at a decreasing trend. Motivated by HCEI goals of reaching 30 % savings by 2030 there is an ongoing downward trend. Only on the island of Kauai and Molokai there is a slight upward trend. Hawaii state agencies' electricity consumption declined 16.1 % from 2005 through 2018. Costs increased 43 % due to higher electricity prices.[89]

The first HCEI energy efficiency measures were designed on two separate paths. One being near term incentives based on different programs. They were aimed at encouraging end users to reduce their electricity use through better practices and substitution of modern appliances and light technologies.[90] Typically, in Hawaii the evening hours are the peak of energy use during a day.

[88] Hawaii State Energy Office, Department of Business, Economic Development & Tourism, and Hawaii State Energy Office, "Hawaii Energy Facts & Figures."
[89] Hawaii State Energy Office and Department of Business, Economic Development & Tourism, "Energy Resources Coordinator's Report on the Status and Progress of Clean Energy Initiatives and the Energy Security Special Fund," 14.
[90] Pintz and Morita, *Clean Energy from the Earth, Wind and Sun*, 88.

On a commercial base 45 % of total energy used during the evening peak is for illumination. One measure to cut the energy use would be changing streetlights to high-efficiency LED lights. Following the Blue Planets foundation's Energy Report Card this could save the state $ 14 million each year.[91] On a residential base most energy is used for cooling followed by water heating and refrigeration. One measure implemented here is Act 204, requiring new single-family residential constructions to have a solar water heater system. If this is not undertaken, an exemption from this state law must be requested and later approved for building plans to be accepted. With single family dwellings also Accessory Dwelling Units are meant. The Act further regulates potential variances.[92] To support this Act the State Energy Department offers an online application service for potential variances. This has led to a major legislative loop hole.

In order to reach their goal of increasing efficiency the state of Hawaii has implemented the following programs:

3.3.1. Energy Performance Contracting (EPC)

The EPC allows government agencies to pay for energy efficiency, distributed energy resource upgrades and RE-installations with the savings on their utility bills. Technical assistance is provided to state and county agencies entering into energy performance contracts and projects that include office buildings, community colleges, airports, highways and prisons. This assistance consists in services like reviewing energy service proposals, evaluating investment grade audits, conducting educational/technical training sessions and also providing ongoing assistance and support services. The 2018 Update report states that $ 507 million were invested for EPC since 1996. Estimations say that with this investment around $1.2 billion costs of electricity were saved. This includes 285 buildings and facilities covering more than 112 million square feet. Following

[91] Blue Planet Foundation, "Energy Report Card," 13.
[92] State of Hawaii, Act 204 §196-6.5, 1.

the Report all savings from EPC put together are equivalent to powering about 400,000 homes for an entire year.[93]

3.3.2. Hawaii Green Business Program (HGBP)

The Hawaii Green Business Program (HGBP) provides technical assistance to recognized 'green Businesses'. These are businesses that operate beyond compliance in an environmentally and socially responsible manner. This works as a partnership among the state Department of Business, Economic and Tourism, state Department of Health, the Board of Water Supply and the Chamber of Commerce of Hawaii. Since the start of this program the savings of participating businesses overall reached 22.7 GWh of electricity. This corresponds to $ 6.4 million in energy costs.[94]

3.3.3. Hawaii Energy Building Code

An instrument in order to update the 2015 International Energy Conservation Code. This code, in its 2015 edition, was planned to meet the needs for a modern, up-to-date energy conservation in designing energy-efficient building and installation of energy-efficient mechanical, lighting and power systems through requirements emphasizing performance. [95] Hawaii this code is aimed at providing 30-33 % increased efficiency for commercial buildings, 9-10 % increased residential efficiency and $ 1.4 billion energy savings over the next 20 years.[96]

[93] Hawaii State Energy Office and Department of Business, Economic Development & Tourism, "Energy Resources Coordinator's Report on the Status and Progress of Clean Energy Initiatives and the Energy Security Special Fund," 4.
[94] Hawaii State Energy Office and Department of Business, Economic Development & Tourism, 4.
[95] International Code Council, "2015 International Energy Conservation Code."
[96] Hawaii State Energy Office and Department of Business, Economic Development & Tourism, "Energy Resources Coordinator's Report on the Status and Progress of Clean Energy Initiatives and the Energy Security Special Fund," 4.

3.3.4. Leadership in Energy and Environment Design (LEED)

The U.S. Green Building Council (USGBC) administers Leadership in Energy and Environment Design (LEED) programs. Spaces that are LEED-certified are requested to use less energy and water, reduce carbon emissions and contribute to a healthier environment for residents, workers and the lager community. The State of Hawaii has 197 LEED certified projects and 239 registered projects. The total gross square footage of all projects put together consists in over 50 million gross square feet. This makes Hawaii stand out among the tip 10 states for LEED certified project square footage per capita. This certified spaces and buildings include private as well as federal, state and county public buildings.[97]

3.3.5. Energy Demand Side Management

Demand response (DR) management is not an energy efficiency as such, but when understood well, it can increase efficiency of energy use and lead to cheaper energy bills on customer side. Energy efficiency aims at 'more work from the same amount of energy' and includes a reduction of kWh throughout the year. Demand response shall reduce load (kW) when requested during unusual events occasional and temporary, called by the utility. This is essential in order to shift energy use from expensive generated peak loads to cheaper times during the day. There are two different forms of DR. Automated-Demand Response and Action- Demand Response.

Automated-Demand Response, the electricity customer (private or commercial) gives permission to the electricity company to steer their electricity demand in certain situations to save energy. On Hawaii this works well for water heating, cooling and refrigeration. The energy that is saved due to this routing permission is also positively represented on each's customer bill. Action is only taken when requested by the utility and involves temporary energy use reduction which is agreed on in advanced. The facility receives a signal from the utility via

[97] Hawaii State Energy Office and Department of Business, Economic Development & Tourism, 4.

internet. This signal initiates an automated load reduction.[98] The second type requires active part taking from customer side.

Action-Demand Response includes three key components that aim at changing consumer behavior, in order to avoid or reduce peak load demand. Through flexible pricing of electricity per kWh the consumer is motivated to adapt their energy use to hours were kWh are sold cheaper. Overall education and transparency on where energy is used gives another opportunity to reduce energy use. The last incentive used by Action DR is the most advanced: here a personalized system is installed that recognizes single devices and knows exactly how much energy is spent on every single one of them. With this personalized information the customer can be informed and learn to adapt his consumer behavior even more precisely. Pilot test with *Bidgely* (a software preparing this personalized data for customers), have shown that on average 7 % of total electricity use can be saved per household.[99]

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98 Hawaiian Electric Companies, "Demand Response."

99 Adler et al., "Power from the People - Action Demand Response."

4. Conclusion

After describing the situation in Hawaii clear, evaluating the potential of solar energy, wind energy and energy efficiency measures and describing the situation in more detail, chapter 4. of this thesis now analyses the categorizes the most relevant problems in a SWOT analysis. The analysis is crucial to later identify the main drivers and challenges of the energy transition and to also determine the achievability of RPS 100 %. Important action steps shall be recommended.

4.1. SWOT of Hawaii

The established method, called SWOT analysis, is often used to formulate a strategy and is aimed at identifying strengths and weaknesses of an organization and the opportunities and the threats existing in the environment. As this analysis already had its origin in the 1960, there were many variations of it developed ever since. Like the TOWS matrix etc.[100] This thesis focuses on the original form and categorizes the main strengths, weaknesses, opportunities and threats of Hawaii's energy transition to energy independence. In this case the *"organization"* is defined as actors taking active steps to achieve the goal of energy independence, such as policy makers, social advocates and utilities. The *"given"* factors are the circumstances in this energy transition, such as the mindset of the people due to their history etc. The analysis is plotted in Table 6.

Table 6. SWOT Hawaii

Strengths	**Weaknesses**
Three administrations in a row on favor of RPS 100 % **Demand and Response measures** Promotion and education	Pace of utilities vs. pace of transition **Blurry strategies** Utility vs. distributed PV Grid renewal
Opportunities	**Threats**

[100] Dyson, "Strategic Development and SWOT Analysis at the University of Warwick," 632.

Abundance and technical feasibility of RE Availability of Community Comprehensive threat of Energy Dependence **Decrease in Storage Costs** International Innovation cooperation	**Community opposition**

The **strengths** are pretty straight forward. As described in chapter 2.3.2. one of the immense strengths that shall not be underestimated during the transition are the three governing administrations in favor of reaching energy independence. A great future is also seen in the possibility of further implementing Demand and Response measures to increase energy efficiency. Experts stated that this should be one of the main focus points of improvement in the near future. There are many promotion and education measures set, inter alia, by the Blue Planet foundation. The Community network established in this sense is an enhancing factor.

One of the biggest **weaknesses**, mentioned by experts and concluded by the author, is the pace of utilities to adapt versus the pace of transition. As closely investigated in chapter 3.1.1. and described in the example of interconnection the lack of adapting and correctly communicating changes can majorly limit the progress of achieving RPS 100 % and inhibit new technologies to set foot in an interesting market. In order to achieve better communication and avoid such difficulties it is crucial to set some clear plans into this energy transition. This includes more detailed definition of the role of the utility, whilst distributed PV gets stronger and stronger in the market. As healthy utility companies are crucial to this energy transition, there needs to be a clear design of tariffs, taxes, grid access plans etc. in order to harmonize utility goals with the RPS goals. Also, the renewal and update of Hawaii's grid systems needs to be updated in order to meet future needs. Like in the matter utility vs. distributed PV there is no clear grid development plan set yet. The blurry strategies effect many sectors and actions at the same time.

The abundance of natural resources in Hawaii and the technical potential of the main RE sources is given and a great **opportunity** for Hawaii to reach their goal. As the Introduction of this thesis mentions the special approach of Hawaii's community, the "Aloha-Spirit" is another natural supporter of the energy transition. In combination to that but in a less romantic way, the true awareness of the dangers of being oil dependent and the therewith associated dependent cost development of electricity prices on the Island supports that energy measures are taken seriously. The dangers, risks and negative effects of being energy dependent seem more comprehensible to a community, then the long-term effects of impacts of climate change triggered by the burning of fossil fuels. The promotion of Hawaii's energy goal when it comes to raising awareness or increasing social acceptance therefore should always be conducted in combination with energy independence and climate change. chapter 3.1.2. describes the interconnection of the possible expansion of PV and the herewith connected need to expand storage capacity. The international decrease of storage prices and improvement in technology is a clear opportunity for Hawaii's energy transition. This cost decrease will lead to the further increase in distributed PV installations. The importance of Hawaii turning into an innovation hub for renewable energies should not be forgotten. Mentioned in chapter 1.1. the unique setting of Hawaii together with the commitment for this energy transition is a great chance for Hawaii's job market, potential investors, emerging businesses and international image.

The last point of this SWOT analysis, the **threats**, only states one issue. However, this shouldn't be disregarded. In this matter it is very important not to underestimate the power of the community opposition in an energy transition. Described in the examples throughout this thesis, such as the refusal of building windfarms on Kauai, the veto against wind farms on the Islands of Molokai and Lanai, the marine cable combined to that, or the rejection of the re-opening of the PGV plant, we could clearly see that no matter the technical feasibility or need, if the people say "NO" there is almost nothing to do about it. Although there is great wind energy potential, geothermal potential it will most likely remain unused and the route to energy independence has to go on without it.

4.2. Main Challenges and Recommended Solutions

The so-called main challenges and at the same time points where most potential is captivated are highlighted in bold letters in Table 6 These are:

Demand and Response measures

As already mentioned, utilities can no longer plan for balancing electricity demand based completely based on turning the fleet of the central generation up and down. But these DR measures and new opportunities from technological side also form one of the great opportunities in the near future of Hawaii's energy transition. Hawaii should continue to support research in quick-response demand management systems on utility side. Also, the advance and support of DR measures on customer side have to be further supported in order to increase energy efficiency. The more customers can control their energy use in a comprehensive way, the more awareness will be raised. It's all about finding ways to plot electricity data in a consumer-friendly way. Moreover, the availability of usage data of private homes for the utility has to be ensured. This way the utility can plan in their energy production accordingly and if possible, can even steer certain usage patterns. Cooperation between utility and consumers is an important part of reaching energy independence. Utility plans should try to minimize total cost and create flexible plans that allow for uncertainty and permit adjustments to balance circumstances that have changed.

Blurry strategies

There is a lot that has to be done in order to plan a strategy. Hawaii has done very well so far in setting a vision. Without even knowing how to achieve it, they set their goal of RPS 100 % until 2045. This sure was important in order to get things rolling but one common strategy would facilitate the transition even more. If there would be a nationwide strategy it would be easier for HSEO and the utilities could accelerate the permission process of new RE generation projects etc. With this increased permission pace come many other processes that would need to have some extra speed. On research side, especially when it comes to grid development plans, proven strategies are imperative to ensure safety, reliability and to also estimate costs and even cost savings that can be ensured. Teaming up with partners in Silicon Valley and drive potential partnerships with Start-Ups, visit technology companies, accelerate young clean-tech ideas, keep testing advanced technologies, all these measures shall be enhanced by the State of Hawaii with one common approach.

Decrease in Storage Costs

This natural development of costs in Storage creates a great opportunity for Hawaii's distributed PV. Secondly, it will also help transitioning the Transportation of Hawaii to clean energy. Storage devices most importantly also help to shave peak demands and without their massive extension a 100 % RPS will not be achievable. So far it is still challenging for storage systems to meet the non-export requirements, as described in chapter 3.1.1. In order to pick up on this chance of improving storage opportunities utilities need to prepare accordingly. The approach of fostering collaborations and attracting new tech firms to Hawaii would also have a positive impact on improving storage possibilities.

Community opposition

This sensitive point stands above all. Not only in Hawaii but also in Europe we can observe the phenomena of "not in my backyard". A phenomena where most people overall agree that they believe in climate change, they agree on taking responsibility of future generations, they agree that severe effects global warming brings and they agree on taking collective action but then they do not want to have their beautiful landscape "destroyed" by windmills, PV plants or anything similar. This is where education, media, regulators and the scientific community needs to do a better job. Letting people know that there is no way around to adapting to new circumstances, landscapes and being open to change. Reminding our world every day, that if we refuse to adapt to changes in landscape or in our neighborhood, we also refuse to slow climate change. Community opposition is what we need to tackle through awareness and credibility of posed solutions. Combined with the new technologies, methods and fast improvement of ongoing research it is our task to turn this great challenge into the biggest opportunity!

4.3. Achievability and Outlook

Throughout this thesis it could be determined that introducing the RPS in Hawaii was an effective tool in order to accelerate the increase of RET in electricity sales. Both HECO Companies and KIUC are well positioned to achieve the 2020 RPS. But as we could see in other states and countries around the world, we know that the transition of the first 30 % to RE is achieved easier, than the last 30 %. In order for the state of Hawaii to achieve their goal of RPS 100 % in 2045 there are still obstacles that have to be overcome. Chapter 3 Explains that potential does not necessarily mean true feasible potential. Thinking of RET in terms of costs, land availability, site control and ability to get permission for projects, reduces the great ecologic potential of RES on Hawaii. Not only the production of RE but also the accommodation and distribution of the decentralized energy technologies has to be considered further. This includes the ability of the electric utilities to adapt on an organizational basis, concerning also commercial operations, and the grid adapting on a technological basis to the fast changes of electricity production. It can be deducted that the achievability of the ‘end goal’ is still uncertain. This is also due to some insecure indicators. It’s hard to predict the future development of electricity demand for example. This is an important factor as the RPS is defined in percentages of electricity sales.

5. Summary

This thesis has shown why it is of such importance for the State of Hawaii to become energy independent. Although Hawaii has the lowest energy use in the United States of America it still has electricity costs that are twice as high as the nation's average. This is due to the dependence on oil price development on the main land and the connected dependence. While the transportation sector is the biggest energy consumer in the Island-State, electricity use produced from coal and gas takes up about the other half. Transitioning to RE and energy independence Hawaii relies a lot on PV and wind energy. The thesis has shown the successful implementation of both but also described some of the main problems.

Concerning PV, the financial aid from both federal and state level has helped the technology to really kick off. Especially on a residential level. After the close investigation within the creation of this thesis, it can be stated that the further increase of distributed PV pretty much depends on the further development of storage technologies and also the costs of battery energy storage systems. Challenges in PV that remain slightly are the interconnection problem and the ability of Hawaii electricity utilities to adapt their business model and also customer services to distributed PV and design the fitting capacity for utility-scale PV.

Looking at wind energy in Hawaii, there is to say that the great initial enthusiasm of RET planners concerning this technology has been massively diminished by the reality check of communities' opposition. After the project Big Wind endangered the whole project of increasing the RPS statewide as a whole, policy makers and utilities see themselves in the difficult position to find other options and solutions. Although there is enough abundant wind energy it will probably be unlikely for Hawaii to harvest this energy. Off-shore wind farms as planned at state are very unlikely to be realized as the U.S. Navy is a pretty strong opponent standing in the way of the planned projects. Seen on the Island of Kauai wind energy could be supplemented with different RET. The fact if really 100 % RPS and total energy independence can be reached without further extending the share of wind energy remains questionable. There is no answer yet to where and how Hawaii wants to build new windfarms.

Increasing energy efficiency holds the biggest hope at the moment. Being a relatively cheap measure and easy to implement there are great expectancies of Hawaii's experts in DR measures on both utility and consumer side. This measure is also one, that can be combined with attracting innovative ideas to the islands and testing new technologies in an uncomplicated way. The importance of aggressively increasing energy efficiency shall not be underestimated as also energy demand will most likely increase dramatically looking at the extended use of technologies in our everyday life.

Looking at chapter 4, which describes and concludes the most important overall strengths, weaknesses, opportunities and threats of Hawaii the author other of this thesis sees the biggest need in developing one overall strategy in addition with driving education programs and raising awareness on a much larger extent than it is happening right now. The research community is advised to prepare their data in an understandable way and make it more accessible for the whole community. Following the author's opinion and after this detailed investigation, the community living in Hawaii in general is a community characterized by a higher extent of sensibility towards environmental issues. As the Nene Goose case shows, people of Hawaii are available to fight for protecting their land, they just need to be triggered in a more efficient way. This would increase social acceptance and give the whole energy transition a whole new level of support.

Consequently, the thesis describes an exciting journey to energy independence, tackled by one of the most remote places in the world. There are many questions that remain unanswered and riddles that still need to be solved. The State of Hawaii is on a great track and could already impress the international community with their set actions. It is important that the enthusiasm of the successful kick-off to the journey remains upheld as there is still a lot to be done in order to really reach their goal of RPS 100 % until 2045.

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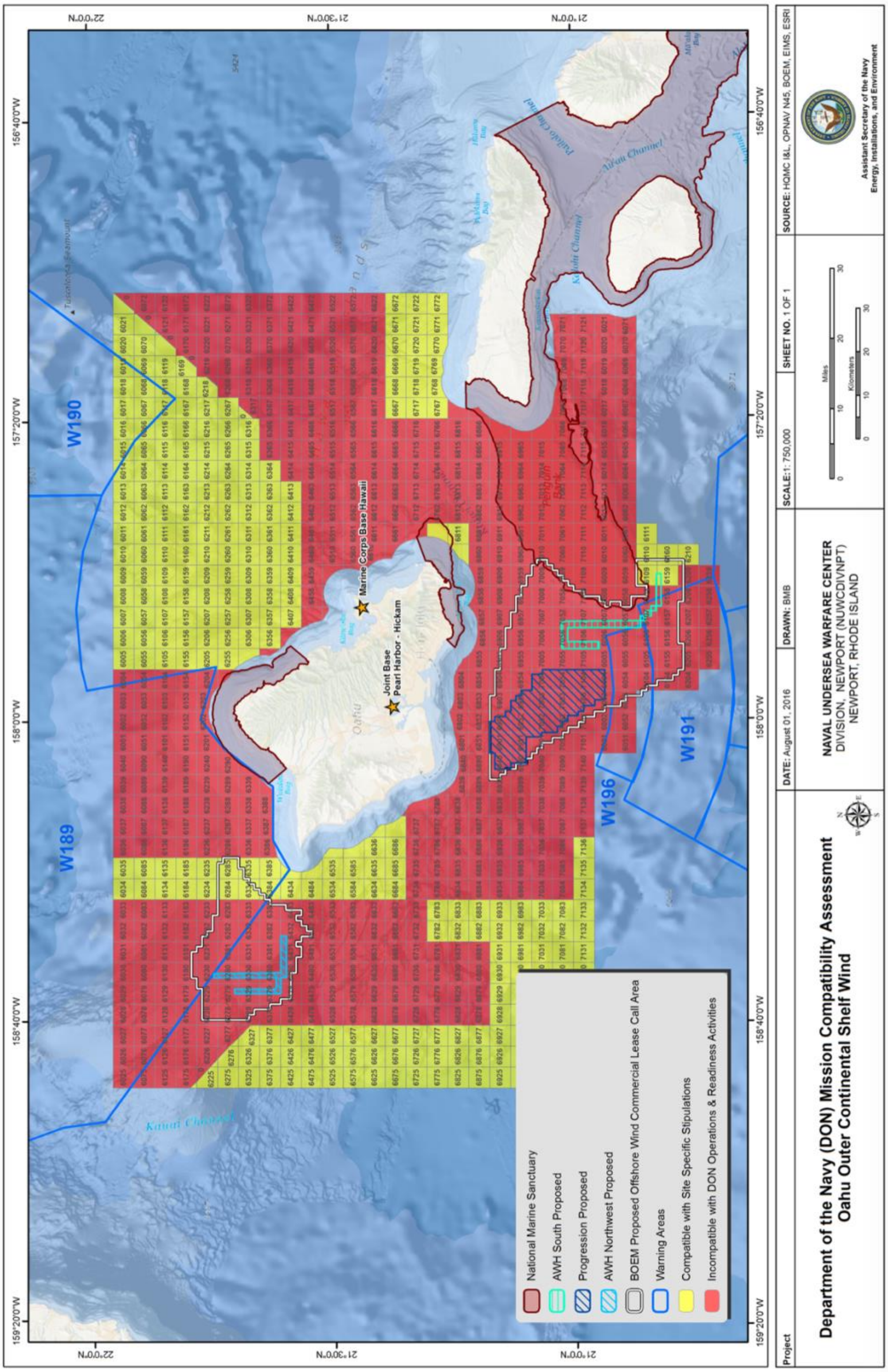
Tables

Figures

Appendices

I. Appendix Map compatibility Oahu Outer Continental Shelf Wind



II. Appendix Summary of relevant Interviews during field trip

1. Interview with Kevin Davis, Hawai‘i Natural Energy Institute, University of Hawai‘i at Mānoa
2. Interview with Mark B. Glick, Hawai‘i Natural Energy Institute, University of Hawai‘i at Mānoa
3. Interview with John Cole, Hawai‘i Natural Energy Institute, University of Hawai‘i at Mānoa
4. Interview with Jeff Mikulina, Executive Director of the Blue Planet Foundation and David Aquino, Creative Director of the Blue Planet Foundation

Note from the Author:

During my field trip to Oahu I conducted 4. Interviews with the people mentioned above. I could gain relevant insights and expertise from both technical and economical perspective. The Experts from the energy sector in Hawaii could help me with the selection of relevant cases, described within this thesis and helped not only during the interview but also throughout the whole creation process of this thesis. They mentioned the particular importance of the main drivers and could help me identify the most important challenges.