100% Renewable Energy Transition In Small Island Developing States (SIDS)

Quick Scan Backcasting for 2 islands in the Caribbean - Curacao and Grenada

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Master of Science Thesis (MSc.) about

100% Renewable Energy Transition in Small Island Developing States (SIDS)

A Quick Scan Backcast for 2 islands in the Caribbean – Curacao and Grenada

By

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In

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Executive Summary

There is growing consensus around the world for the need to transition to a more sustainable society. This is transition is currently being led by making the energy sector more sustainable by shifting to renewable energy sources from fossil fuel sources at a steady pace. However, there seems to be increasing recognition that the steady pace may not be fast enough. Therefore, there are many cities, countries, organizations that are coming out in support of a 100% renewable energy transition. There is sufficient attention given to this the endeavour of transitioning in developed nations and major developing nations. However, Small Island Developing States (SIDS) have historically lagged behind in proceeding with this transition even though they are arguably going to be the most severely affected by the inaction. Majority of SIDS energy comes from imported oil products. As we speak there are islands disappearing because of sea level rise. That said islands present an interesting geographical scope to analyse for an energy transition because of their unique challenges. These challenges stem from their isolated location and small size; which leads to high energy prices, lack of economy of scale and this is worsened by their potential vulnerability to environmental catastrophes. In recent years, however, there has been more attention given to SIDS and their issues. This is marked by Fiji being the President of COP23, and the COP23 paying special attention to SIDS. Following this recent surge in attention, many islands have set ambitious targets to pursue for the transition yet their execution has been bleak. It is astonishing that even though islands have the most renewable energy potential they have made limited progress, literature very widely states that the lack of economy of scale, technical knowledge and expertise, political will and lack of human capacity are leading causes and all of this leads to a larger risk perception leading to lack of investments. However the literature on islands transitioning is concentrated on either on a combination of technological, economical or societal issues and is geographically concentrated on the Pacific and Mediterranean islands.

Therefore, to overcome the aforementioned research gap, this research investigates a more holistic approach to a 100% renewable energy transition (electricity sector and transport sector, the other uses of oil products on the islands have not been discussed predominantly because of the lack of data on them) for the islands of Grenada and Curacao in the Caribbean. This is studied by creating a potential quick scan methodology to create transition pathways utilizing the Backcasting approach to this. Backcasting has the potential to aid in breaking forecasting trends and patterns that may be a hindrance to the required rate of transition. Therefore, adapting the generic Quist framework of Backcasting by combining it with Robinson's approach and various research methods like PESTEL, EPM, and incorporating energy sizing models to create consistent normative scenarios establishes a robust theoretical framework to help strategies for transition in these islands. The objective of this thesis is to figure out how islands can transition a 100% by providing implementable actions and strategies. The vision of this research was to have 100% EVs in the transport sector and the entire electricity sector is powered by 100% renewable energy.

To achieve this objective, 4 steps were undertaken for each of the two islands of Curacao and Grenada. The first step involved completely mapping the energy scenario and the factors and actors influencing the energy sector for the islands. This also involved calculating the potential for all probably renewable energy sources on the islands and figuring out the cost of the these technologies. As expected and mentioned by literature the energy system was over 90% dependent on imported fossil fuels, the system was largely inefficient, historically monopolistic market structure and the main actors were the government and the energy companies. No substantial power given to the users. In terms of potential, Solar and Wind were found to have the most potential in mature technologies. Geothermal in Grenada and OTEC in Curacao also stood out for their immense

potential. Further, efficiency gains were calculated and immense potential to reduce energy consumption was identified especially in the household and transport sectors.

Because of the interesting resource potential of Variable Renewable Energy Sources and at least one base load renewable energy source in each island, two plausible technically consistent scenarios were created. The first scenario used only Solar, Wind and Batteries for powering the future electricity demand while the 2nd scenario incorporated OTEC for Curacao and Geothermal for Grenada. Another difference between the 1st and 2nd scenarios is that the first scenario does not incorporate efficiency gains, while the 2nd scenario incorporates aggressive efficiency gains. The sizing of the system for both the scenarios done by existing cost-optimal energy models showed that in the first scenario with only variable RE the required installed capacity is tremendously large. There is a need for a lot of overcapacity and battery plays a limited role. While in the second scenario because of the inclusion of baseload technology the required installed capacity reduces. It was also realized that irrespective of the scenarios pursued for transition, this transition will cost less than sticking with fossil fuels and further it will also create more employment on the island. Finally, an LCOS calculation was established and determined that the system will be cheaper than today's cost of electricity. The only down side to the 1st scenario is the large land requirement. But this is assuming all wind and solar remain on land over the years until 2040.

The required technical, societal and structural changes for the implementation for the determined scenarios where described. This identified the need to the implementation of renewable energy systems at a little ambitious rate of growth, the electrification of the road transportation sector will be the toughest sector to tackle, upgrades on the energy infrastructure, a requirement to introduce strong standards and codes for equipment and buildings to meet efficiency requirements, the implementation of capital subsidies to reduce the need for large investment costs, the establishment of technology-specific feed-in-tariffs, the increase in energy related research and education through collaboration, establishment of training programs to increase human capacity on islands, achieving long-term social and institutional commitment, reducing red tape by reforming administrative processes, and the creation of a coordinating institution for the energy transition have all been identified as common measures leading to the realization of the objective.

Specific changes for Curacao had to do with the requirement of grants and loans guarantees to help with OTEC and SWAC penetration and utilizing the advantage of being a part of the EU and the Netherlands for any and all purposes. Also, the need for potentially establishing a research fund used for funding demonstration plants. While in Grenada there was a specific need for higher collaborative work because of their low credit rating and also the need for establishing a separate transition policy for the rural population. This is not to mention that Grenada lies in the Hurriance Belt which complicates the situation even further. There needs to be specific attention given to understanding where the society stands with regards to this transition and finding innovative ways to involve them in decision making. Further, there needs to be a serious study performed for the potential of SWAC and Geothermal based cooling systems in Curacao and Grenada respectively.

In conclusion, the energy supply side seems to be technically and economically feasible. And an interesting hypothesis of the first scenario is that there may not necessarily be an economy of scale issue. The benefits obviously are not going to be as big as in larger market but there definitely doesn't seem like there is no economy of scale as suggested by earlier research. Electrification of the road transport sector is going to be tough, there needs to be a specific study performed for that and also a very aggressive capital and revenue subsidy scheme will be required. Most importantly, a regional commitment for the same could be more beneficial. In terms of efficiencies, the first step is to create codes and standards and take it from there apart from studying the feasibility of SWAC and Geothermal Cooling systems. But none of this matters if there isn't a strong political and societal commitment to this transition. There needs to be an understanding of how to reduce the risk perception which will help with access of capital and reducing the cost of capital and an understanding of what is hindering private energy companies from coming into the sector (this is more pertinent for Grenada than Curacao). All of this leads to creation of the E3R strategy to transition. This means you establish the required institutions, the required networks and using that the required base policies and roadmaps to assuage investors, after which you start educating the public and even the government (depending on the pathway chosen) on this transition, perform the required technical research for the future. And finally, in the expand part the government should essentially see a large expansion of renewable energy deployment and to make sure this realized there is a need for an annual review mechanism.

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Acknowledgement

I would also like I present to you my master thesis report. I have been working on my research project based on the implementation of renewable energies in Island states by using backcasting. This report represents the research work, presenting the used methods and previous work and the obtained conclusions.

I would like to start by thanking with all my sincerity Dr. Jaco Quist. It has been a long and hard 3 years with me and I am not entirely certain how he managed me. If not for his guidance and patience I would have never reached this milestone in my life. This period in my life has very vividly shown to me my short comings and the fact that Jaco handled everything with such professionalism was absolutely fantastic.

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1. Introduction

Since the 1870's it is estimated that sea level has risen by 8 inches (Solomon et al., 2007). Recent research suggests that this has led to 5 islands in the Pacific to disappear and another 6 islands facing serious recession of shorelines and in two out of those other 6 islands villagers have been relocated (Simon et al., 2016). The perils of climate change and the need for the sustainability have taken centre stage in the 21st century. The Paris Climate Change Agreement that entered into force on 5th October, 2016 was a pivotal moment (UNFCCC, 2017) for this. This signifies the importance of a more environmental friendly, largely decarbonized society. To realize such a society the enter sector needs to be seriously studied and fundamentally changed. One way to do this is by introducing more renewable energy into the energy mix of a country. There are mainly three reasons to concentrate on the energy sector:

1. he energy sector has direct correlation with helping alleviate poverty, and making people healthier (World Bank, 2005; Wynia, 2016). This creates the need for a secure and reliable energy sector.

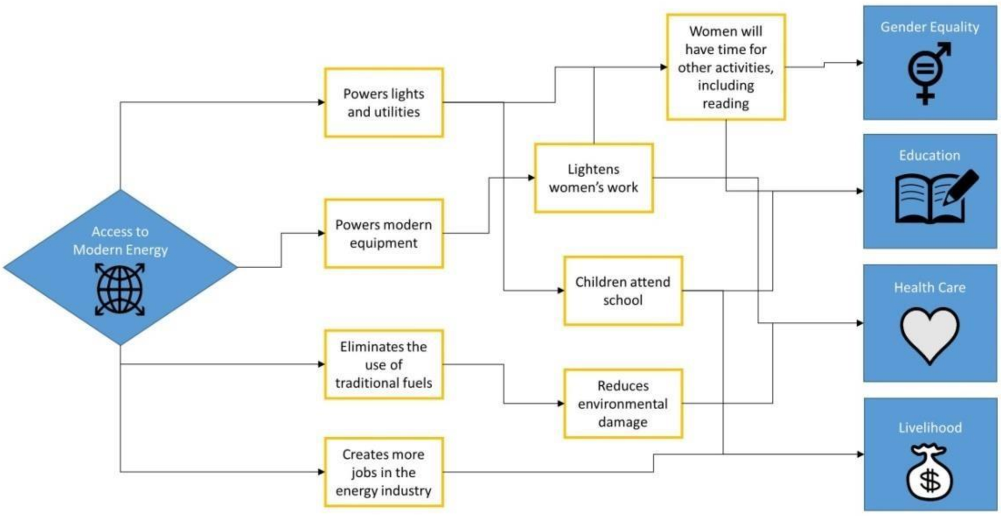


Figure 1. Benefits of Access to Energy, modified combining (World Bank, 2005; Wynia, 2016)

2. The energy sector is responsible for 41% of CO_2 emissions in the world (World Bank, 2014).
3. Technological progress - Renewable energy is the future (White House - USA, 2015).

This establishes the need to change the sector from fossil fuels to renewable energy.

Correspondingly, the remaining chapter focusses on presenting a brief overview of the research scope and background. It begins with presenting an overview of the geographical scope of the research, explaining why Small Island Developing States (SIDS) and providing some relevant background information on them.

1.1. Small Island Developing States (SIDS)

In the major developing and developed economies there is sufficient attention, presently, given to access to secure, reliable and affordable renewable energy (Jaramillo-Nieves and Del Río, 2010). However, this is not true for SIDS, which are, arguably, the most vulnerable to the global trends of population increase, rise in food, water, energy prices, and creation of fragile ecosystems due to the ill effects of climate change (Carbon War Room, 2013). They rely terribly on fossil fuel imports for their energy needs and therefore are exposed to global price fluctuations that affect them severely. SIDS are trying to balance the need for economic growth, and the impacts of climate change and fluctuations in energy prices. This is primarily because of their geographical location. Due to this they face isolation, remoteness, poor connectivity, generally underdeveloped technological sectors (Daniel Arens, 2013). Therefore, a transition to Renewable Energy Technologies (RETs) will greatly help in utilizing local natural resources to power their energy sector. Therefore incentivize the local economy by creating jobs, technology sectors.

There are more than 50,000 islands on the Earth that constitute around 750 million people (Kuang et al., 2016). But, in this research the concertation is on a specific group of islands which are considered under the umbrella term of Small Islands Developing States (SIDS). The name was officially recognized by the UN in 1994 before which in the 1970s and 1980s the UN recognized a group Island Developing Countries. While there have been many attempts to define SIDS in terms of level of development, geographical factors, and based on size, it has all been in vein. So, there was an attempt to describe certain characteristics of the SIDS and categorize them based on a Vulnerability index. Two organizations came up with their own respective Vulnerability index namely referred to as Commonwealth Vulnerability Index (CVI) created by the Commonwealth Secretariat and the other was the Economic Vulnerability Index (EVI) created by the Committee of Development Policy of the United Nations (UN). Both these indices use their own methodology but come up with broadly similar outcomes. However, the concept of vulnerability and these indices are not without scepticism. But, it has been largely agreed that these can prove as acceptable indicators for the countries (Prochazka, 2012).

It is sufficed to say that "SIDS are distinct group of developing countries facing special social, economic, and environmental vulnerabilities" (UN-OHRLLS, 2011). The UN Department of Economic and Social Affairs and the Office of the High Representative for the Least Developed Countries, Landlocked Developing Countries and Small Island Developing States (UN-OHRLLS) maintain that there are currently 52 countries that are on the list of SIDS. They are split into 3 geographical regions the Caribbean, the Pacific, and the Atlantic, Indian Ocean, Mediterranean and South China Sea (AIMS). Out of the 52, 38 are UN members while 14 are not.

UN Members: 38 countries – Antigua and Barbuda, Bahamas, Bahrain, Barbados, Belize, Cape Verde, Comoros, Cuba, Dominica, Dominican Republic, Fiji, Grenada, Guinea-Bissau, Guyana, Haiti, Jamaica, Kiribati, Maldives, Marshall Islands, Federated States of Micronesia, Mauritius, Nauru, Palau, Papua New Guinea, Samoa, São Tomé and Príncipe, Singapore, St. Kitts and Nevis, St. Lucia, St. Vincent and the Grenadines, Seychelles, Solomon Islands, Suriname, Timor-Leste, Tonga, Trinidad and Tobago, Tuvalu, and Vanuatu.

Non-UN Members/Associate Members of the Regional Commissions: 14 countries – American Samoa, Anguilla, Aruba, British Virgin Islands, Commonwealth of Northern Marianas, Cook Islands, French Polynesia, Guam, Montserrat, Netherlands Antilles, New Caledonia, Niue, Puerto Rico, and U.S. Virgin Islands (UN-OHRLLS, 2011).

It is worth noting that all lists have different countries and not all are just islands. However, in this research strictly speaking islands will be used as one parameter to narrow the scope.

1.2. Common Characteristics and Problems of SIDS

The common characteristics are as follows:

1. Geographical isolation is a prime characteristic. They are not close to or easily connected to the main land (IRENA, 2012; UNCTAD, 2014)
2. Populations for the islands are low. From the 52 SIDS recognized, 40 of them have populations lower than 750,000. (Prochazka, 2012)
3. They have limited resources and a small market to cater to (FED, 1998).
4. They are physically small in size (FED, 1998; IRENA, 2012)

As a consequence of that they face several issues in every sector. If we look at the energy sector specifically then we can say the following:

1. Lack grid connection to the mainland
2. Major reliance on imported fuels
3. Small scale generation of electricity, they cannot reap the benefits of economies of scale
4. Distribution costs are very high and remote areas do not have access to electricity/energy
5. Susceptible to global fluctuation of oil prices and high fixed cost of energy (Prochazka, 2012)
6. Security of energy supply is questionable because sometimes there is no feasible way of connecting the island to the mainland (Duić and da Graça Carvalho, 2004; Jaramillo-Nieves and Del Río, 2010)

This is not a complete list of all the issues that they face. There are other issues as well related to lack of a high tech sector or a lack of knowledge and skills which are all common to SIDS and are all inter-related to the development and progress of the energy sector (Jensen, 2000; Prochazka, 2012; UN-OHRLLS, 2011). However, the main paradox here is that even though SIDS have immense renewable energy potential, there has been limited stride towards implementing them and they still rely on petroleum based fuels for the energy (Weisser, 2004a). On this note, the next section states the knowledge gap that this thesis is going to cover.

1.3. Knowledge Gap

While the broad similarities have been well documented, the situation changes drastically as you narrow the spatial scope, that is to say that the same transition pathways that are implemented in the islands located in the Mediterranean Sea may not work for islands located in the Caribbean. This could be because of various reasons ranging from the fact that the access to energy is different in different regions, the amount spent on fuel as a percentage of GDP is different, the growth rate of energy in the regions are different. Because of this it is always interesting to perform research on a specific region/island. However, there is only limited research available for islands in the Caribbean and predominant research is available for islands in the Mediterranean (Jaramillo-Nieves and Del Río, 2010). This could be attributed to there being more data available for islands located in the Mediterranean by virtue of being part of the EU. However, in recent years after the multiple international organizations from Carbon War Room (CWR), Rocky Mountain Institute (RMI), International Renewable Energy Agency (IRENA), International Energy Agency (IEA), the United Nations (UN) and regional collaborative organizations like Caribbean Community (CARICOM) have started seriously researching the Caribbean also, so availability of data is improving.

Unfortunately, energy transitions have no consensus with regards to their visions, goals, and pathways. Rittel and Webber (1973) call such an issue a “wicked problem”. In wicked problems there is neither agreement on the goal of the policy, and the norms and values at stake, nor on the knowledge that is needed to solve the problem. For example: looking at the transition only from the technological stand point. Or there are also times when there is a disagreement on which technologies should contribute to the transition. While transitions in islands has received attention from the academic research community which have covered issues such as policy for the adoption of RET (Weisser, 2004a, b); energy supply (Bağcı, 2009; Duić et al., 2008; Singal et al., 2007; Zsigraiová et al., 2009); Techno-economic feasibility of RETs (Bueno and Carta, 2006); (Miranda and Hale, 2005; Oikonomou et al., 2009; Zafirakis and Kaldellis, 2009). None of them seem to have performed a comprehensive research considering technological, structural, and societal changes that need to be made for an energy transition to take place. This is very clearly stated by Jaramillo-Nieves and Del Río (2010):

1. The public is left out of the research a lot of the times. The societal impact is sparingly studied.
2. A lack of broad based assessment of the impact of Renewable Energy Technologies (RETs) can have on Sustainable Development of islands is missing.
3. There has been a good amount of concentration on how innovations can be developed and techno-economic analysis.

This is not to say that things haven't improved in recent years, as mentioned above thanks to the attention given by various international organizations, which has also improved the volume of academic research performed on islands. However, similar problems persist where the concentration of research is mainly on EU related islands.

Therefore, the knowledge gap that this research will fill is the following:

1. Will look into the Caribbean SIDS and clearly map their current situation and provide holistic pathways to desirable scenarios for them (100% energy transition). These will look into how each element of the energy system is linked and create pathways based on that.
2. It will look into the societal impact of renewable energy in the Caribbean and the role society can play
3. Will use literature from Future Studies and Transition Pathways to create a framework and analysis the situation.

Based on this the next section will state the research objective, deliverables and problem statement.

1.4. Problem Statement, Research Objective and Deliverable

The problem statement stems from the aforementioned information wherein small island developing states like countries in the Caribbean are the most vulnerable to the adverse effects of climate change and require doing the most to create a climate change resilient economy, which starts with creating a renewable energy based energy system. However, while the potential of renewable energies is immense in these regions, they are underutilized and further; the Caribbean region is under studied.

Therefore, the objective of this study is to be able to recommend implementable actions based on analysis of drivers and barriers for the region that can be taken by the various governments.

The deliverables of the research will be:

1. A thorough mapping of the current energy scenario of the Caribbean islands.
2. Creation of various pathways to reach those desirable scenarios.

1.5. Research Approach

This section extends from section 1.4. to state how the research objective and deliverable will be met.

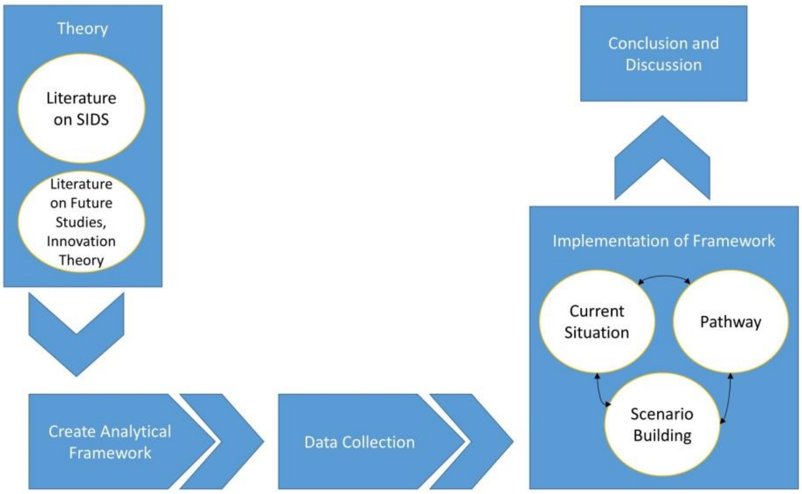


Figure 2. Research Approach

1. **Theory:** There is literature review initially conducted which gives us two important pieces of information. (1) The scope of the research and (2) the academic theories that can be used to perform the required research
2. **Creation of Analytical Framework:** This leads to creation of analytical framework that will be implemented to perform the research and helps narrow the geographical scope.
3. **Data Collection:** The data collection will be performed during the implementation of the framework, more like the first step of the framework where we discuss the current scenario
4. **Implementation of the Framework:** It consists of the mapping of the current situation using an energy balance, stakeholder analysis, and PESTEL, following which a future vision and different scenarios to meet the vision are delineated on, then the technological, societal and structural changes are mentioned, following which a pathway for each scenario is created
5. **Conclusion and Discussion:** The Discussions take place in the cross-case analysis section wherein the derived results will be compared to literature and within themselves. Then short conclusions will be presented, with a reflection on the used theoretical framework.

1.6. Societal Relevance

This will be useful to the government and the society of the islands. They will be able to take the following from it:

1. The role the population of the islands can play to improve their energy situation
2. The role the government needs to play to make sure the population takes interest
3. The role the government needs to play to increase stakeholder interest in the transition
4. The government will have recommended pathways that it can use for referral
5. Other stakeholders will realize the potential and the environment for deployment of RETs

1.7. Research Questions

How can Curacao and Grenada islands of the Caribbean reach the goal of 100% renewable energy transition?

1. What is the current energy system of on the islands?
2. Who are the main actors involved in the current energy system?
3. What are the various factors affecting the energy system that influence the transition?
4. What are the energy potentials and costs of different renewable energy sources?
5. What does the future scenario for each island look like?

6. What are the required technological, structural, and societal changes for the transition?
7. What pathway(s) can be followed to implement the required changes?

1.8. Structure

1. **Chapter 2** discusses the main theories that will be relied on for the thesis. The section will discuss in detail about Backcasting, Energy Potential Mapping, PESTEL and the reason for its use in this research. The document will then move onto explaining different types of scenario building technique. Following which, it will briefly speak about how pathways can be created and how they should be complemented by a good follow-up agenda. The second part of this chapter deals in detail with SIDS in Caribbean and specially their energy sector.
2. **Chapter 3** will integrate chapter 1 and 2 in an attempt to create a detailed quick scan Backcasting methodological framework while establishing the connection to the research questions and methods. It will present a detailed outline for the entire thesis, therefore creating the analytical framework. But, before all that the chapter initially deals with the criteria used to select the two cases of Curacao and Grenada
3. **Chapter 4 and 5** starts with describing the 2 cases. It introduces the island by talking about standard parameters like economy, location, and population. Then it describes the energy system of the island supported by information on the stakeholders, the PESTEL factors affecting the system, the RETs potentials on the island, and comparison of cost of electricity with cost of the RETs. Then there are 2 future scenarios created for to reach the 100% RE vision; both these scenarios are predicated around the technical system. This is then followed by a detailed delineation of each scenario and how they can be achieved. This ends with presenting a transition timeline for each scenario.
4. **Chapter 6** performs a cross-case analysis where 2 things mainly happen. One is that the most important similarities and differences are delineated and discussed. Second, all this related to the literature to provide a more comprehensive discussion of the results of the case analysis.
5. **Chapter 7** concludes the work by presenting the answers to my research questions, providing recommendations for the government, companies and the people of the country and finally, reflecting on the process of conducting this research, the methodology adapted and future recommendations on how to improve the methodology.

2. Literature Review

There are going to be **4 main sections** within the literature review chapter. **Section 1** deals with, at a conceptual level, understanding the type of future this research will deal with, the required type of future study for it and the kind of scenario that embraces. This section concludes with explaining why Backcasting was chosen for this research. **Section 2** deals with literature for the various kinds of Backcasting, comparing them in terms of assumptions and intended usage. Finally provides a list of advantages and disadvantages of Backcasting. **Section 3** will deal with the literature relating to the various research methods that will be used for each step of the research. So, there will be discussion on PESTEL, on different Scenarios and the toolkit for Scenario Building, then transitions are spoken off succeeding with how to create transition pathways are mentioned. To end the methodological literature review we speak of the follow-up agenda. After this, in **Section 4**, the literature review moves into presenting a picture of the Caribbean Islands, specifically their energy sector.

2.1. Future Studies

It is hypothesized that modern day approaches and techniques that are used to conduct numerous future studies today originated back during World War II (WWII) as a military strategy exercise in the U.S., which quickly helped in making strategic decision making in companies (Coppel, 2011).

Future Studies distinguishes between three different kinds of futures, which is based on its expected outcome, namely likely future, possible future, and desirable future. These futures are then associated with Predictive Scenarios, Exploratory Scenarios, and Normative Scenarios. And this relationship helps us understand the functioning of different methods of future studies like forecasting, scenario analysis, transition management and backcasting. These are today probably the most frequently used methods for alternative futures.

Type of Future	Type of Future Study	Type of Scenario
Likely Futures	Forecasting, Scenarios	**Predictive**
Possible	Forecasting, Scenarios	**Predictive,**
Desirable	**Backcasting, Transition**	**Normative**

Table 1. Relating Different Kinds of Futures and Scenarios to particular Future Study Method (Broich, 2015; Quist, 2007, 2013; Roberts, 1969)

In Future Studies (FS), the concept of a 'Scenario' is quintessential and will be further delineated upon briefly now. A scenario can be both, a description or an image of potential future states or a description of any development. This is sometimes used interchangeably with visions in FS literature.

2.1.1. Predictive Scenarios

Predictive scenarios try to forecast what will happen in the future. They work on estimating likely futures and are projective by virtue of extrapolating trends and historical data (Quist, 2007). Another characteristic of predictions is that they can be self-fulfilling. Further, it can be said that forecasting methods rely on dominant trends which lead to results that are unlikely to break these trends (Dreborg, 1996). Also, the uncertainty of a specific set of conditions to exist over a long period of time makes predictive scenarios or likely futures so unreliable. Hence those predictive scenarios are most suited for well-defined and stable systems; such as the ones in the short term (Quist, 2007). Almost all forecasting methods concentrate on likely futures.

2.1.2. Explorative Scenarios

Explorative scenarios describe a number of plausible futures based on a variety of perspectives. Generally, a broad scope is attempted to get covered while indulging in the process of creating explorative scenarios. Most popularly, explorative scenario is used when there is a lack of knowledge of the future or even when there is lack of knowledge on the structure of how to create a scenario. They deal with creating many alternate paths for the future (Börjeson et al., 2006). They are constructed using an individual's knowledge and perspective to create the possible future scenarios. This can act as an obstruction by narrowing the scope of the possible future; and creating an obstacle in figuring out what is reasonable (Broich, 2015; Dreborg, 1996; Quist, 2007). This is one of the main drawbacks of explorative scenarios or possible futures or scenario design. Examples of exploratory scenarios are Shell (2008), International Energy Agency (IEA) in 2003 (Virdis, 2003).

2.1.3. Normative Scenarios

They create desirable futures which are attainable (Quist, 2007). This process of creating a desired future image and then working towards it is very useful in the field of sustainability and by extension for energy transitions. Therefore, there are two main approaches which can be used which are potentially not governed by the present. They are Transition Management and Backcasting.

Transition Management is a participatory learning and experimenting process used to solving complex societal problems by creating a societal movement that puts pressure on dominant policies (Quist, 2007). It is mainly based on Network Theory (Petrasova, 2010). However, Transition Management is said to have less methodological liberty than Backcasting (Quist, 2007). Therefore, this research uses Backcasting and the reason for this is provided in the next section.

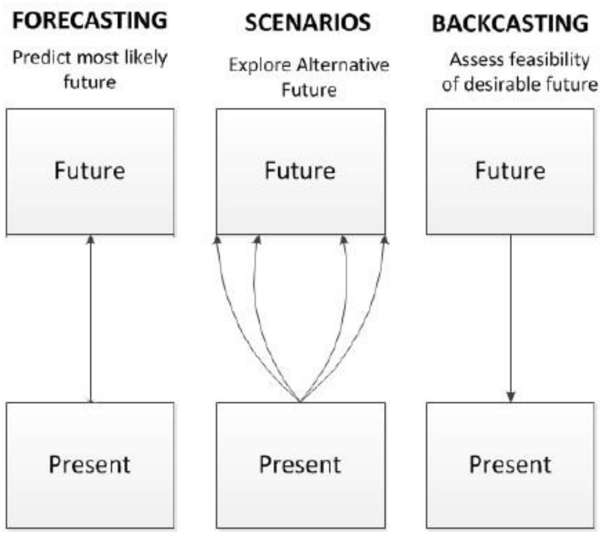


Figure 3. Comparison of Forecasting, Scenarios, and Backcasting(Broich, 2015)

2.1.4. Why Backcasting: A Conclusion to Future Studies

A summary of why Backcasting is chosen is presented by mentioning the drawbacks of all the other types of methods predominantly used in each scenario type: the fields of Forecasting, Scenario Development, and Transition Management.

1. Drawbacks with Forecasting
    a. Forecasts indicate most likely future
    b. Forecasts are predictive in nature
    c. Good energy forecasts converge towards the most likely future and predict the probability of it occurring
    d. The results of Forecasting are governed by the present
    e. Forecasts as mentioned by Quist (2007) and Dreborg (1996) are based on dominant trends, trend extrapolation and historical data. They are unreliable in situations that are long term where trends may not necessarily still existent.
2. Drawbacks with Scenario Development
    a. Scenarios on the other hand are based on one's own knowledge and perspective of the future, which can act as an obstacle, in itself.
    b. The alternate paths are also projected with the perspective of the present condition, as shown in figure 9.
3. Both Forecasting and Scenario Development have the potential to promulgate today's problems into the future.
4. Transition Management is said to have less methodological diversity (Quist, 2007).

Therefore, Backcasting is a very useful. It predominantly works with term goals the timeframe of around 50 years or longer. It is normative in nature and does not rely on dominant trends of the present. They deal with desirable futures and most importantly, a good backcast diverges and denotes the possible implications of a particular policy implementation. Simply put, the role of backcasting is to look into how a desirable future can be attained rather than look into what a likely future might be (Robinson, 1982). More on Backcasting have been discussed in the next section.

2.2. Backcasting

Backcasting is a future studies approach that examines the feasibility and impacts associated to the achievement of specific desired end-points (Dreborg, 1996). Also, Backcasting can be defined as "generating a desirable future, and then looking backwards from that future to the present in order to strategize and to plan how it could be achieved" (Vergragt and Quist, 2011).

2.2.1. History and Evolution of Backcasting

In response to the oil crises in the early 1970's and energy forecasting practices held in the 1970s and 1980s, Amrory Lovins in the USA in 1977 proposed a new method called 'Backwards-looking analysis'. This was an alternative planning method that also started looking into the demand side of energy and not only the supply. This led to Robinson (1982) converting this into a proper framework called 'energy backcasting' and therefore, also coined the term Backcasting. After this the field started developing and soft energy pathways towards alternative futures that emphasised decentralized renewable energy and energy conservation were proposed. These were compared to Business As Usual (BAUs) scenarios and concluded that if there were policy changes then the alternative soft energy paths would be feasible (Quist, 2007, 2013; Quist and Vergragt, 2006; Vergragt and Quist, 2011). Initially, it was angled more towards a government-oriented perspective (Quist, 2007). The assumption was that instead of dealing with uncertain trends and complex futures; the approach will be able to picture a (set) desirable future and then assess how to reach it (Anderson, 2001).

Then towards the end of the 1980s and in the 1990s two major shifts happened. One, the scope expanded by being applied for sustainability issues and not just energy. This originated from Robinson (1990) with his article "Future under Glass". Two, stakeholder participation was recognized as an important factor. This originated from the Netherlands. The idea was to create robust future scenarios by utilizing input of all relevant stakeholders. This led to the creation of multiple participatory frameworks like Robinson et al. (2011), Quist (2007) and Dreborg (1996), to name a few. This evolution has been recorded by Quist (2007, 2013; 2006) in his various publications. It is worth noting that all sustainability issues fall under the criteria described by Dreborg (1996) – complex issues, which require long time to solve, have externalities that cannot be solved by markets, and the following the present trends is a problem.

Over the last three decades Backcasting for sustainability has been applied in various topics. This has been well documented by Quist (2013). Utilizing the comparison done by Quist (2007) of 4 Backcasting approaches and the aforementioned information the following observation can be made; there is variety in the degree of stakeholder participation, in the number of steps the backcasting frameworks propose, the methods that are used for analysis, the time frame, the geographical scale of application, the number of visions developed and in many more areas (Vergragt and Quist, 2011).

2.3. Comparison between Backcasting Approaches

Based on the observation made by Vergragt and Quist (2011), it is important to understand how a certain selection of frameworks was made. The selection was based on key words search through SCOPUS and using 5 thesis/articles. The 5 thesis articles are Dr. Jaco Quist's PhD Dissertation (Quist, 2007), the 2 meta-analysis (Akintan, 2014; Saghafil et al., 2013) and 2 MSc. Thesis given by my supervisor Jaco Quist (Broich, 2015; Ricken, 2012) and the keywords used were Backcasting, Backcasting Energy, Backcasting meta-analysis, Backcasting Renewable Energy.

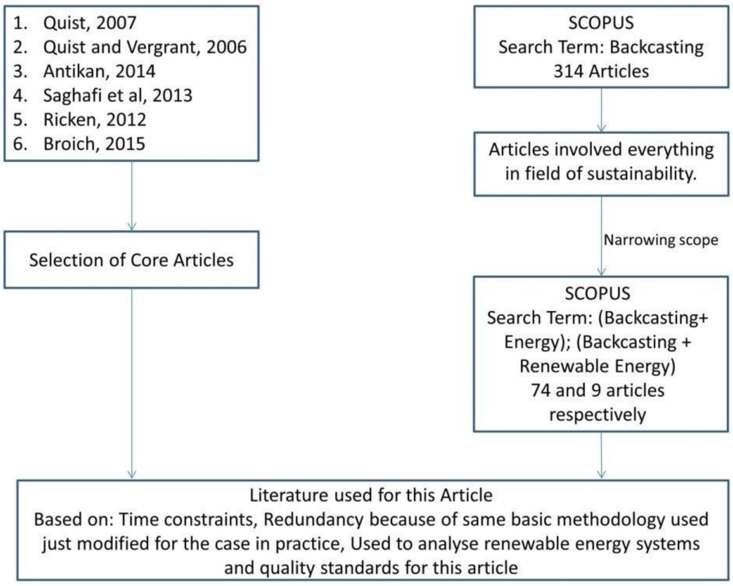


Figure 4. Overview of Backcasting Framework Selection Process

There is a potpourri of 6 frameworks discussed here in different levels of depth which use participatory methods, analyse sustainability issues, developed specifically for energy issues and on whether the paper described the Backcasting process well. The frameworks are; Robinson (1990), The Natural Step approach (Holmberg, 1998), Quist (2007), Anderson (2001), Saghafil et al. (2013), and Ng (2009).

2.3.1. The Natural Step Framework, 1998

The natural step methodology was described by Holmberg (1998). It operates through the rationale that guiding principles are required to act as a framework for possible futures therefore finding strategies to achieve envisioning scenarios. It was made to make companies more sustainable and while it lacks specific methods, it does mention stakeholder involvement, employee involvement and training, creativity techniques, and strategy development which may be highlighted as proposed methods (Coppel, 2011; Quist, 2007).

It is based on 4 non-overlapping sustainability principles which is a combination of ecological and social sustainability (Holmberg and Robèrt, 2000). Based on this 4 steps are proposed for the framework (Coppel, 2011; Holmberg, 1998; Holmberg and Robèrt, 2000; Quist, 2007):

1. Define criteria for sustainability, based on the four sustainability principles previously stated
2. Identify sustainability bottlenecks by describing and analysing current situation, present activities and competences, analyse the supply and consumption chains of the organization.
3. Creating future visions using creativity techniques and involving employees.
4. Find strategies to drive the organization to the future vision. Certain questions may be considered to establish strategies:
    a. “Will this measure bring us closer to sustainability and is our perspective broad enough socially and ecologically to determine this?” (Holmberg and Robèrt, 2000)
    b. “Is each measure a flexible platform for the next step towards sustainability?
    c. Will each measure pay off soon enough?
    d. Will the measures taken together help society making changes to achieve sustainability without too many loses during transition?” (Coppel, 2011)

2.3.2. Robinson's Backcasting, 1990

After Robinson (1982) provided a structure and backbone to Lovin's work, the methodological framework was still in its infancy, and it was in 1990 that Robinson culminated all his work for the past decade (almost) and proposed a more comprehensive structure. The framework mentioned by Robinson is design oriented in nature and explicitly normative in nature. In the words of Robinson himself, "In order to undertake a backcasting analysis, future goals and objectives need first to be defined, and then used to develop a future scenario. The scenario is then evaluated in terms of its physical, technological and socioeconomic feasibility and policy implications. Iteration of the scenario is usually required to resolve physical inconsistencies and to mitigate adverse economic, social and environmental impacts that are revealed in the course of the analysis".

It leads to policy recommendations and analysis as mentioned by Quist (2007). However, even this was not without its drawbacks as further mentioned by Quist (2007). He mentioned that this framework has no stakeholder participation. There is no mention of particular methods to do the analysis rather just mentioned broad groups. It further lacks clarification on who is supposed to carry out the goal setting, create the scenarios. Anderson (2001) goes a step further and mentions that because of the various exogeneous elements of the framework like social and environmental desirability, it falls into trouble of using too much of predictive data which goes against the whole idea of backcasting. However, in terms of methods it does mention some groups like scenario impact analysis, modelling, and scenario approaches. In conclusion, Robinson's method, while an excellent reference by virtue of being the 1st method; it is very government oriented.

Step 1: Determine objectives
(a) describe purpose of analysis
(b) determine temporal, spatial and substantive scope of analysis
(c) decide number and type of scenarios

Step 2: Specify goals, constraints and targets
(a) set goals, constraints and targets for scenario analysis
(b) set goals, constraints and targets for exogenous variables

Step 3: Describe present system
(a) outline physical consumption and production processes

Step 4: Specify exogenous variables
(a) develop description of exogenous variables
(b) specify external inputs to scenario analysis

Step 5: Undertake scenario analysis
(a) choose scenario generation approach
(b) analyse future consumption and production processes at the end-point and mid-points
(c) develop scenario(s)
(d) iterate as required to achieve internal consistency

Step 6: Undertake impact analysis
(a) consolidate scenario results
(b) analyse social, economic and environmental impacts
(c) compare results of step 6(a) and 6(b) with step 2
(d) iterate analysis (steps 2, 4 and 5) as required to ensure consistency between goals and results

Figure 5. Robinson's Backcasting Method, 1990

2.3.3. Quist's Backcasting Framework, 2007

This is a participatory approach to Backcasting, similar to the Natural Step Backcasting but this is not particularly made for companies, therefore broad stakeholder participation is required (Quist and Vergragt, 2006). This approach was created based on various different backcasting approaches as more of a generic framework.

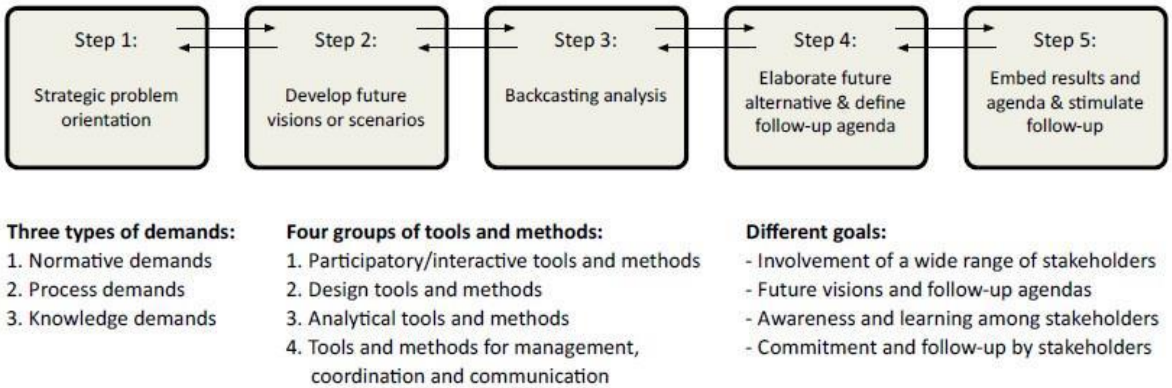


Figure 6. Quist's Backcasting Framework, 2007

As seen in Fig. 6, this approach consists of 5 steps. Step 1 is used to present the current situation to understand the shortcomings that could possibly be required to be addressed. This also entails performing an actor analysis to understand each stakeholder's interest in the work. Step 2 creates future visions or scenarios. Then the backcasting analysis can be performed, which describes the interventions required and the changes required to carry forward the interventions from the present state to future state. In the next step the results of the backcasting step will be elaborated on by means determining drivers and barriers for the required change and then creating transition pathways. The last step will involve creating a follow up agenda wherein the action plan for each stakeholder is illustrated. While the framework looks liner Quist has clearly stated that this is an iterative process. It can also be seen in Figure 5 that there is a list of 4 groups of tools and methods. This can be a useful to utilize while conducting the backcasting experiment. Each group of tools and methods are useful in specific steps of the framework. This has been elaborated more by Quist (2007) and Ricken (2012).

While there are could be possible disadvantages to this framework like not having a quantitative element and being overly qualitative as inferred by the goals of the backcast listed by Quist. That said, one of the biggest advantages of this simplistic framework is that is provides the option for Backcasting to be combined with other methodological frameworks to make it more robust, like done in Ricken (2012). Further, because of the flexibility it can also be used sufficiently when in situations where stakeholder participation is not possible, like in Broich (2015).

2.3.4. Saghafi et al Framework, 2013

Saghafi et al (2013) have a very similar end results as Quist (2007) the difference is Quist very specifically emphasises on the follow up agenda and the implementation. Saphafi et al do not emphasise on particular steps rather just lays out the reference model based on the meta-synthesis method. There is a detailed qualitative comparison performed to realize the most common elements of 11 different frameworks and formulate a singular reference model involving 6 steps. The drawback of this framework is that there isn't enough emphasis given on particular methods or even groups of methods and it lacks a proper critiquing of all the frameworks. It seems to just incorporate all the available knowledge. While not taking into the fact that for long term transitions sometimes also requires structural, and institutional changes.

2.3.5. Artie W. Ng's Framework, 2009

Ng (2009) was developed for the Chinese Renewable Energy Sector. So, it has been written from an emerging markets perspective. In that it is mentioned that the framework has derived heavily from Anderson (2001) and Robinson (1982), he further mentions that the control loop of the framework has been derived from Quist and Vergragt (2006). But, the most interesting factor here is that the fact that this iterative framework has an intermediate review step where the stakeholders review the milestones proposed and based on that the scenarios are altered. The author claims that this will enable policy makers to determine effectiveness and introduce policies required, example, infrastructure, in order to meet the next plausible targets. The drawback lies in the fact that this study uses backcasting as a tool to create the policy and looks very little into implementation of the policy and creation of a follow up agenda between the various stakeholders. It further lacks delineation on how each step can be operationalized in terms of methods.

	ROBINSON	ANDERSON	ARTIE W. NG	SAGHAFI ET AL	QUIST	THE NATURAL STEP (TNS)
KEY ASSUMPTIONS	Criteria for social, and environmental desirability are set externally to the analysis Goal-oriented Policy-oriented Design-oriented System oriented	Electricity Supply and Demand are internalized Social desirability is set externally Goal-oriented Government-Oriented Rejects the Market	Emerging Market Perspective Stakeholder Participation Policy Oriented Increase intermediate steps in the process	Stakeholder participation Stakeholder Learning People participation in Government Policy	Stakeholder participation Goal-oriented Stakeholder learning Achieving follow-up is relevant	Decreasing Resource Use Diminishing Emissions Safeguarding Biodiversity & Ecosystems Fair and efficient usage of resources in line with the equity principle
METHODOLOGY (STEPS)	(1) Determine objectives (2) Specify goals, constraints and targets & describe present system and specify exogenous variables (3) Describe present system and its material flows (4) Specify exogenous variables and inputs (5) Undertake scenario construction (6) Undertake scenario impact analysis	(1) Specify the strategic objectives. (2) Describe present generation and consumption. (3) Choose end-point year. (4) End-use analysis. (5) Supply analysis. (6) Policy development (7) Review Procedure	(1) Development of sustainable development goals and determining end-points. (2) Evaluation of constrains (3) Development of alternate forecast scenarios (4) Assessment of scenarios (5) Stakeholders and review endorsement (6) Detailed policy formation (7) Formulating performance measurement, intermediate goals and control metrics. (8) Realization of plausible stepping stones	(1) Orientation of Strategic Issues (2) Formation of future outlook (3) Describing the present system and determining influential factors (4) Drawing one or more images of the future (5) Analysis of Backcasting (6) Expansion, analysis, follow-up and necessary actions	(1) Strategic problem orientation (2) Develop future vision (3) Backcasting analysis (4) Elaborate future alternatives & define follow-up agenda (5) Embed results and agenda & stimulate follow-up	(1) Define a framework and criteria for sustainability (2) Describe the current situation in relation to that framework (3) Envisage a future sustainable situation (4) Find strategies for sustainability
EXAMPLES OF METHODS	Social impact analysis Economic impact analysis Environmental analysis Scenario construction methodologies System analysis & modelling Material flow analysis and modelling	System Analysis Technological Analysis Environmental Analysis Electricity Demand Analysis Electricity Auditing	Stakeholder analysis Stakeholder workshops Problem analysis Technology analysis Construction of future visions System design & analysis	Stakeholder analysis System analysis Backcasting analysis Stakeholder workshops Scenario construction Scenario evaluation Trend Analysis	Scenario Construction and Analysis Stakeholder Workshops Backcasting Analysis Process Design Communication and Management Methods	Creativity techniques Strategy development Employee involvement Employee training

Table 2. Overview of al Backcasting Frameworks reviewed in the Literature; modified from (Quist, 2007)

2.3.6. Anderson's Framework

Anderson (2001) on the other hand modifies the framework proposed by Robinson and removes a few of the drawbacks, and believes in a more circumspect view of the field and therefore involves environmental and social factors also. Anderson, proposes to make the electricity demand and supply sector an endogeneous element of the framework (in contrast to what Robinson (1990) proposed) and by extension the policy making process. The proposed methodology is more inclusive of different factors and leads to more flexibility and iteration of the proposed policies. The method depends on governmental intervention heavily. Though, a drawback of this method is that there is still a lack of stakeholder participation but also fails to mention the various tools that can used during the analysis. This process relies heavily on the government for operationalizing and implementation of the required actions. This is questionable because of the various pressures that the government has to go through because of the public, opposition parties and lobbyists. This framework while taking into account the changing governments, does not offer a solution to this problem and how this framework can minimalize this effect. It relies heavily on a top- down approach to drive change, and this belief in top-down approach is questionable.

2.3.7. Difference of Frameworks

The Robinson and Anderson framework do not recognize the requirement for participation of various stakeholders to be involved. There is also a difference in terms of which methods are used, where Robinson and Anderson are more quantitative, the other 4 more qualitative. There is difference in who can drive the required transition where Robinson, Anderson and Artie W. Ng believe in a government driven change, the others believe in change happening with each stakeholder. And because of the scope of the TNS method the change can only be brought about by the singular company.

Further, in terms of process structure one can see that the Anderson, Robinson, TNS and Artie frameworks do not have a specific Backcasting step and consider the entire process to be a Backcasting framework; Quist and Saghafi mention a particular step for Backcasting and looks at the entire process as something that aides the Backcasting step.

In general there is lack in mentioning of specific methods that can be used to undertake this process. There isn’t any explicit mention. Quist does make an effort to take about 4 groups of methods from which different techniques can be derived from, as can be seen in Table 2. This, in general, signifies a lack of methodological development in these frameworks. Further, while talking about participatory approaches as mentioned in Saghafi, TNS, Quist and Artie there is an intrinsic drawback wherein there is a need to reach consensus between different stakeholders and to have an objective process there needs to be engagement from a diverse group of stakeholders, which can prove challenging.

Finally, not all these frameworks recognize the need to analysis the follow up agenda properly, in terms of concrete steps. Anderson, Quist and Saghaffi do talk about a follow up requirement but Anderson and Saghafi fail to be more descriptive about this step, while Quist talks about it only to say that communication, and management methods should be used. Therefore, in the following sections of literature there will an attempt to fill the void of the methodological development of the Backcasting approach.

2.3.8. Advantages and Disadvantages of Backcasting

Advantages (Broich, 2015; Coppel, 2011; Dreborg, 1996; Quist, 2007):

1. It determines feasibility of desirable futures and helps create pathways to them.
2. Aides in breaking large dominant, undesirable trends
3. Very useful for complex issues, affecting various sectors and different levels of societies

4. Especially useful when the time horizon is so large that the level of uncertainty is very high
5. Encourages stakeholder learning; therefore there is a potential for a perspective change
6. Some Backcasting approaches are generic enough to be combined with other theories thereby increasing the robustness of the entire research

Disadvantages (Broich, 2015; Nodar, 2016; Quist, 2007):

1. Lack of methodological development leads to no clear guidelines on creating future visions
2. This can lead to improbable visions as it is sometimes based on expert opinion
3. The visions can arbitrary because of lack of information about the future
4. For quantitative models there is a lack of transparency as it is difficult to represent fundamental scenario features like values, lifestyles, structural and institutional changes
5. Lack of interest in determining the success of previous backcasts
6. No general sense of how to communicate just a vastly complex study
7. Lack of specific methods to operationalize the entire framework

2.4. PESTEL

PESTEL stands for Political, Economic, Social, Technological, Environmental and Legal; this analysis method is widely used in business to understand the macro environment that they are working in. In recent times, the results of these factors have been used in SWOT (Strength, Weakness, Opportunity and Threats) analysis.

It will be used in this research to give structure to the content when discussing the current energy system. Therefore, helping with operationalize the framework. So in this context, each term could be defined as the following (Nodar, 2016; Verma, 2011):

Political – The political factors that establish the extent to which the government may influence the energy industry. So, the indicators for this can be whether there is consensus within the different political parties regarding the policies for the energy industry, and whether there is political stability.

Economic – These are factors that directly or indirectly affect the energy industry. The indicators can be economic growth, interest rates, exchange rates, inflation rate, unemployment rate and many more.

Social – Indicators are cultural trends, environmental concerns of the public, usage of public transport, adopting energy efficient measures, age distribution, population growth rate, education level and many more.

Technology – R & D, maturity of technologies, potential of technologies, rate of technological innovation and diffusion, current sources of energy, current sources of consumption of energy, etc.

Environment - weather, climate, forests, dunes, lagoons, climate change, and many more. Basically, if any RE infrastructure needs to be implemented then it needs to take into consideration all of his.

Legal – These are laws, regulations, rules that are specifically made for the energy industry. Example: Feed in Tariffs for subsidising renewable energy.

2.5. Energy Potential Mapping (EPM)

Broersma et al. (2013) states, "… purpose of an EPM study is to provide a comprehensive overview of the characteristics of energy sources, sinks and infrastructures within an area." It is because of this overview that this provides that this will prove to be an excellent tool in this study to understand the technical limitations of the energy system in question. There is a formal methodology that has been proposed to achieve exergetic optimisation of the built environment based on Heat Maps (HM) and EPM.

Step 1: Determine all energy sources and sinks that are necessary for the study and divide them into smaller groups based on physical categorization and based on energy origin
Step 2: For each source apply limitations and determine actual possible potential. This will depend on limitations that are technical, social, economic, political, and geographical. Then represent all the energy sources in uniform units. This will get you the yield.
Step 3: Looking at the EPM Map starting from the left the actual demand is mentioned and the actual potentials are calculated and both of this meet at the centre where they can be connected using energy plans.

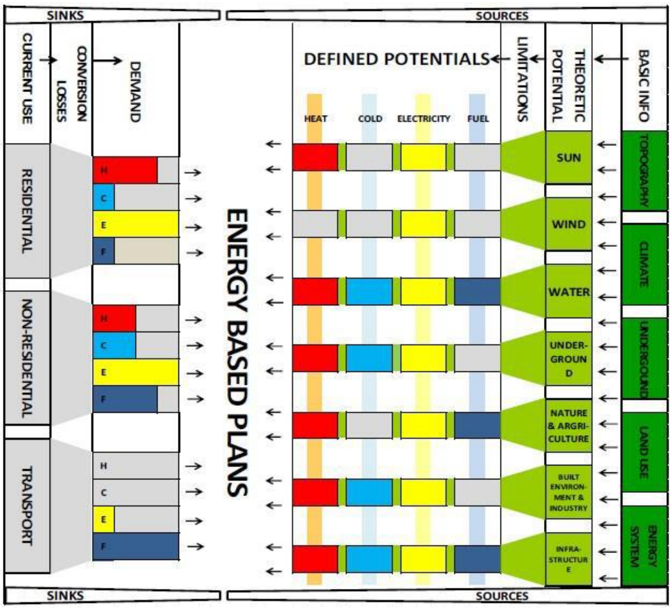


Figure 7. Scheme of the EPM Methology (Broersma et al., 2013)

2.6. Scenario Building

Scenarios generally help with creating long term futures, and understanding driving forces. It helps with handling uncertainty and also providing visualization with all the opportunities available. As mentioned in section 2.1 there are 3 different kinds of scenarios differentiated in the field of future studies: (1) Predictive Scenarios (what will happen?); (2) Explorative (What can happen?) and (3) Normative (What should happen?).

2.6.1. Characteristics of Scenarios

There are a number of definitions for scenarios but all can be summarized in these two definitions.

1. Stating that a scenario is just a description of a future that may be possible, desired, or likely
2. Stating that the scenarios also include pathways to development of such a future (Kosow and Gaßner, 2008)

For the purpose of this research, the 1st definition for scenarios is used. However, it should be noted that the pathways will be made but in the next section and not in this section.

Mahony (2014) when looking into proposed characteristics for scenarios, he mentions the characteristics stated by Alcamo (2001), and Institute for Prospective Technological Studies (2007). If these characteristics are all combined then the following list is developed:

1. They satisfy the objectives of the exercise
2. They are Plausible
3. They are consistent
4. They are different from one another
5. They challenge beliefs and conventional wisdom
6. They should be transparent and sufficiently documented

And while these are excellent characteristics to concentrate on, there are methodological limitations because, for example, there isn't always an easy way to access whether the scenarios are internally consistent. In general it is worth noting that there are three kinds of inconsistencies: *purely logical contradictions* (i.e. those based on the nature of the concepts involved); *empirical inconsistencies* (i.e. relationships judged to be highly improbable or implausible on empirical grounds), and *normative constraints* (e.g. relationships ruled out on e.g. ethical or political grounds) (Nodar, 2016) (Ritchey, 1998). Further, there remains a question regarding objectively verifying plausibility of a scenario which happens over the next 50 years.

Nonetheless, there are techniques to minimize the uncertainly, which depends on the topology of the scenarios and the objective of the scenario, where the scenario is going to be qualitative or quantitative.

2.6.2. Scenario Typologies

Over the years several categories of scenario typologies have been suggested to create a better overview of the field of future studies. The most basic overview is presented by Börjeson et al. (2006) wherein they compare 9 studies suggesting different scenario typologies and finally suggest the typologies presented in the figure below.

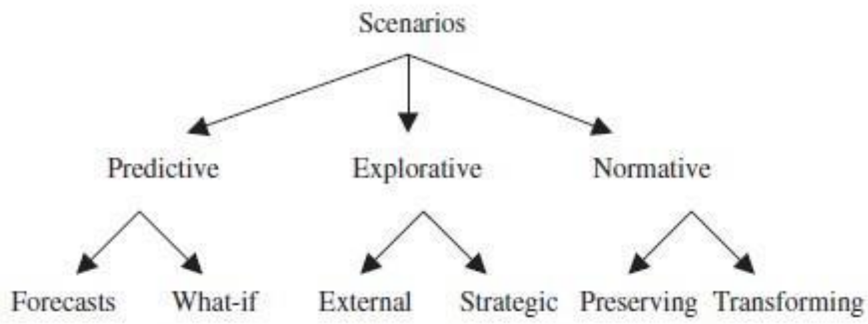


Figure 8. Scenario Typologies (Börjeson et al., 2006)

Since Backcasting deals with normative scenarios the two scenario typologies under this are discussed further.

1. **Preserving Typology**

This typology is invoked when the normative targets/goals that are decided on can be attained efficiently just by making small changes to the current system structure in function. However, this is not what this study will be looking into because this directly defeats the purpose of performing a Backcasting based on the purpose of using a Backcasting as stated by Dreborg (1996).

2. **Transforming Typology**

This typology is invoked when the normative targets and goals set are not attainable by making small changes to the current system, they rather require drastic changes and the current system is a hindrance to meet the set targets. The result of a Backcasting study is generally a number of images/scenarios fulfilling the targets of the future (Börjeson et al., 2006).

At this point, it is probably worth noting that based on the scenario typology different techniques can be used for scenario development.

2.6.3. Scenario Techniques

Each scenario is generally said to have 3 phases Generation of idea, Integration of different elements of the ideas and finally, checking if the scenario is consistent. The table below created by Börjeson et al. (2006) clearly illustrates the different techniques based on the phase and the type of scenario. These are just the most widely used techniques and not necessarily all the techniques.

Scenario types	Techniques		
	Generating	Integrating	Consistency
Predictive			
Forecasts	• Surveys • Workshops • Original Delphi method	• Time series analysis • Explanatory modelling • Optimising modeling	
What-if	• Surveys • Workshops • Delphi methods	• Explanatory modelling • Optimising modeling	
Explorative			
External	• Surveys • Workshops • Delphi modified	• Explanatory modelling • Optimising modeling	• Morphological field analysis • Cross impact
Strategic	• Surveys • Workshops • Delphi methods	• Explanatory modelling • Optimising modeling	• Morphological field analysis
Normative			
Preserving	• Surveys • Workshops	• Optimising modeling	• Morphological field analysis
Transforming	• Surveys • Workshops • Backcasting Delphi		• Morphological field analysis

Figure 9. Overview of Different Techniques used for Different Scenarios during Different Phases

The author emphasis the necessity for the use of the right generation technique for a Transforming Normative Scenario, because of the profound nature of the change required. Use of workshops and backcast Delphi methods are specifically dealt with.

However, this research is not participatory because of time and financial constraints and therefore will not use these techniques. In this research, a more simplistic understanding is utilized for creating an energy scenario. This research uses two already created energy system models by Gioutsos (2016) and van Velzen (2017) that size the energy system for a particular energy demand/consumption value, which is determined based on certain parameters. Everything else is assumed to be a consequence of the proposed futuristic energy system. By utilizing an already established model we minimize issues of consistency. By utilizing only energy demand to create a future energy system based on future cost estimates of various RETs, the scenario can still be transformational in typology.

2.7. Transition Pathways

This section deals with operationalizing transition pathways. In other words, giving a structure to how transition pathways can be described and discussed. However, before doing that there is need to understand how transitions take place.

2.7.1. Socio-Technical Transitions

Here the dynamic view of socio-technical transitions proposed by Geels, Multi-Level Perspective (MLP), will be used to explain how an energy transition from fossil fuels to renewable energy can take place.

The MLP distinguishes between 3 levels, the landscape (macro-) level, regimes (meso-) levels and niches (micro-) level. A simplistic way of thinking about transitions complements to this model is that, generally, interactions between the three levels will cause a transition. The dynamic visualization of such a process is clearly illustrated in Geels (2011). Basically, increased pressure on the regime causes destabilization of the regime and thereby opening a 'window of opportunity' which can be used by niches to transition.

Geels and Schot (2007) created 4 different generic transition pathways based on two transition pathway typologies. The two typologies were Time and Nature of interactions of the different levels. Based on this the 4 pathways described where:

1. *"Transformation path:* If there is moderate landscape pressure ('disruptive change') at a moment when niche-innovations have *not* yet been sufficiently developed, then regime actors will respond by *modifying the direction* of development paths and innovation activities.
2. *De-alignment and re-alignment path:* If landscape change is divergent, large and sudden ('avalanche change') then increasing regime problems may cause regime actors to lose faith. This leads to de-alignment and erosion of the regime. If niche-innovations are not sufficiently developed, then there is no clear substitute. This creates space for the emergence of multiple niche innovations that co-exist and compete for attention and resources. Eventually, one niche-innovation becomes dominant, forming the core for re-alignment of a new regime.
3. *Technological substitution:* If there is much landscape pressure ('specific shock', 'avalanche change', 'disruptive change') at a moment when niche innovations have developed sufficiently, the latter will break through and replace the existing regime.
4. *Reconfiguration pathway:* Symbiotic innovations, which developed in niches, are initially adopted in the regime to solve local problems. They subsequently trigger further adjustments in the basic architecture of the regime."

This section is described more in detail in the article by Geels and Schot (2007).

There are other similar pathways created by Foxon et al. (2010) for the UK electricity market. The general process is described in Fig. 10. The advantage of the Foxon path is that there is more detail on how to operationalize the transition path by stating the factors that should be considered while creating a pathway and these factors are taken into account while delineating using the PESTEL analysis in this research.

They came up with 3 pathways; market-driven, central government driven, society driven (Thousand Flowers path).

It should be noted though that no transition is ever going to strictly follow one of the 3 pathways mentioned by Foxon et al. (2010).

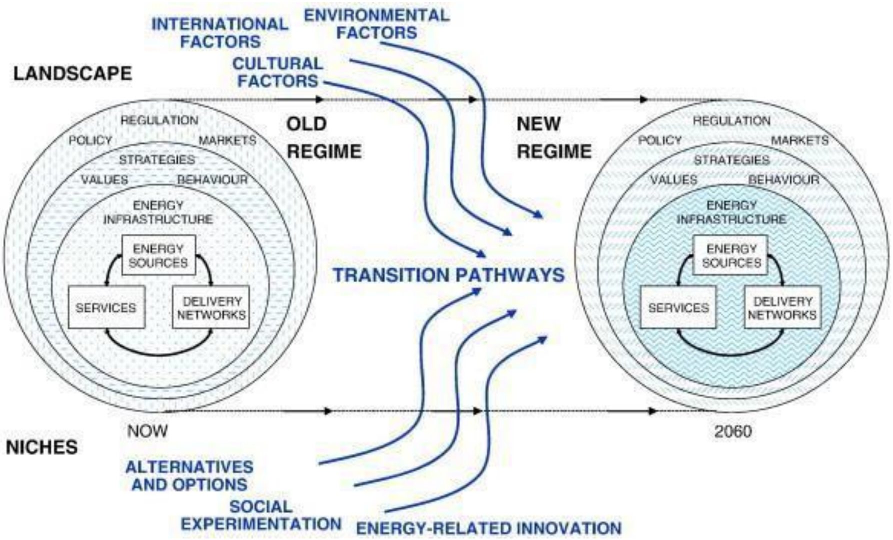


Figure 10. Transition Pathways and Factors that Influence them (Foxon et al., 2010)

Therefore, the following section deals with how to represent a transition pathway for this research.

2.7.2. Transition Pathways Structure

For this research there will be a simple structure followed; a structure that follows a what-who-how-when analysis. This is described by (Dixon, 2011).

1. What changes need to be made to the present system to reach the desired future system?
2. Who is responsible for the execution of these changes?
3. How will they execute these changes (activities)?
4. Why are these changes required?
5. And finally, by when do they have to implement these changes?

To make this more comprehensive and explicit this research will also have the section on why the mentioned changes are considered, this is generally an implicit assumption that the reasoning should always be mentioned.

2.8. Follow-up Agenda

There is serious lack in creation of legitimate follow-up agendas so that the outcome of the Backcasting can be collected and analysed. This was recognized by Quist (2007) and in the earlier sections when comparing Backcasting methods.

There needs to be balance between simplicity and being substantive. Based on IEA (2014), it can be determined that the follow-up agenda should at the very least by able to answer the following questions:

1. What will be responsible for monitoring the progress?
2. What new information will be required to adapt the scenarios?
3. Who should be involved in re-evaluating the pathways?
4. What policies need to be adjusted to meet the new pathways?
5. How often should a review process take place?

2.9. Caribbean Region

There are two main reasons why the Caribbean is interesting as a region for this analysis:

1. It has been researched the least (Jaramillo-Nieves and Del Río, 2010). One could assume that this is because of data availability being scarce.
2. It has the highest percentage of conventional thermal power production compared to all the other regions in the world (Daniel Arens, 2013).

So this section talks in detail about the Caribbean islands and gives an overview of their situation in terms of stating which islands are considered as Caribbean Islands, number of islands under each island country, economy, demographics, the political affiliations, renewable energy penetration and more.

2.9.1. List of Caribbean Islands

This region consists of around 7000 islands, islets, reefs and caves that are situated in the Caribbean Sea, or rather more specifically the Caribbean plate (Allcountries, 2007). Based on the perspective one chooses to look at the region from, there are different definitions of what constitutes a Caribbean nation. These are the few explanations and organizations that try define the scope of what the Island countries of the Caribbean region actually consist of:

1. From a physical/geographical perspective, the Caribbean islands, is the group of islands that fall within the region of the Gulf of Mexico, the Straits of Florida and the Northern Atlantic Ocean in the North, East and Northeast respectively; and by the continent of South Africa to the South (Allcountries, 2007; Wikipedia Contributors, 2016a).
2. From a political perspective, there are groupings within the Caribbean region based on socio-economic factors that can be considered. An example of this is the "Caribbean Community (CARICOM)", which is a group of 15 nations (island and inland nations) as members. They consist of Guyana, Suriname and Belize as members. Bermuda and the Turks and Caicos Islands which are in the Atlantic as associate members and Bahamas as another island country located in the Atlantic as full time members (Allcountries, 2007; CARICOM, 2016; Wikipedia Contributors, 2016a).
3. Another group like that is the Association of Caribbean States, which includes a far greater number of members including even El Salvador (Pacific Ocean) and the country of Mexico (ACS, 2016; Wikipedia Contributors, 2016a).
4. Finally, there is a list that very clearly distinguishes between islands in the Caribbean and inland countries and considering those inland countries as part of that specific country and not the Caribbean. The United Nations Geoscheme for the Americas considers the Caribbean as a unique group within the Americas (United Nations Statistics Division, 2013; Wikipedia Contributors, 2016a).

Therefore based on United Nations Statistics Division (2013), the following are the list of Caribbean islands considered for this research.

Caribbean Island Countries/Islands	Number of Islands
Anguilla	**21**
Antigua and Barbuda	**37**
Aruba	**4**
Bahamas	**700 (only 30 inhabited)**
Barbados	**2**
Bonaire, Sint Eustatius and Saba	**20**
British Virgin Islands	**43**
Cayman Islands	**3**
Cuba	**23**
Curaçao	**1**

Dominica	**7**
Dominican Republic	**2**
Grenada	**39 (only 3 inhabited)**
Guadeloupe	**38**
Haiti	**12**
Jamaica	**26**
Martinique	**50**
Montserrat	**4**
Puerto Rico	**142**
Saint-Barthélemy	**13**
Saint Kitts and Nevis	**20**
Saint Lucia	**17**
Saint Martin (French part)	**8**
Saint Vincent and the Grenadines	**39**
Sint Maarten (Dutch part)	**1**
Trinidad and Tobago	**21**
Turks and Caicos Islands	**40 (only 12 inhabited)**
United States Virgin Islands	**81**

Table 3. List of Caribbean Islands and Island Countries along with the Number of Islands under each Island Country (Nationsonline, 2016; Turk and Caicos Tourism, 2016; United Nations Statistics Division, 2013; Wikipedia Contributors, 2016b)

2.9.2. Overview of the Caribbean Islands

This overview will talk about economy, demographics, political affiliations and energy industry just to give you an indication of the diversity present in that one small region.

2.9.2.1. Economy

In the early 19th and 20th century the Caribbean Sugar industry was the primary industry. But, for the large part of the 20th century there was an economic slowdown caused by the European Sugar flooding the globalized market. Fortunately, in the 1990s this slowdown was overturned by the rise of the tourism industry. Further, the individual islands are slowly diversifying the export industry portfolio to bananas, eggplants and flowers. Recently, these islands have become hot spots for offshore banking, especially Aruba and Bahamas. That said all of these industries come second to the tourism industry. For example, in the US Virgin islands 70% of the GDP is Tourism based.

While it is difficult to paint the economic situation of almost 30 different island countries with the same brush, there is said to be at least 3 similarities to their economic condition:

1. **Trade Openness:** They have always been open to regional and international trade. This is because while the economies are so small that it is almost impossible for individual economies to have everything that their population needs. For example: Montserrat does great with construction industry however relies on Dominica for its fruits and vegetables.
2. **Limited Natural Resources:** While tourism and financial services play a vital role in earning foreign currency reserves, the other sectors also play an immeasurable role in filling coffers. This also not to mention that not all the islands rely heavily on tourism (example: Haiti). They make money by exporting goods and raw materials to international markets.
3. **Vulnerable to Natural Disasters:** Natural disasters have always proved to be an obstacle to economic progress for the islands. For example: between June and November is Hurricane season for a few countries; there is also a possibility of their being volcanic eruptions in certain islands. This could lead to loss of lives, capital and infrastructure. And most importantly, when there is a natural disaster to deal with then important funds which would

otherwise go to crucial social services like healthcare and education and provided for disaster relief (Example: Jamaica 2004, Hurricane Ivan). This can worsen the already poor education situation in many islands. This is further concerning with the increasing effects of climate change that these islands are poorly prepared for.

When the Caribbean Developmental Bank performed a review of the 2014 economic condition of the countries in the Caribbean, they said that in general there has been economic growth in most countries, tourism seems to be recovering, unemployment rates seem to decreasing, the private sector is helping with the rejuvenation of the construction sector in most islands, the manufacturing sector was a mixed bag with their being growth in most countries while a few still showing declining growth in that sector. Overall, the Caribbean Developmental Bank estimated that there was a 1.3% real GDP growth in the sector.

And all of this is good news in terms of the energy sector because if the islands are doing better economically then they will be more willing to act on their energy sector to improve its conditions. Also, not to mention that there is correlation between economic growth and more energy usage and therefore, a requirement for a more robust energy infrastructure.

Country	Population (2014)	Total Land Area	Urban Population Share (2014)	GDP (2015)	GDP Per Capita (2015)	Major Industries
		square kilometers	percent	billion USD, PPP	USD, PPP	
Antigua and Barbuda	91,295	443	24	2.1	22,966	Tourism, construction, light manufacturing
The Bahamas	321,834	13,380	83	9.3	25,577	Tourism, banking, cement, oil transshipment
Barbados	289,680	430	32	4.6	16,425	Tourism, sugar, light manufacturing, component assembly
Belize	340,844	22,966	44	3.0	8,321	Tourism, oil, food processing, garments, construction
Dominica	73,449	751	69	0.8	11,154	Agriculture, tourism, financial and other services, water bottling, soaps, essential oils
Grenada	110,152	344	36	1.3	12,231	Food and beverages, textiles, light assembly, tourism
Guyana	735,554	214,969	29	5.8	7,200	Bauxite, sugar, rice milling, timber, textiles, gold mining
Haiti	9,996,731	27,750	57	19.1	1,799	Textiles, sugar refining, flour milling, cement
Jamaica	2,930,050	10,991	55	24.7	8,784	Tourism, bauxite/alumina, rum, chemicals, agricultural processing
Montserrat	5,215	102	9	0.04	8,500	Tourism, rum, textiles, electronic appliances
Saint Lucia	163,362	616	18	2.0	11,832	Tourism, clothing, assembly of electronic components, beverages
St. Kitts and Nevis	51,538	261	32	1.3	21,585	Tourism, cotton, salt, copra, clothing
St. Vincent and the Grenadines	102,918	389	50	1.2	11,088	Tourism, food processing, cement, furniture, clothing
Suriname	573,311	163,820	60	9.5	17,062	Bauxite and gold mining, alumina production, oil, lumber, food processing
Trinidad and Tobago	1,223,916	5,128	9	44.3	32,654	Petroleum and petroleum products, LNG, methanol, ammonia, urea, steel products, beverages, food processing, cement

Figure 11. Overview of selected Caribbean SIDS(Ochs et al., 2015)

2.9.2.2. Demographics

The demographics of the Caribbean are the same as in a developed country. Wherein, there were high fertility rates in the 1970s and 80s and now fertility rates are on a decline, while the mortality rates are on a decline too. This decrease in fertility unlike in developed countries is not because of more career oriented women but rather a fall in fertility rates among men and women of the region. This is leading, to a very aged population to look forward to and further which is decreasing population growth in the islands. Currently, most of the islands are in the phase where the number of people aged in-between 19-59 is high, but considering the same patterns in a decade from now the number of people above 59 (threshold for when people are back to being a dependant person and do not work anymore) will increase (Achanfuo Yeboah, 2009; Saad, 2009). This possess a severe problem when looked at from the energy sector perspective because with all these new technologies it would help to have newly educated, highly skilled, and abled youth to lead the transition and further, there will soon be a lack of even people in the age bracket of being able to work which is again not good for the economy as a whole and the energy sector too.

2.9.2.3. Political Affiliations

As a result of the European colonization of the Caribbean islands, even to this day, there are certain islands that politically come under some other country and are governed to some extent by another country. These are called Dependent territories as recognized by the UN General Assembly Resolution 1514. It should be noted that the level dependence/autonomy for these dependent islands are varying. Based on this the Caribbean Islands can be categorized either as a sovereign state or a dependent territory, as shown the table below:

Caribbean Island Countries/Islands	Sovereign (S)/Dependent (D)
Anguilla	D – British Overseas Territory
British Virgin Islands	D – British Overseas Territory
Cayman Islands	D – British Overseas Territory
Montserrat	D – British Overseas Territory
Turks and Caicos Islands	D – British Overseas Territory
Guadeloupe	D – France
Saint-Barthélemy	D – France
Saint Martin (French part)	D – France
Martinique	D – France
Aruba	D – Kingdom of Netherlands
Bonaire, Sint Eustatius and Saba	D – Kingdom of Netherlands
Curaçao	D – Kingdom of Netherlands
Sint Maarten (Dutch part)	D – Kingdom of Netherlands
Puerto Rico	D – USA
United States Virgin Islands	D – USA
Antigua and Barbuda	S
Bahamas	S
Barbados	S
Cuba	S
Dominica	S
Dominican Republic	S
Grenada	S
Haiti	S
Jamaica	S
Saint Kitts and Nevis	S
Saint Lucia	S
Saint Vincent and the Grenadines	S
Trinidad and Tobago	S

Table 4. Categorization of Islands based on Political Affiliations(Foreign and Commonwealth Office, 2012; Ministry of Foreign Affairs, 2015; Wikipedia Contributors, 2016b)

Therefore, these different political structures might be interesting to take into account while performing research and checking if there is correlation between this and RETs deployment.

2.9.2.4. Energy

The energy sector is dominated by the electricity sector and the transportation sector. It was estimated that in 2010 around 85% - 90% of the primary energy in the Caribbean was supplied through imported fossil fuels. This combined with high costs associated with transportation of fossil fuel imports, a limited domestic market for fuels, and the absence of economies of scale makes energy production very expensive in the region. Consequently, this can have adverse effects on the regions potential to grow. Further, it makes the region extremely susceptible to oil market price fluctuations that can eat into their annual budget, budgetary money that can be well spent in other sectors (Arnold McIntyre et al., 2015; Daniel Arens, 2013; IRENA, 2012; Kuang et al., 2016)

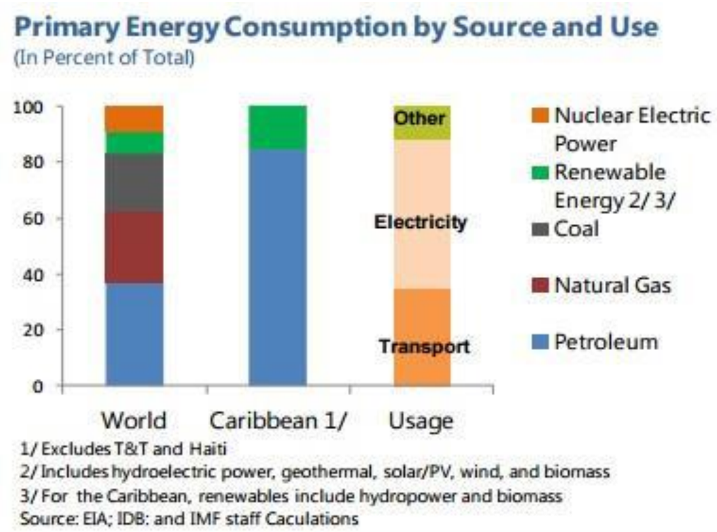


Figure 12. Primary Energy Consumption by Source and Use (Arnold McIntyre et al., 2015)

The situation is far more concerning because of two reasons. One, because even though energy prices increased by 80% over the period of 2002-2012 the consumption of oil based energy kept increasing in the region. The prices were 0.34 USD/kWh; this was twice the average of the Latin American Countries.

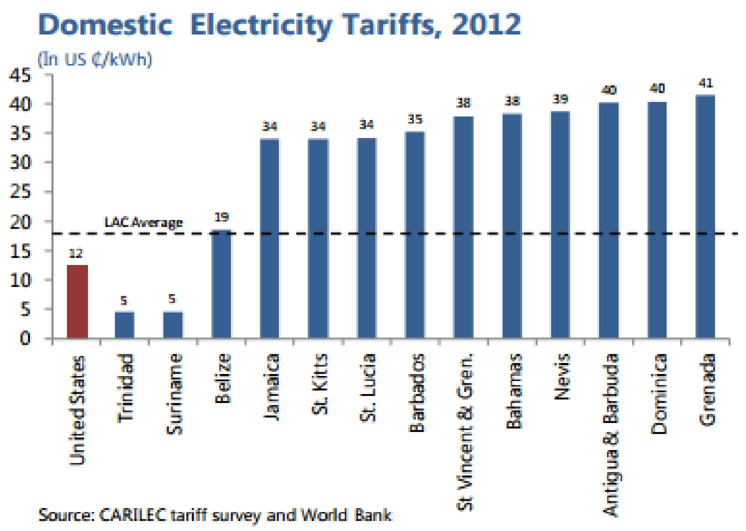


Figure 13. Domestic Electricity Tariffs in the Caribbean, 2012 (Arnold McIntyre et al., 2015)

The reason for the low tariffs of the Trinidad, Suriname and Belize is because Trinidad generates almost half of its energy through gas present on the island itself and Belize and Suriname use high amounts of Pumped Hydro systems to their advantage (Ochs et al., 2015). This leads to an important conclusion that producing energy locally is always going to be cheaper.

Two between 1970 and 2009 the Caribbean has seen the electricity sector grow at an average rate of 1.7%. And for the future, it is estimated that by 2028 the energy consumption of the region will become double of what it is today. This will cause a severe problem if all this extra energy is also supplied by fossil fuels. It will severely affect the economy and the environment. Especially considering that the electrification rate in the region is around 90% at an average. Further, the islands spend at an average 12.5% of their GDP on oil imports.

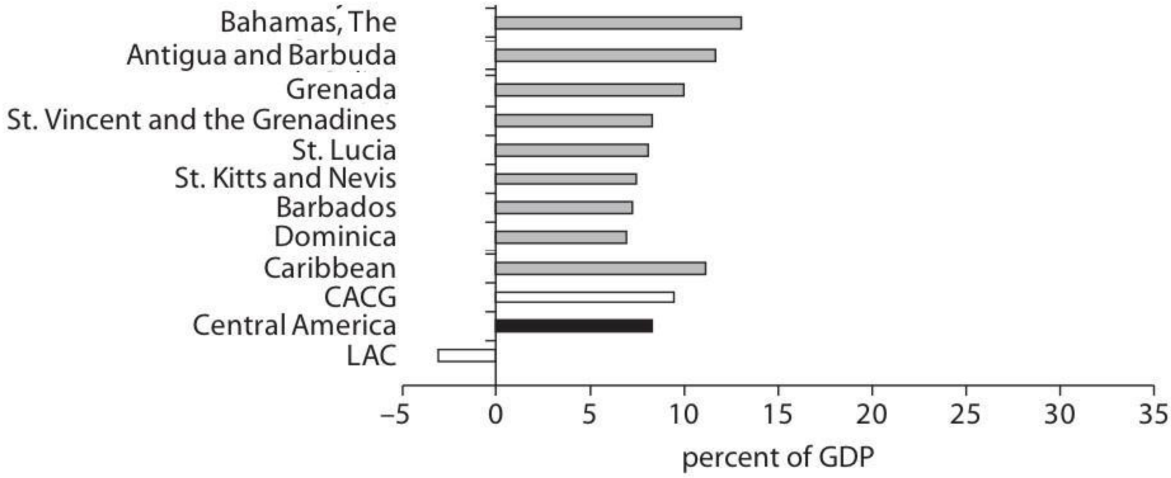


Figure 14. Share of Oil Imports as a percentage of the GDP(Daniel Arens, 2013)

A few other characteristics of the energy market at the Caribbean islands are the fact that the entire supply chain is state owned and it has a single utility system. Further, they mostly employ a centralized structure of their system. These come with their own set of vulnerabilities especially considering there is not back up because of no connectivity of grid either with the nearest mainland or regional islands. In terms of regulations and laws, the region has regulated the energy market sufficiently. Quite often, it perpetuates the monopoly. On the other side, even if the market is liberalized there is no guarantee that there will be sufficient competition because of the small market size.

However, in recent years, things are changing for the good. There are far more countries that are serious looking at energy transition. The Caribbean Community (CARICOM) is helping with analysis and actions required to create a regional electricity network. Montserrat has already set a target for 100% Renewable Electricity Sector by 2020. There was the Eastern Caribbean Energy Regulatory set up to assist with the transition. There has been recognition to diversify the electricity network in terms of supply sources. Barbados with the help of government push has managed to install 50,000 solar water heaters (IRENA, 2012; Ochs et al., 2015).

Therefore, it makes it interesting to understand what the renewable energy penetration is in the individual countries now. Fig. 15 shows that (discounting Guyana, Belize, and Suriname) we can say that RE penetration is limited at the highest level of 28.6% of Dominica and lowest at 0 for Montserrat and Bahamas. It should also be noted that this is just for the electricity sector. There is no transition in the transport sector yet.

In conclusion, the Caribbean while picking up momentum has a long way to go and still today faces serious issues related to:

- Small scale economies hence, small energy markets.
- Relatively high GDPs.
- Extreme dependence on (oil) imports.

- Longstanding electrical utility monopolies.
- Extensive electric power coverage.
- Some of the highest electricity prices in the world.
- Readily available, but unexploited RE potential.

Country	Installed Power Capacity	Installed Renewable Power Capacity	Renewable Share of Installed Power Capacity
	MW	MW	percent
Antigua and Barbuda	113.0	0.8	0.7
The Bahamas	536.0	0	0
Barbados	240.0	5.5	2.3
Belize	141.8	82.5	58.2
Dominica	27.7	7.6	28.6
Grenada	48.6	0.7	1.4
Guyana	383.0	55.1	14.4
Haiti	390.0*	62.4	16.0
Jamaica	926.4	72.0	7.8
Montserrat	5.5	0	0
Saint Lucia	88.6	0.2	0.2
St. Kitts and Nevis	56.4	3.2	5.7
St. Vincent and the Grenadines	52.3	6.4	12.2
Suriname	410.0	189.0	46.1
Trinidad and Tobago	2,368.0†	0.01	0.005
CARICOM Total	5,787.3	485.4	7.9

** Only 244 MW of this capacity is currently operational. † Capacity of the generators has been derated from 2,368 MW to 2,117 MW due to the age, manufacturer, and ambient conditions of the machines that are presently available to the grid.*
Note: "0" indicates that there is no installed renewable power capacity at present. Data reflect the most updated information available for each member state at the time of publication, compiled from a variety of sources including national utilities, country representatives, and secondary sources.

Figure 15. RE Share of Installed Capacity, 2015 (Oschs et al., 2015)

3. Methodological Research Framework

It became clear that a lot of different techniques and theories can be used in a combined manner to establish a strong backcasting structure and therefore, by extension, a cogent research framework. This will talk about how different Backcasting frameworks can be combined to create a strong backbone for the type of non-participatory research that is going to be conducted. Further, it will delineate upon how other theories of Scenario Building and Analysis, and Transition Pathways, when combined with techniques like PESTEL can complement the Backcasting structure to create a strong research framework. But first, this chapter will discuss the selection of the two cases that are going to be analysed for this research.

This section is heavily derived from Broich (2015), Ricken (2012) and Brais (2016).

3.1. Selection Criteria and Defining SIDS

Based on all the information mentioned above in an aim to focus this research further to aid in being able to generate more focused recommendations, there is selection criteria that has been decided on which reduces the number of researched islands to 2.

In this part age old criteria like economic growth, and land size are not used. Even the usage of population is only from a functional sense of defining what this research considers a SIDS.

Criteria	Value
Population	100,000 – 3,000,000
RE Penetration	Low - <5% High - > 10% Select 1 island in each category
Political Autonomy	Dependent or Independent At least 1 island in each category
Grid Connectivity to Mainland or Peripheral Islands	No
Official Language	English
Data Availability	Indicators: Part of CARICOM National Energy Plan Renewable Energy Targets

Table 5. Criteria to Narrow Research Scope

Based on these criteria the three islands that have been chosen are:

- **Grenada (110,000; 1.4%; Independent Country; No; Meets all indicators of Data Availability)**
- **Curacao (156,000; 12%; Dependent Country; No; Yes Data)**

It is worth noting that the reason why regular parameters like population, GDP growth were not considered as selection criteria because in the near future they will no longer be related to energy consumption increase in view of increasing energy efficiency.

This leads to a requirement to understand why not large islands for this research; there are 2 reasons:

1. There isn't really a definition for large island. Many would argue Jamaica is a large island.
2. If it is a large island then it does not necessarily experience the same difficulties of a limited market size and not being able to utilize economies of scale.

3.2. Backcasting: A strong Structural Backbone

The Backcasting framework will provide this research with the required stability and yet be dynamic enough to be complemented by various other techniques and theories to assist in a robust execution of this research.

The framework proposed by Quist helps with exactly this. The 5 step methodology is generic enough to provide the core elements of this research and still have room to be combined with other theories. Therefore, this method combines the tasks prescribed by the Robinson (1990) framework (because of its reliance on government interventions and policy) along with Quist's approach to backcasting. The integration is done as seen in table 6. A couple things to note here are:

1. While there is no explicit mention of calculating Renewable Energy Potentials in either of the frameworks, both the frameworks talk about establishing targets, and limitations. Therefore, calculating the RE potentials aides in establishing the technical limitations of the system of the future. And hence, it is considered as elements that both frameworks suggest.
2. In the Scenario Construction step it has been mentioned that the Quist Framework doesn't recognize the element iterating till there is internal consistency within the scenarios described. This has been done so because Quist actually does not explicitly

state anything about this in his Backcasting Framework but it could be an implicit assumption that the scenarios have to consistent.

Steps	Tasks	Quist	Robinson
1.Strategic Problem Orientation	Analyse Present Energy System	Y	Y
	Analyse Current Developments	Y	Y
	Identify Stakeholders	Y	N
	Identify Exogenous Variables	N	Y
	Specify Goals, Constraints, Targets	Y	Y
	Identify RE Technology Potentials	N	N
	State Assumptions	Y	Y
	Define Exogenous Variables	N	Y
	Specify Timeframe	Y	Y
2.Scenario Construction	Idea articulation and elaboration	Y	Y
	Generation of Multiple	Y	Y
	Perspectives Scenario Elaboration	Y	Y
	Iterative as required to achieve internal consistency	N	Y
3.Backcasting Analysis	Identify required Interventions	Y	N
	Define necessary changes	Y	N
	Identify possible Driver and Barriers	Y	N
4.Elaboration	Define Possible Transition Pathway	Y	N
	Policy Recommendations	Y	Y
5.Implementation	Action plan for Follow –up Agenda	Y	N

Table 6. Steps and Tasks of the Methodological Research Framework

Now that the combined framework is established to provide a backbone; other theories and techniques can be integrated into this framework.

Finally at this point it is worth differentiating between what this research considers to be a vision and scenario:

A VISION is the overall aim of the Backcast. That is what the main goal of the desirable future is. In this situation the vision would be, wanting to achieve a 100% renewable energy based energy sector by a certain year.

A SCENARIO on the other hand is defined as the details of how the vision can possibly look. So an example of this would be whether the energy system of our desirable vision is centralized or decentralized, the RET that plays the most important role in this future.

The following part of this chapter with tackle each step of the framework one at a time and explain how based on the literature review performed in the previous chapters, which theory and technique will be used to operationalize each step and how this is used for a quick scan instead of a full backcast.

3.3. Step 1: Strategic Problem Orientation

This is one of the main parts of the Backcast, therefore it combines 2 techniques. The PESTEL represents the Political, Economic, Social, Technological/ Technical, Environmental, Legal factors that influence the energy sector of the country. The technological/technical part is established by eventually creating an energy balance table of the country; wherein the energy supply and demand is described in detail. Further, the RE sources potentials are also calculated, through a simplified version of the EPM method, to establish the technological limits for the country. This will also include the structure of the energy system and a stakeholder analysis.

This very clearly fills the methodological void of not having sufficient information of specific methods for each step. By doing so we are able to create a time period within which the transition can take place by virtue of knowing my systems limitations. Obviously, this step will be repeated for each of the 2 islands. This provides the essential starting point to create future scenarios.

3.4. Step 2: Scenario Construction

In this section, after the common vision is established, and a list of parameters is created; 2 scenarios for each island will be created such that eventually the future system can fulfil the desired vision. This will be a transforming normative scenario typology. Keeping in mind the requirement of a quick-scan; the scenarios created for each of the islands will be done by using the energy balance table, the technology potentials and the maturity of each technology and also utilizing an energy system sizing model created by Gioutsos (2016) and van Velzen (2017), students of Prof. Kornelis Blok. This will establish very clearly a possible future energy system. Other aspects like structure of the grid, societal norms, and institutional structure will not be considered here, rather is assumed to be a by-product of the designed energy system.

3.5. Step 3: Backcasting Analysis

This section deals with how the created scenarios can be achieved within the given time frame. Once the scenarios fit the required criteria of the research; this step will make use of the what-how-why-who-when analysis to create a backward timeline. The process starts with understanding 'what' interventions need to be made at a technological, structural and social level to enable the achievement of the 100% energy transition. It should be noted that this is the first step of creating the transition pathways; answering the question 'what needs to be done'. This is followed by answering 'how' do these changes take place (this is where policy recommendations will introduced), at this point the reason for choosing a particular policy action is reflected upon (this is to be able to present a package policies), then there is a mention of who will make these changes happen.

In short this step in conjunction with step 4 will create a transition strategy. It will concentrate on short term concrete actions, which can initiate the process of transition successfully. And then the long term actions will be dealt with in a more abstract manner. This is another step towards making it a quick scan.

3.6. Step 4: Implementation

This step will finally take about by when all those interventions and actions need to be made. Therefore, this will create a timeline for the transition to follow. Further, this concentrates on short term concrete actions within a long term strategy. This essentially will create the transition pathway. The final part of this step will follow the questions stated in the follow-up agenda section (chapter 2.9) to create a simple yet comprehensive follow-up agenda which defines aspects like actions required in future, date required, responsible organization and a timeline for the pathway to be reviewed and adapted. Technically, follow-up agenda will answer the question 'how can the transition pathway(s) be managed, so that it gets implemented'?

3.7. Research Boundaries

1. Geographical boundaries entail only researching 2 Caribbean islands and trying to create a common transition pathway.
2. The second physical boundary will be determined by The United Nations Convention on the Law of the Sea (UNCLOS) which determines how many miles of the sea surrounding the country actually belongs to a particular country and more specifically how many nautical miles of the seas surrounding the island can be used for a specific islands economic benefits. This is important because this research intends on making use of each islands oceanic renewable sources (offshore wind, OTEC, Tidal, and many more).
3. System boundaries entail not considering air travel and maritime travel for the transportation sector. Looking into just road transport on the islands. This is because air travel and maritime travel, the routes and companies are international and it would be complicated for one country to unilaterally impose rules on these two fields.
4. The second system boundary is that the research considers only locally available renewable energy sources, therefore fossil fuels and nuclear are not considered to be a part of the future energy mix.
5. It is assumed that energy self-sufficiency will be attained in the future by each of the two islands. It is assumed to be an implicit characteristic of using locally available renewable energy systems. So both energy supply and demand will be renewable
6. Methodological boundaries entail this research being non-participatory. Therefore this enables making certain bolder yet realistic decisions when deciding on scenarios and actions because the drawback of attaining consensus between stakeholders is no longer a factor.
7. In terms of scope it has been mentioned that this research will mainly look at governmental actions for transition. This decision was made simply to limit the scope of the thesis because it would be rather futile to try and perform a comprehensive stakeholder analysis without actually talking to the stakeholders and further out of the realization that any niche technology requires government subsidy to develop.

Within these prescribed boundaries and using the aforementioned methods and techniques the following research questions will be answered.

How can certain islands of the Caribbean reach the goal of 100% renewable energy transition?

1. What is the current energy system of on the islands?
2. Who are the main actors involved in the current energy system?
3. What are the various factors affecting the current energy system that influence the transition?
4. What are the energy potentials and costs of different renewable energy sources?
5. What does the future scenario for each island look like?
6. What are the technological, structural, societal interventions that need to happen for the future to be achieved?
7. What pathway(s) can be followed to implement the required interventions?

It should be noted that all these questions will be answered for both my cases of Curacao and Grenada.

3.8. Methodological Novelty

1. Removal of the methodological void the general backcasting approach. Especially, step 1 by integrating PESTEL, and EPM.
2. This leads to the 2nd novelty that is mapping the current state of certain islands in the Caribbean in such detail.

3. Creating a Quick Scan process for a Backcast which is otherwise, generally, a very crowded and time consuming approach. While this novelty is not particularly depicted through the content mentioned above, it is worth noting that the precise structure of the entire process enables a quick scan and also in terms of density of information, the emphasis will not be on each and every element mentioned. And this can only be noticed once the research is done. There have been attempts in terms of narrowing the scope through only speaking about government related transition and by implementing a simplistic transition pathway and follow-up agenda technique. By answering those specific questions the reader will receive all the necessary information.
4. Implementing this on SIDS is also something that has never been done before. So, this will be something absolutely new.

Steps and Tasks	Research Theory/Technique	Research Method
Strategic Problem Orientation • Energy Supply/Demand Profile • Institutional Structure of Energy System • Main Stakeholders • Policies • Cultural and Societal Aspects • Technical Aspects • Energy Potential • Cost of Technologies	• PESTEL method illustrating indicators • Energy Potential Mapping and cost of technologies adding to PESTEL • Energy Balance Table to indicate technical future system	Desk Research (through documents of various organizations and scientific articles and National Energy Policies)
Construct Future Scenarios • Time Period • Assumptions • Future Energy Sector	• Trends • Using Energy Models for system sizing	Desk Research and Consultation with Supervisors
Backcasting Analysis • Interventions • Changes	• Technological • Structural • Societal • Policy Recommendations • What-How-Why-Who Analysis	Desk Research
Implementation • Transition Pathways • Follow-up Agenda	• By When Analysis to create strategies and short term actions • Creation of time bound review plan	Desk Research

Table 7. Research Methodological Framework

4. Curacao

Curacao is a Small Island Developing State (SIDS) (Ministry of Health and Office of Foreign Relations, 2014) located in the Caribbean about 50km off the coast of Venezuela (Haro, 2013). When it was a part of the Netherlands Antilles, it was the largest territorial area of the Netherlands Antilles (Resources and Logistics, 2014). It was part of the Netherlands Antilles, along with 5 other islands, until the 10th of October 2010 (10/10/10). After which, it received the status of an autonomous country under the Kingdom of Netherlands. This means that the island of Curacao will have complete autonomy in formulating and implementing their own set of regulations and policies for every sector apart from defence, and foreign policy. There also exists are certain other limitations as dictated by the five consensus-statutory laws (Prochazka, 2012).

Curacao is 444 km^2 in area, with a population of 158,986 as of 1 January 2016. This leads to a population density of 358 persons per km^2. They have 3 official languages, Papiamentu, Dutch and English. Their capital is Willemstad. This is where most, almost 90%, of the population resides. They have a parliamentary representative democracy under a constitutional monarch as a government structure. Curacao has a high Human Development Index (HDI) at 0.811 (Central Bureau of Statistics, 2015; Ministry of Health and Office of Foreign Relations, 2014).

Figure 16. Map of Curacao

It is worth noticing that mostly only the yellow areas in the map are the areas that are inhabited by human population. Therefore, there is technically a lot of free land area available, which is good when considering a transition that may rely on Wind and Solar technologies. Further, a high density of population in and around Willemstad is beneficial for Sea Water Air Cooling technology.

This research concentrates on the energy sector of Curacao. This will start with delineating on the current energy scenario; consisting of the technical energy system, market structure, stakeholders, factors affecting the sector through a PESTEL analysis. This will be supported by the economic status of all the potential renewable energy technologies along with the resource and technical potential on the island. This also enables us to understand the boundary conditions of this work.

4.1. Strategic Problem Orientation

4.1.1. Technical Energy System

To present a comprehensive overview of the energy system the following things will be delineated upon; first the energy sector will be defined, following which the energy supply in terms of primary energy and the fuel type will be mentioned, which is followed with information on the grid infrastructure, then the energy demand in terms of final energy consumption and sectors with most consumption will be mentioned, and finally the market structure of each part of the energy sector will be discussed. All of this will conclude with an energy balance for Curacao been developed.

4.1.1.1. Energy Sector

The energy sector of Curacao constitutes the fuels used by the transportation sector and the fuels used by the electricity sector. There is no heating infrastructure required in Curacao because of the average annual temperature being around 28^{o} C, with the lowest monthly average temperature being around 26^{o} C (Meteorological Department of Curacao, 2010). However, for this reason there are cooling systems required.

Energy Supply

Close to 99% of Curacao's primary energy comes from imported petroleum based products or crude oil. The ISLA oil refinery, located on the island, theoretically has the capacity to process 1958 TJ of fossil fuels (mostly crude oil) in a day, that is, an annual capacity of 710,000 TJ. But the plant never processes theoretical maximum. In 2014, the refinery imported and processed only 513,774 TJ of fossil fuels. This is a difference of approximately 27% from their theoretical capacity and a 20% drop from how much fossil fuel was being processed in 2011 (642600 TJ). This can have 2 main reasons, the first being because of the turbulent Venezuelan political situation that has terribly affected its economy, and the second being the terrible situation of the ISLA oil refinery on the island. It is riddled with issues and therefore is never able to function at full capacity. There could be a third small reason which is the switch from almost complete fossil fuel electricity generation to having an approximately 25% renewable electricity penetration into the electricity market. This hardly makes up 1% of the primary energy need of the island. Apart from the imported fossil fuels, in terms of primary energy for Curacao, the island also has 30 MW of onsh ore wind power and 16 MW of Solar PV installed as of 2014 (Central Bureau of Statistics, 2017; National Renewable Energy Laboratory, 2015; Niel Gardner et al., 2013; RdK, 2017).

ISLA produces gasoline, diesel fuels, jet fuels, lubricants, petrochemicals and other petroleum-based industrial products after processing the 513774 TJ of imported fossil fuels. There are 6 sectors within which the processed fossil fuels are distributed (Niel Gardner et al., 2013; PDVSA, 2017a, b).

- The fuels are exported to other countries (approx. 75% of the processed fuel)
- The fuels are sent to international aviation and marine bunkers (4% of the processed fuel)
- The fuels are used for the local (on island) transportation sector
- The fuels are sent to power plants to produce electricity,
- The fuels are used for operating the ISLA refinery in itself (10% of the processed fuel)
- The fuels are used for other miscellaneous things like for cooking, lubrication etc

The total primary energy used on the island is calculated by removing the amount of processed fuel exported and sent to international bunkers. Therefore, the total of around 129,000 TJ of primary energy was used in the island. Out of which 1480 so approximately 1500 TJ (1%) were Renewable Electricity.

In terms of electricity production for the public grid, there is a total installed capacity of 185 MW. This has a 16% share of wind energy and 9% share of small scale Solar PV (they can also sell back to the grid: Prosumers). This represents 25% of the installed capacity. The rest 75% share is various forms of fossil fuels (diesel, Industrial Fuel Oil (IFO) and gasoil). To generate the required amount of fossil fuel electricity the plants are supplied with 9340 TJ of the refined fossil fuel (Central Bureau of Statistics, 2017). There are 4 fossil fuel electricity generating plants. The distribution of installed capacity is as follows:

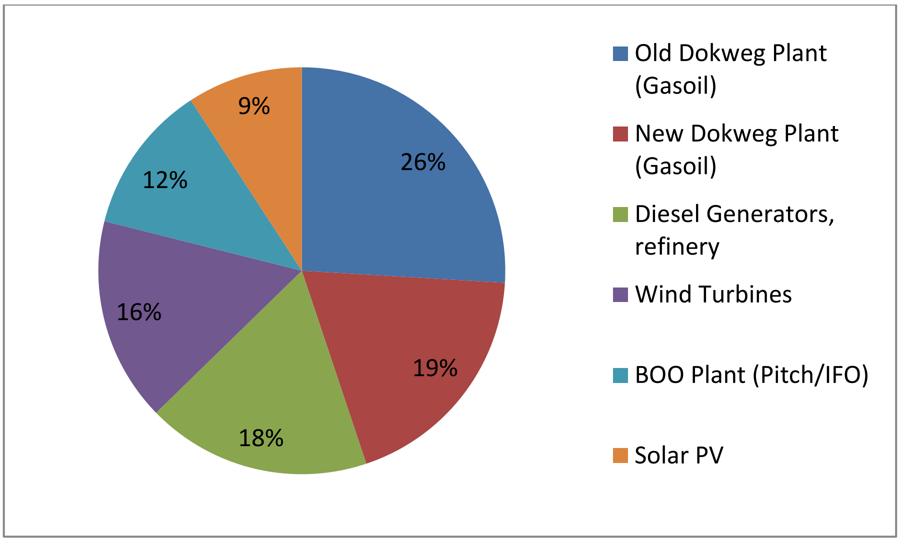


Figure 17. Distribution of Installed Electricity Capacity (MW) based on Plant and Fuel Type (Central Bureau of Statistics, 2017)

This total installed capacity of various power pants eventually after taking into account conversion losses and for renewables capacity factor generated a total of 3140 TJ of energy in the year 2014.

Further, it should be noted that the transmission of electricity is intermittent and unreliable. Also that almost all fossil fuel power plants are beyond their lifetime for operation and that they suffer from serious maintenance problems (Niel Gardner et al., 2013). And because of this they have severe negative impacts on the environment around them. Therefore, Aqualectra, the sole utility company, in the past made a contract with Aggreko International Projects for emergency electricity supply. The contract started with an emergency supply of 315 TJ (=10 MW) in 2008, but as of 2011 has gone up to 1385 TJ (=44 MW) (Board of Managing Directors, 2014; National Renewable Energy Laboratory, 2015). Whether this still continues is not clear, though. There are conflicting reviews on how much installed capacity of electricity is actually present on the island and that most reports only talk about the electricity supplied to the public grid and not the 1100 TJ (=35 MW) of installed capacity used to power the refinery itself (there are reports that claim a much higher installed capacity for the refinery). Lastly, this year, 2017, an extra 520 TJ (=16.5 MW) of onshore wind turbines will be installed (Kolader and Schaubroeck, 2016); a 16 TJ (=500 kW) OTEC plant is also going to be installed in the next few years and that there are plans for upgrading the refinery and making it run completely on liquefied natural gas.

Parameters	Values
Total Primary Energy Use (2014)	129,000 TJ (including 1500 TJ of RE)
Electricity Sector Total Installed Capacity (2014)	5828 TJ (=185 MW) - Total 1732 TJ (=55 MW) – CRU (1040 TJ - Diesel and 692 TJ - IFO) 945 TJ – Onshore Wind Farms 535 TJ – Prosumers (Small scale Solar PV)
Future Installed Capacity	520 TJ Onshore Wind from April 2017 (estimated)
Total Electricity Generation (2014)	3140 TJ
Renewable Energy Penetration (2014)	25% of the installed capacity - electricity market
Renewable Installed Capacity (2014)	Currently 1480 TJ + 520 TJ in April 2017
Source of Installed Renewable Capacity (2014)	Wind Turbine Parks and Solar Panels

Table 8. Overview of the Electricity Supply Sector at Curacao, 2014 (National Renewable Energy Laboratory, 2015; Niel Gardner et al., 2013; Resources and Logistics, 2014)

Note that the values for TJ are based on installed capacity that means assuming that the plants run for 100% of the time. This in reality will never happen there are massive efficiency and conversion losses in the case of fossil fuels and in case of renewable energy the capacity factor has to be considered. This is why there is a difference between the TJ of electricity generated and the TJ of installed capacity. Approximately 46% of all installed electricity is lost. This can be reduced if the fossil fuel based electricity plant are made more efficient and made to run whenever required.

Grid Infrastructure

The grid consists of two parts, the first being the high voltage transmission lines and the second is the low voltage distribution lines. The high voltage lines are used to reduce losses when transferring over long distances, while the voltage is reduced when finally supplied to the end consumers. It should be noted that this reduction from high voltage to the voltage required for the end consumers is done in 4 stages. Therefore, it can be said that within the transmission and distribution network each have their individual high and low voltage segments, as explained below.

Currently in Curacao the high voltage transmission lines consist of 66kV after which within the transmission network itself the voltage is first dropped to 30 kV lines. The 66KV lines are mainly connected to the BOO plant (or rather the production that happens within the ISLA refinery) and then through step-down transformers the voltage is dropped to 30kV lines that are connected to the Dokweg plants and the wind turbines.

After which the distribution network starts with the voltage further dropping to 12kV and finally just before reaching the users the voltage is further dropped to 127 V, 220 V, or 380 V.

Currently, the grid is strong enough to handle small in-feeding from prosumers, however, it still cannot handle medium (large) producers in-feeding into the network and this becomes very important for a renewable energy future. Further, there are massive losses in the grid infrastructure. It was 16.4% loss in 2004, which reduced to 13% in 2008 and in 2010 it was projected by government that the losses will reduce to 12% but as of 2011 it seems to have remained at the 13% mark and after that there is no new data regarding this. For this study, it is assumed that the losses have reduced to 10% by now (Government of Curacao, 2011; Haro, 2013).

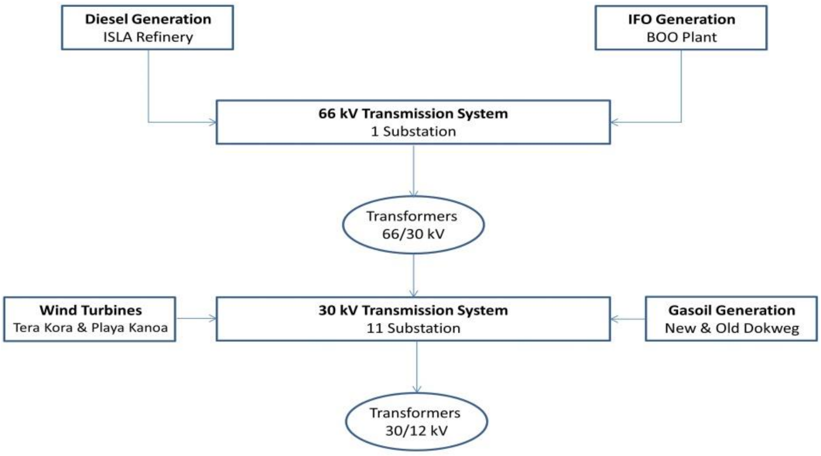


Figure 18. Transmission Network of Curacao (Haro, 2013)

Energy Demand

The demand sector can be divided into 3 main categories, fuels used in the transportation sector, sectors that consume electricity (produced by fossil fuels and renewable energy) and other miscellaneous uses (in the form of oil products like for example lubricants).

The transportation sector it can be divided into amount used for the international marine and aviation bunkers and the amount used for road transport (no trains). The international bunkers though significant will not be included in this research because global factors will still dictate the type of fuel used in that industry. The road transport consists of privately owned cars, public buses, taxis and a few motor cycles. According to Niel Gardner et al. (2013) the road transport consumes 60% of the fossil fuels locally consumed (defined as fuels used to provide electricity + fuels used for local transportation + other refined petroleum products). This is higher than general. In most developed countries transport sector accounts for around 30% to 35%, but in the Caribbean islands around 40% to 50% is justifiable because of lack of proper public transport and inefficient transport sector, but 60% is a little on the higher side. The public bus network consumes 9.84 million litres (378.3 TJ) of diesel per annum transporting around 3 million passengers. That means around 3.3 litres (127.4 MJ) of diesel per passenger. The fuels for local transportation are a mix of petrol and diesel. There is a robust network 550 km of road and in 2015 there were a total of 83,311 vehicles (Central Bureau of Statistics, 2017; Niel Gardner et al., 2013).

The electricity sector serves 62,000 households and 7000 businesses (commercial, industrial, public lighting, hospitals) that consume 750 GWh (2700 TJ in 2014) with a 40% and 60% of the electricity consumption distribution respectively. The electricity sector can be further understood by looking into the seasonal and the daily demand in Curacao. The two figures below give an insight into the electricity consumption over one day (weekday, weekend) and electricity consumption over months of the year.

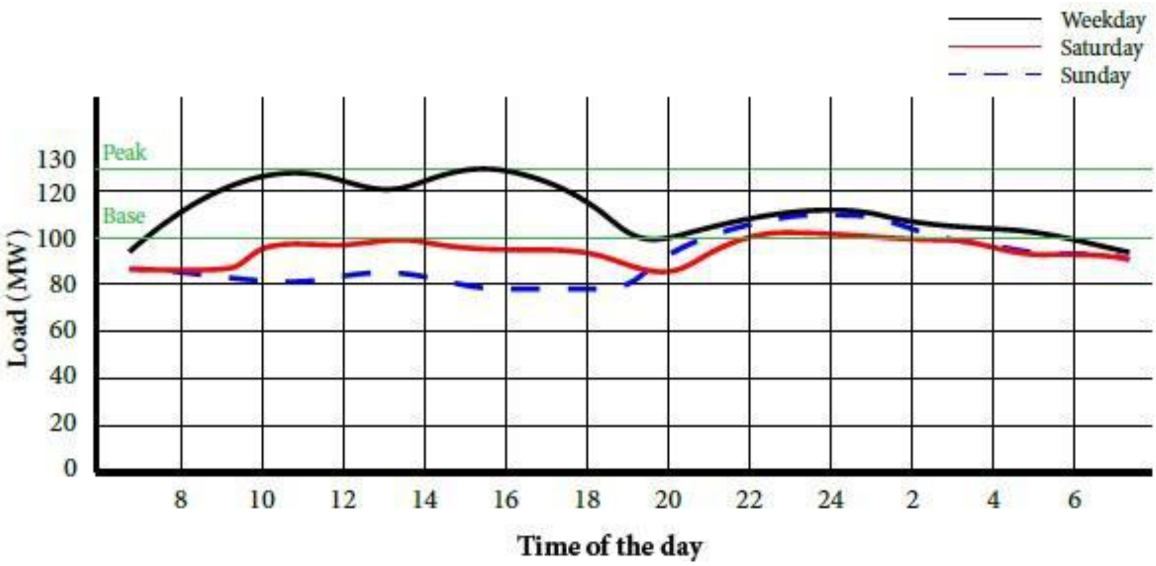


Figure 19. Electricity Demand throughout the Day (Government of Curacao, 2011; Prochazka, 2012; van Eldik, 2015)

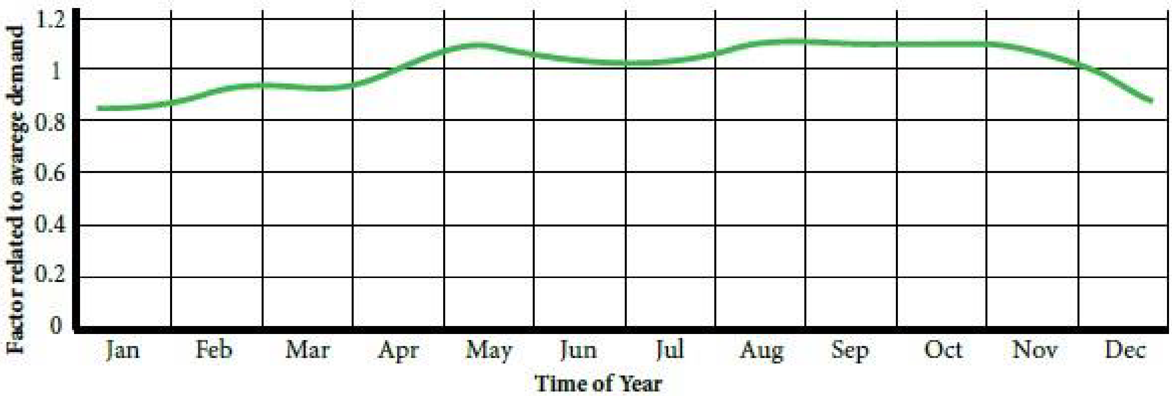


Figure 20. Electricity Demand per Month, 2004-2007 (Government of Curacao, 2011; Prochazka, 2012; van Eldik, 2015)

The above graphs help in understanding the peak load and the average load of Curacao. Also, it can clearly see through the hourly demand graph that there are 2 main peaks one at 1000 hrs and the other at 1300 hrs and that electricity demand is significantly higher over the weekdays when compared to the weekends. This is attributed to the fact that businesses consume around 60% of all the electricity. Also, there is a reduction by around 20% in the months from November to April because of the low temperatures and therefore lower use of air conditioning devices. In terms of the predictions for the future, Aqualectra predicts major increase in demand by 2020. They predict that the peak load will shift to 200 MVA (=190 MW, approx.) and they will require close to 280 MW in installed capacity to be in a position to carter to the increase (Government of Curacao, 2011). While van Weijsten, an advisor to the Government of Curacao on energy policy in an interview in 2012 (Prochazka, 2012), predicts not a lot of change because of the improvement in energy efficiency of the products that consume energy. This idea is also resonated by the government target of wanting to reduce energy consumption by 40% by the year 2020 (Government of Curacao, 2011; National Renewable Energy Laboratory, 2015). However, there is little to no evidence to support the fact that there will be reduction of energy consumption in the near future.

Finally, to understand what uses so much electricity by sector and use of electricity by appliance in the residential area and businesses these two graphs will help.

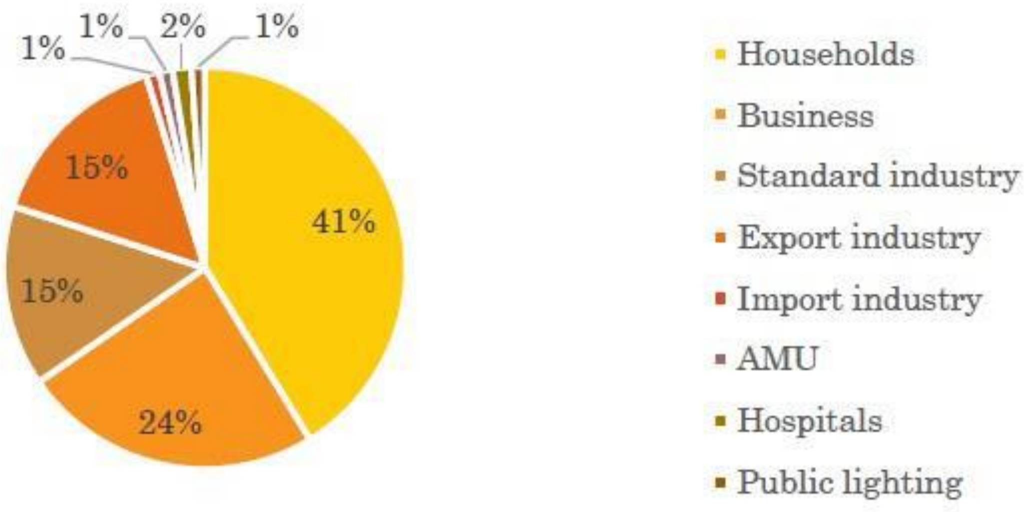


Figure 21. Electricity use by Sector (Caithlin Ann Marugg, 2016; van Eldik, 2015)

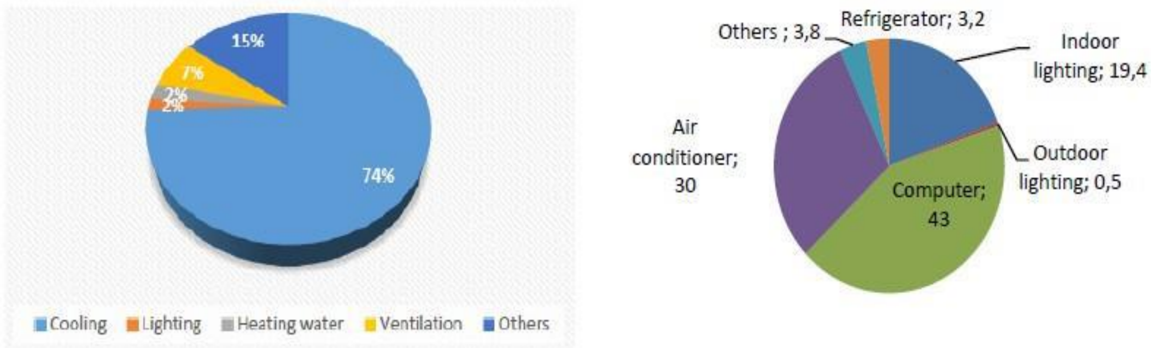


Figure 22. Electricity use by Appliances at Home (left) and Commercial Buildings (Right) (Caithlin Ann Marugg, 2016; van Eldik, 2015)

A few things to note over here, there is no information on what constitutes business, standard industry, export industry and import industry. AMU stands for Aqualectra Multi Utility but there is little understanding to why is consumes 1% of all electricity consumed. Public Lighting over the years has consumed a constant 7 GWh every year (van Eldik, 2015).

Further, the largest consumption of electricity at households can be seen as the cooling systems. Cooling systems are defined as including air conditioning, freezers, and refrigerators (van Eldik, 2015). In general, this is also very high. Therefore, while calculation efficiency gains it will be assumed that ACs consume 50% of residential electricity, which leads to an overall consumption of 40% on the islands of Curacao. Even 50% seems high but this is partly attributed to the bad insulation of the homes. In the business sector cooling is 30% and the 2nd largest contributor to consumption after computers. While this makes sense, what also becomes apparent is that this is mainly for offices and not necessarily industries. However, due to lack of data on industries the same percentages are assumed for every other business. Lastly, it is worth noting that the two thesis referenced here do not have active references for their data.

Parameters	Values
Electricity sector consumption (2014)	**2700 TJ**
Average Load	**100 MW**
Peak Load	**130 MW**
Total Generation (2014)	**3139 TJ**

Electricity consumption by Businesses	**60%**
Largest consumption by Appliances	**Computers and ACs (43% and 30% respectively)**
Electricity consumption by Households	**40%**
Largest consumption by Appliances	**ACs (50%)**
Transport Sector consumption	**60% of total energy**
Total Amount of Road	**550 km**
Total Number of Vehicles (2015)	**83,311**

Table 9. Overview of the Energy Demand Sector at Curacao (International Energy Agency, 2016; National Renewable Energy Laboratory, 2015; Niel Gardner et al., 2013; Resources and Logistics, 2014)

Energy Balance

Units – TeraJoules	Crude Oil and	Oil Products	Wind	Solar PV	Electricity	Total Energy	RE Share
Primary Production			946	536		1482	**1482**
Imports	513774					513774	
Exports		-366064				-366064	
International Aviation and Marine Bunkers		-48808				-20254	
Total Primary Energy	513774	-414873	946	536	0	100384	**1482**
Private Power Plants			-946	-536	580	-902	
Refineries	-	488085				-25689	
Public Power Plants		-9341			3269	-6072	
Energy Industry Own Use		-48035			-773	-48809	
Losses					-385	-385	
Total Final Consumption		15836			2691	18528	
Transport		10768					
House Holds		1013			1077		
Businesses					646		
Standard Industry		1013			404		
Export		1013			404		
Import Industry		255			27		
Public Lighting					27		
Others		**1773**			**81**		

Table 10. Energy Balance – Curacao

There is a lack of data on how the processed oil is used locally on the island. The data says three things:

1. The processed fossil fuel used on the island is split between the transport sector, electricity sector, and other purposes.
2. Out of this 60% of the local fossil fuel consumption is used in the transport sector excluding international aviation and marine bunkers.
3. Based on electricity generation data we can calculate the amount for the table above. There are 2 problems with this data:
    a. 60% of final fossil fuel consumption for local transportation is an enormously higher number. Generally countries are around 35%-40%. And according to the IMF 36% of the Primary Energy is used for transportation in the Caribbean region (this could potentially mean 40 to 45% of the final energy consumption).
    b. There is no understanding of how remaining fuel is distributed between the international bunkers and the other places of consumption. For this work we have followed the distribution set by International Energy Agency (2016).

Clearly looking at this it becomes clear that there is striking lack of data with respect to how the oil products are used within the country. Most of the energy consumption right now is from the transport sector. Which makes sense because of the high amounts of tourism and also in general the transport sector contributes to around 50% of the energy consumption (for a household) even in the Netherlands.

Market Structure

Based on this understanding from Chappin and Dijkema (2007) and the understanding of different **electricity market structures** from Martina (2009), there are 4 kinds of electricity market structures. All while the physical structure of the system remains the same, consisting of 4 phases, namely; generation, transmission, distribution and consumption. While the 4 market structures are:

1. A monopoly structure, which is what most small island nations subscribe to.
2. A single buyer structure: This is where there are multiple generation organizations but only a single entity buying the electricity from them and supplying it to the consumers. Or in other words a single entity owns the transmission and distribution lines.
3. A wholesale market structure: This is "*where multiple distributors buy electricity from competing generators, use the transmission network to deliver it to their service areas under open access arrangements, and maintain monopolies on sales in their service areas*." (Martina, 2009)
4. A retail market structure: This is where the consumers have total open access to choose their generators through different distributors. This has competing generators, choice of retailers (distributors), and choice for customers.

Curacao currently has a variation of the single buyer system. At Curacao, while there are multiple generators of electricity there is a single entity, all owned by the government, which owns the transmission and distribution lines and also a certain percentage of the generation. The variation is that there is a different company handling each specific phase (generation, transmission, and distribution). There are vision documents that talk about implementing a retail competition based market structure and coupling that with smart grids. But, there is no indication of by when they plan on doing it and whether they still want to do it also (Government of Curacao, 2011).

The **transport sector** has a monopolistic market structure. Where the entire supply chain is predominantly state owned. The sole government owned company named Curoil is in-charge of marketing and distributing the fuels over the island.

4.1.2. Stakeholder Analysis

The stakeholder analysis will talk about 7 groups of stakeholders Financers, Research and Education Institutes, Non-State Actors, Companies, Policy Makers, Media, and Users.

Companies

ISLA the oil refinery in Curacao, which is owned by Refineria di Korsou (RdK – a state owned enterprise) and operated on lease by Petróleos de Venezuela S.A. PDVSA, a Venezuelan state owned oil company. The crude oil refined by ISLA is bought from PDVSA in Venezuela. The Curucao Refinery Utility (CRU) which operates the BOO plant and the Diesel Generators of the refinery, is owned by Refineria di Korsou (RdK – a state owned enterprise) and is the energy provider for the ISLA refinery. The electricity and water company on the island is called Aqualectra. Aqualectra is a state owned company responsible for a part of the production of electricity and solely responsible for the distribution of energy and water on the island of Curacao. NU Capital owns the two wind farms in Curacao (Government of Curacao, 2011; National Renewable Energy Laboratory, 2015; van Eldik, 2015). However, in latest news next year onwards PDVSA will no longer be in charge of the ISLA plant. A preliminary agreement with China's Guangdong Zhenrong Energy, one of China's 4 state owned petroleum trading companies, to operate the aging ISLA refinery and invest some $10 billion in upgrading the facility has been made. This is subject to them being able to prove that they can make the agreed upon investment by sometime in 2017 (Urribarri, 2016).

Apart from this you have close to 40 registered and legally recognized companies that help with setting up solar panels in the island (BnTP, 2017). Further, BlueRise is a prominent player in the renewable energy industry over there for OTEC. They have been working with the government and the Curacao Airport Holding (CAH) for the last few years to set up an Eco- park which with run a Demo OTEC plant of 200 kW capacity. This should be operational soon.

In the transport sector, Curoil, a state owned company, is sole supplier of fuels and gas to the consumers. The gas/diesel stations where this is sold is owned by 3 agencies, one being Curoil itself and the other 2 being Curacao Oil Products Distributors Association (COPDA), an association of gas stations in Curacao, and Asosashon Doñonan di Pòmp di Gasolin (ASOGAS), another association of gas stations in the Dutch Caribbean. The buses on the island are operated by Autobusbedrijf Curaçao.

Policy Sector

The 2 most important agencies that are responsible for policies concerning the electricity and transportation sector are the Bureau of Telecommunications and Post (BTP) and the Ministry of Economic Development (MED). The BTP is an independent supervisory body for the transportation and electricity sector. The BTP creates policy and suggests it to the MED for implementation. While, in general, it should be the Minister of Economic Development and his/her Ministry in-charge of creation of policy. That doesn't seem like the case here. Here, BTP is in charge of developing policy and regulatory framework for the electricity sector and also in charge of monitoring developments in the local and international electricity markets. Further, BTP also plays an advisory role on every other issue concerning the electricity sector.

Users

The primary role of users in the energy market is that of consumption of energy. However, in recent years there has also been a few users that return some electricity to the grid. The Central Bank of Curacao and St. Marteen set up a 700kW solar system to run their bank. While 3 major super markets (Goisco, Mangusa, Centrum Supermarket) have also begun using solar panels to run their stores. Apart from this there are small individual households also that use solar energy to power their houses.

Research and Knowledge Institutes

These institutes are generally present to improve understanding and knowledge of the situation. In terms of local research and knowledge institutes, Curacao has the University of Curacao that provides for a BSc. in Electrical Engineering with a major in Energy Technology. They perform limited research on Energy Technology on the island. The Caribbean Research and Management of Biodiversity (CARMABI) is one of the most influential environmental and ecological research centres in Curacao. Almost all the research on the energy infrastructure is conducted by the Curacao government or private/ state owned energy companies through foreign consultancies; mainly using their relation with the Dutch mainland through Ecorys, or Dutch Universities like Technical University of Delft and Twente. Further, UN Economic Commission on Latin America and the Caribbean (UN ECLAC) a local UN organization also helps with research sometimes.

Non-State Actors

Their role is predominantly using the media to raise awareness. There is only 1 organization called the Association of Sustainable Energy that tries to fight for the energy issues of the island, to an extent. They seem to be association of all the small scale renewable energy generators. Further, there are several environmental organizations that try to get the ISLA plant closed because of its severe negative environmental effects.

Media

They are the most important information dissemination tool. They have 28 licensed radio stations, 6 licensed TV broadcasting stations, and 8 daily newspapers. They are currently sparingly used to inform the public about the energy issues and the energy transition.

Financers

Financial institutions play a role for the purpose of providing loans to finance the large projects, insuring these projects from any liabilities and providing financial reliability for the government to trust a particular company with a certain project and also provide reassurances for other companies working with the particular company. It should be noted that almost all banks and investors are looking for low risk, high profit adventures to finance. Maybe a few developmental banks and a few locally owned banks may have a higher threshold for risk but not too high. In total there are 55 financial institutions in Curacao. International developmental banks (Eg: World Bank) and other regional developmental banks are also generally quite interested in funding such projects.

In an attempt to concisely present all the aforementioned information there is infographic presented below in which the most important stakeholders and the energy system are presented together.

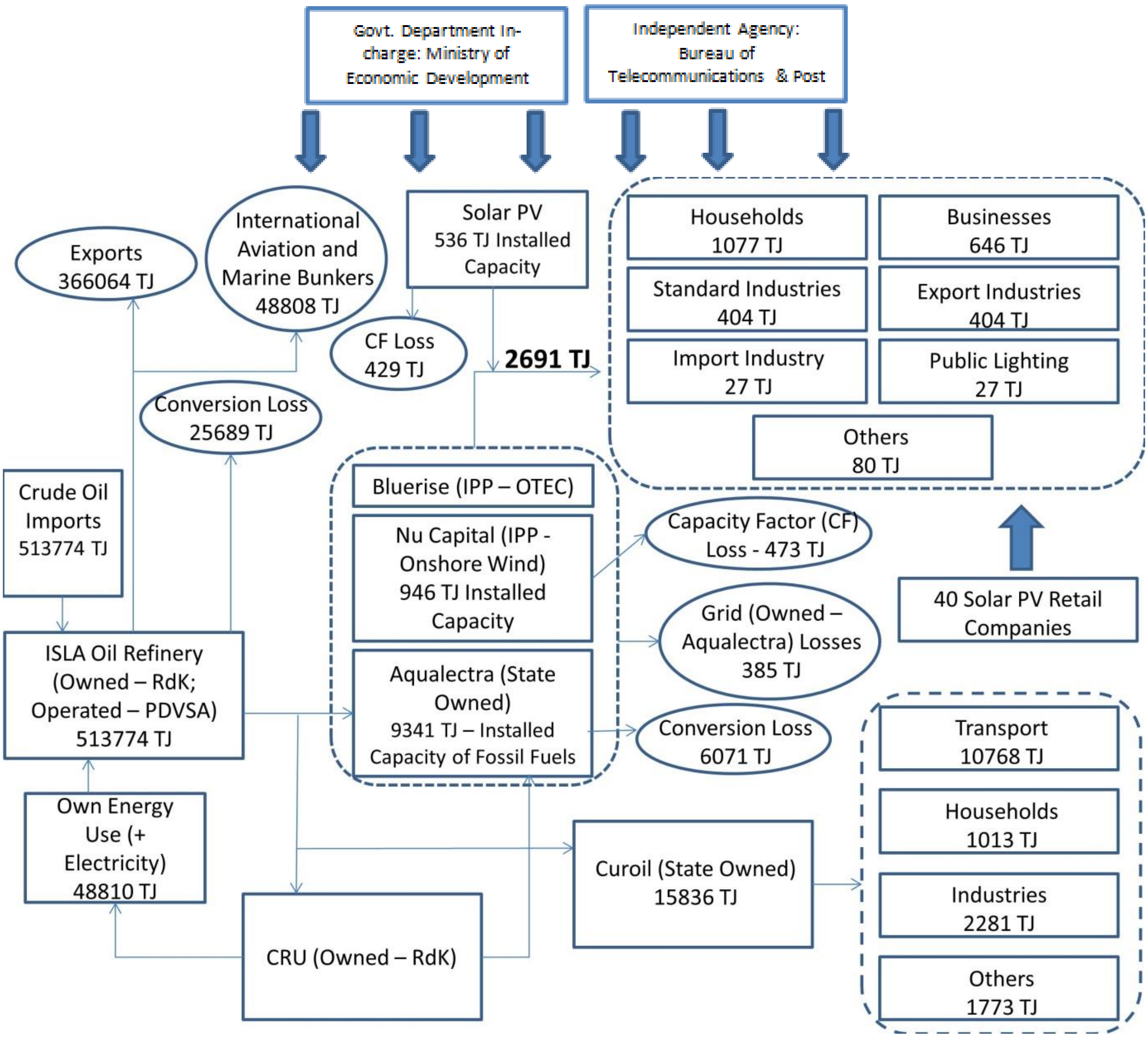


Figure 23. Connection between Stakeholders and Energy System

4.1.3. PESTEL

Factors	
Political	• Having a Coalition. No single party majority. • Criminal and Civil cases NL Supreme court still the highest authority • Constant change in Government • No ministry for Energy • The Bureau of Telecommunications and Post an independent agency supervising the development of Energy sector (Advisory and Supervisory role). • High amounts of bureaucracy • Need not adhere to international treaties if NL doesn't *'extend'* the treaty to Curacao • Rampant Corruption within the state actors • The state of Venezuelan politics • The UNDP is currently assisting the Central Bureau of Statistics with the creation and institutionalization of the national socio-economic database,

Economic	• GDP per Capita 20, 126 USD (2014) • Economy Tourism, trade, oil refinery industry, ship repair and maintenance, and financial offshore • Cost of electricity – Residential – 0.38 USD/kWh (Average) Commercial – 0.39 USD/ kWh Industrial – 0.28 USD/kWh (Averaged across all categorizes of Industries) • FiT rate – 0.15 USD/kWh (2015) • Solar Tax (2015) 9 USD/ month – Residential Systems 18 USD/ month – Commercial System Eco Energy reports that they request for solar installation reduced from 4 a week to around 4 a year. They laid off 16/22 staff. Payback period for rooftop solar has risen from around 5 years to more than 10 years • Economic Crisis in Venezuela • EU has offered to fund RE Development in Curacao
Social	• No evidence of large population interested in transition • ISLA Power plant employees a large number of people a 1000 direct jobs (this number was higher earlier) • Technical (Engineering) education is sparse. • No technical training programs • Main incentive to improve energy efficiency is monetary • In Aruba there is already opposition to more wind turbines. May not be the case in Curacao because of the large amount of available land. Area of Aruba is around 180 km^2 and for Curacao is 444 km^2
Technologica	Has been dealt in detail earlier.
Environmental	• Land Use: 10% for Agriculture - 44 km^2 Total Protected Land – 84 km^2 Available land left – 316 km^2 • Average Temperature Around 29^o C • Average Wind Speed @ 30 m 8-9 m/s • Average Wind Speed @ 50 m 9-9.5 m/s • Direction of Wind NE to SE • Sun hours per day 9 (approximately) • Solar Irradiation in 2015 2027 kWhr/m^2
Law	Sun Tax Feed in Tariffs Energy Conservation of 40% by 2020 but no policy to support this No Sustainable Energy plan No Renewable Energy Targets PPAs for large scale Renewable Installations Tax exemption for RETs imported No Energy Efficiency Laws No laws governing the transportation sector 2 laws regulating the price of the electricity and transport sector

Figure 24. Factors affecting Deployment of Renewables in Curacao (Caithlin Ann Marugg, 2016; Centrale Bank van Curacao en Sint Maarten, 2015; Curacao Chronicle, 2016; Government of Curacao, 2011; Hanst, 2006; Ministry of Health and Office of Foreign Relations, 2014; Niel Gradner et al., 2013; Prochazka, 2012; van Eldik, 2015)

4.1.4. Renewable Energy Resource Potentials

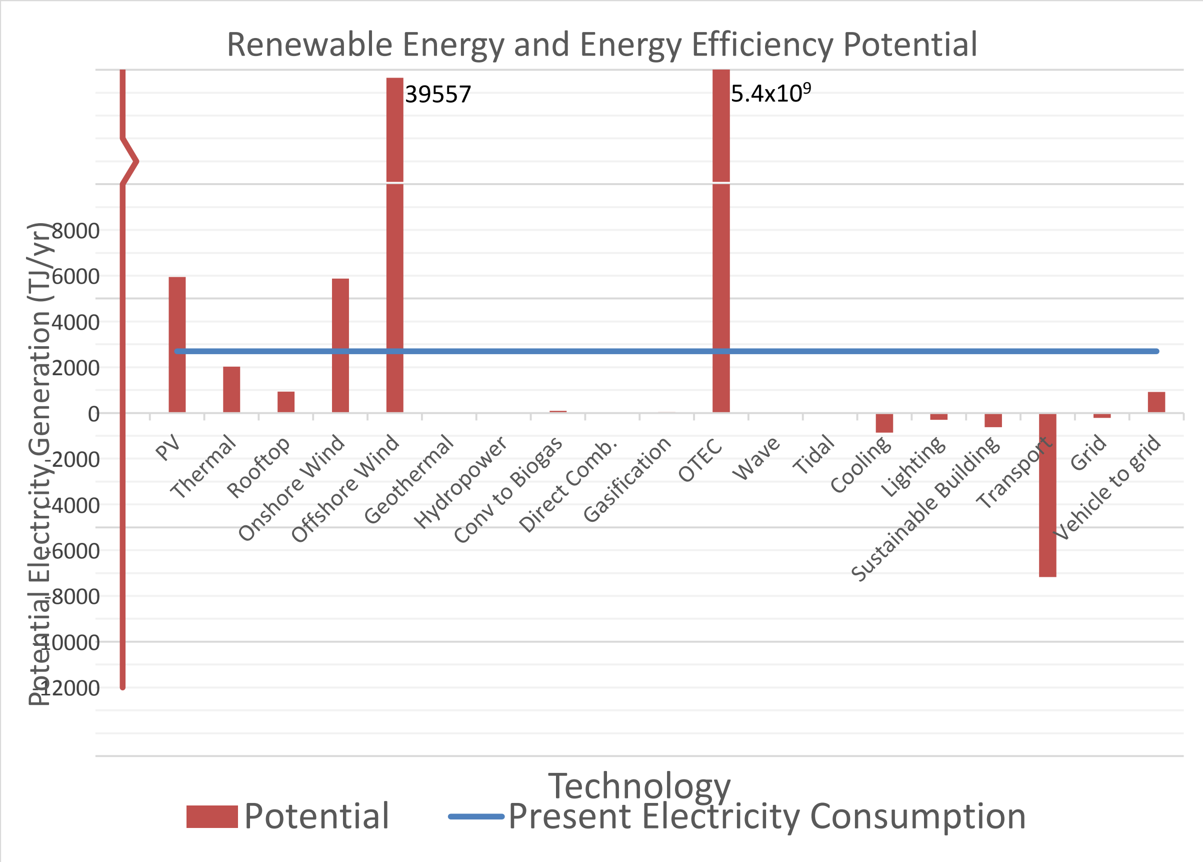


Figure 25. Renewable Energy and Energy Efficiency Potentials of Curacao

The present consumption today is 2700 TJ. It can be seen the utility scale solar PV, Wind energy, OTEC have the greatest supply side technical potential to contribute towards the transition. From an efficiency stand point, very clearly shifting the transport sector to all EVs will have the greatest impact. Vehicle to Grid can also serve a very crucial role provided the supply side is largely intermittent.

Please note that all the assumptions and the calculations of how these values were arrived to are mentioned in appendix 1.

Further, there are a few more points to be noted here:

1. Almost all these estimations are conservative estimates and go higher.
2. Solar Energy and Wind Onshore calculations have assumed only a 5% usable land area for deployment. However, there is a lot more land available which can be potentially utilized.
3. Solar energy potential has been calculated using the Global Horizontal Irradiation however in reality the irradiation for the optimum angle of the panel is used. This data was not available. The optimum inclination angle of course is equal to the latitude of the location (12^{o}-13^{o} North)
4. Offshore wind was considered deployable only for water depths up to 60m and that coupled with the fact that the trend is to install them as far away as possible from the shore the calculation considers only a 1 km length within which offshore turbines can be

installed. However, if floating turbines are commercialized by 2040 (which they could be) then the potential can increase by 200 times and more.

5. With regards to OTEC the only limiting factor to calculate resource potential is the temperature difference between the surface and the water at a depth of 1000m. This should be more than 6-7 degrees which is the case in Curacao. This temperature difference is noticeable 3 km from the shore. Therefore, beyond that mark an OTEC plant can be installed anywhere.
6. The efficiency calculations are all based on the current year of 2014.
7. The transportation efficiency increase is dealt with the simple perspective of converting the entire transportation to electric. This is simply because my vision supports this change.
8. There is a case to me made that there are other efficiency measures that have not been considered and that what is being proposed is more a case of the substitution effect and not traditional efficiency gains. But how this needs to be looked as from a perspective of a range. What I have spoken about it the maximum possible efficiency gain in a sector, so if any other efficiency measure is considered then it will fall within the range mentioned above.
9. Other household appliances are not considered because it is assumed that even if they do have efficiency gains there would in general be an increase in the quantity of the appliances which will negate the efficiency gain.

4.1.5. Cost of Renewable Energy Technologies in the form of LCOE

It helps now that we know the potential of various RETs to know how much they cost because if they are not economically competitive then the technologies may never be used.

The data below has been collected from different sources and therefore the process of calculation is not looked into. There are still a lot of technologies that can be covered in this table but to limit the scope only the above are going to be considered.

There are 2 things to note for the cost of OTEC mentioned here:

1. The plant size varies from 1MW to 400 MW
2. The IRENA report has a table with publications from 2007 until 2012 which have calculated the LCOE for OTEC and what is seen here is the least value and the highest value from that table.

Last and most importantly, it should be noted that currently the cost of electricity is close to 0.32 USD/kWh and the information over here provides nothing more than an indication of cost competitiveness of renewables when compared to the current actual price in Curacao. However, beyond this indication the LCOE holds no more value, this is because decisions by businesses on whether to invest in an energy project is based on Payback period and the Net Present Value. Further, when talking about Renewable Energy sources it makes more sense to talk about it from a Levelized Cost of System (LCOS) perspective than from an individual technology perspective because with the intermittency comes a lot of auxiliary equipment that’s needed. Mainly, the LCOE doesn’t reflect the biggest barrier of investing in RE Technologies which is the high investment costs and here is where it is an issue for islands.

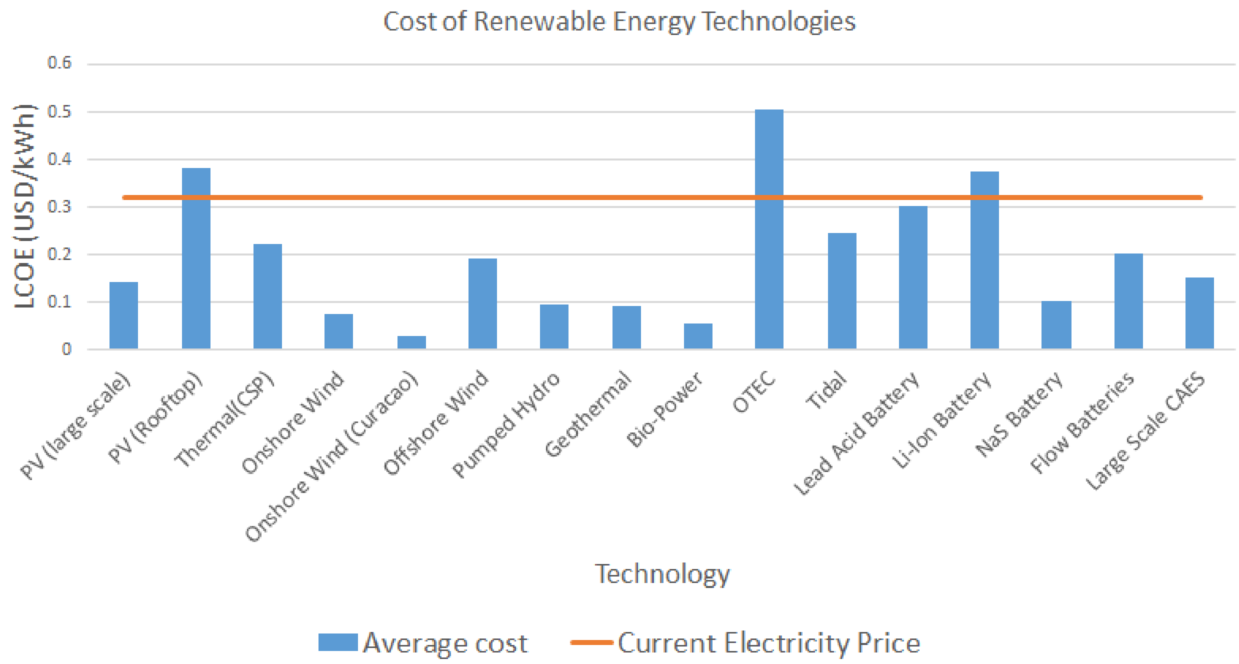


Figure 26. Cost of RETs in comparison to today's Electricity Price at Curacao (Hensley et al., 2012; IRENA, 2015; Ochs et al., 2015; REN21 Secretariat, 2015; REN21 Secretariat, 2016; Schelleman and van Weijsten, 2016; Shirley and Kammen, 2013)

4.2. Step 2: Creation of Future Scenario

There will be 2 scenarios created for the island of Curacao. Both these scenarios will be technical scenarios which will involve only sizing of the energy system using different technologies. Every other aspect is assumed to be a consequence of the desired technical structure of the energy system.

The two scenarios are

1. Wind Energy, Solar Energy and Battery system (including Vehicle to Grid)
2. The Ocean Hybrid Renewable Energy System: OTEC, SWAC, Wind Energy, Solar Energy and Battery system (including Vehicle to Grid)

The reason for not selecting other potential technologies is because of the simple reason of limiting the scope of research.

Assumptions:

1. Giving 23 years from today (2040) for OTEC to reach maturity and become commercially competitive
2. The entire local energy sector will be electric by 2040
3. The tourism industry will also grow and the population will also increase.
4. The import of crude oil will stop because of the closure of the oil refinery
5. Only oil products will be directly imported.
6. Every power plant producing electricity using fossil fuels for the locals will be shut down by 2040
7. The island will be energy self-sufficient at the very least
8. **Transportation sector:** the number of cars grows at the same rate as the population in the country. The current population is 159000 that will increase to around 179000 by 2040 at a rate of 0.5% increase per year. Similarly currently there are 85000 vehicles in Curacao. At the same rate of increase there will be approximately 96000 vehicles.

a. With regards to transportation we assume complete electrification therefore the energy consumption will reduce from the current 44000 TJ to 11000 TJ. However, there are studies that show that if the entire car fleet of the EU were to electrify it will increase electricity consumption between 20% and 30%.
b. **So, we are going to use that and say that in 2040 the energy/electricity will increase by 25%.**

4.2.1. Scenario 1: Technical System (2040) of Wind, Solar and Battery

The first step is to understand the **energy demand** that has to be met:

1. The GDP is going to increase at a nominal 1% or less at least still 2021 based on IMF projections. It is safe to assume a similar trend until 2030 and after which the economy will grow at a rate of 3% based on estimations made by the Curacao government which assumes a certain few programs to be implemented and a few regulatory changes to happen. Unfortunately, there is no sign of that happening immediately. Therefore, this research assumes that kind of growth to happen much later and assumes a growth rate of 1% until 2021, 2% until 2020 and 3% until 2040.
2. However, the energy consumption flattens after the GDP per capita of a country reaches close to 20000 -22000 USD, this is trend visible in other countries. This predicated on energy efficiency improvements and also the economy shifting from a manufacturing economy to a service based economy. This may not hold true for Curacao even though the current GDP per capita is close to 21000 USD because it never really had a manufacturing based economy, mainly a service based economy. And also currently there are no policies in place to improve energy efficiency.
3. So, assuming that the electricity consumption increases linearly with GDP; for this scenario this research the electricity consumption will increase from 2800 TeraJoules (TJ) to 4500 TJ, in line with the estimation that the economy will grow at a rate of 1% per year until 2025 and then 2% until 2030 and then at 3% until 2040.
4. Therefore while in general the energy consumption will decrease because of the electrification of the transport system, the electricity consumption will increase dramatically.
5. This scenario also assumes that there isn't really any efficiency gains made otherwise that can help reduce the energy consumption of the system.
6. The scenario assumes approximately a 3% increase per year of electricity consumption at an average. But, of course, this will not happen because the increase will depend on the electrification rate of the transport sector.
7. Including the energy increase by 25% due to electrification of transportation sector, overall energy/electricity consumption increases from 4500 TJ to 5625 TJ. This is a double of today's electricity consumption which is 2800 TJ.

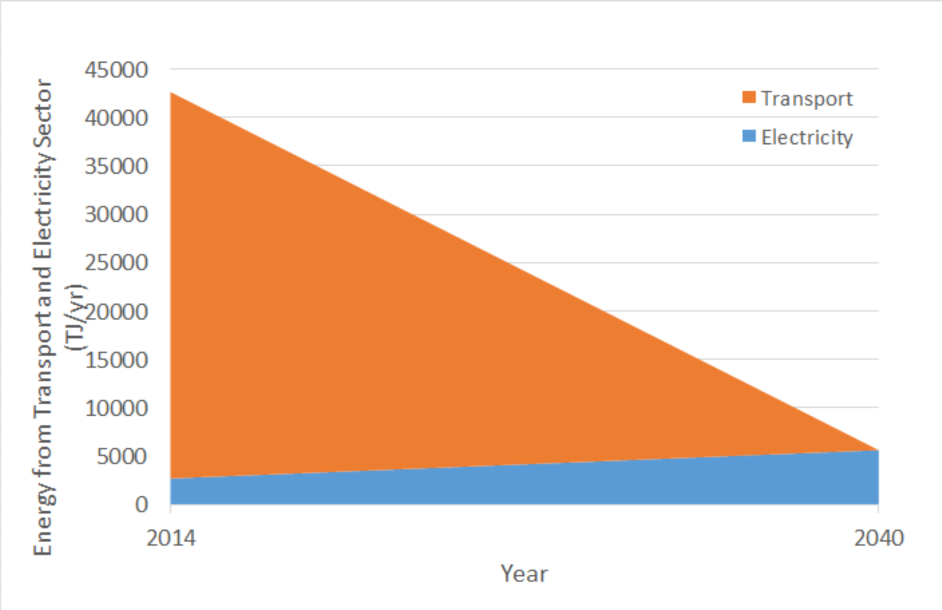


Figure 27. Change in Energy Sector from 2014-2040

Now, we need to figure out how this 5625 TJ of demand will be met. **<u>How does the energy supply look.</u>**

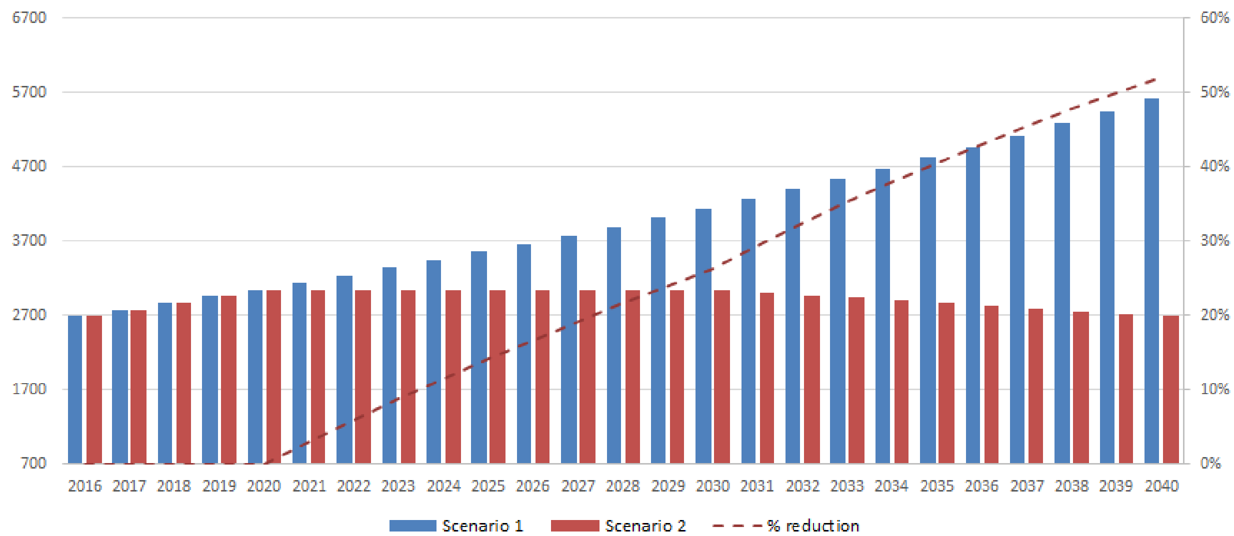
8. Based on Dean's Energy Model for this consumption installed capacity of PV is 910 MW; 440 MW of wind and 7.65 GWh of Battery at a cost of 0.33 USD/kWh (after incorporating cost reductions for 2040). This is comparable to today's cost of electricity.
9. Though the **<u>land area</u>** required for this large an installation needs to be checked.
    a. 910 MW of PV will occupy a land area in between 25 to 30 km^2 which is between 5.6-6.7% of land area on the island.
    b. At a capacity factor of 20% 910 MW will produce 1595 GWh of energy which is within the technical potential of Solar PV on the island. Further, comparing this to the conservative Rooftop PV estimate it can be said that around 20% of all production (319 GWh) can be covered by rooftop PV however the rest of it will need utility scale solar PV.
    c. 440 MW of onshore wind turbine will also require around 26 km^2 of land area or around 6% of the total land area of the island.
    d. At a capacity factor of 50% 440 MW of wind will produce 1925 GWh of electricity annually which compared to the potential of total (onshore and offshore) wind energy is definitely feasible.
    e. Of course, if the installed wind turbines are off shore then only 1 wind turbine can be installed within a circular area of 3 km^2. This means that a total area of 330 km^2 (0.2% of the total) would be required assuming installation of 4 MW turbines, which is plausible considering there is potentially 158000 km^2 of available ocean area to use.
    f. **<u>So, in total around 10-12 percent of the land area of the island is required to install the required amount of Solar and Wind (onshore).</u>**
    g. **<u>To put this in perspective, the entire land area of Delft is around 26 km^2</u>**
10. In terms of **<u>installation cost or investment cost</u>**:
    a. 990MW of utility scale solar PV will cost at a maximum 2.08 Billion USD. (1810 USD/kW)
    b. 440 MW of Wind Onshore will cost a maximum 6.86 Million USD (1560 USD/kW)
    c. 7.65 GWh of Li-ion Battery will cost 3.8 Billion USD (500 USD/ kWh)

11. The costs for Solar PV and Wind are from 2014 but it should be noted that Solar PV costs have reduced by more than half in the last 3 years. The costs for Li-Ion battery is from 2012 at 500 USD/kWh but today prices are at around 250 or less. This is also the reason the term maximum cost is mentioned because the prices will keep reducing and will never actually cost 12.74 Billion USD. In comparison assuming that Curacao like most other Caribbean islands spends around 10% of its GDP on importing oil, then it will spend approximately 560 million USD per year, which is also approximately 12.8 billion USD by 2040. However, the difference is that there are no guarantees that the oil prices will remain low.
12. **Jobs:** There are various ranges for how many jobs will be created but at an average 1.5 jobs per MW of Solar PV and 0.5 jobs per MW of Wind onshore. So, in total 1500 jobs by Solar PV and 220 jobs from Wind onshore. So, 1700 direct jobs at the very least. Of course, because of rooftop solar, wind offshore, and battery installation the number of jobs will only increase. This is not to mention from the EV industry. Compared to the 1000 jobs created by the oil refinery today and 0.8 jobs at an average per MW of diesel installed so today there is 135 MW that means a 108 jobs. So the electricity industry employees around 1100 direct jobs. This number will only decrease if the oil refinery and the plants are made more efficient.

4.2.2. Scenario 2: Technical System for an Ocean Hybrid RES

1. Using the electricity increase pattern as a baseline for this scenario.
2. Assuming that the electricity demand will rise until 2020 and then flatten out until 2030 because of energy efficiency playing a role and then between 2030 and 2040 the energy efficiency will lead to a drop in the electricity demand to levels comparable to today. This leads to an energy efficiency target of 50% by year 2040.
3. **This is 3% energy efficiency gain per year starting from 2021.**
    a. This reflects an almost 50% reduction in energy consumption value in the year 2040 compared to the energy consumption value in Scenario 1 for the year 2040.
    b. The efficiency values calculated here are lower estimates what can actually be accomplished. And not to mention that the efficiency gains mentioned here are based on values achievable today and it is assumed that over the next 20 efficiency gain percentages in each appliance will only increase.
4. The energy demand in the transportation sector will see the same change as aforementioned.
5. Therefore based on L. van Velzen's thesis: This demand is met by **150 MW of OTEC, 150 MW of Solar PV, 50 MW of Wind Energy and 175 MWh of Battery Storage.**
6. This system will **cost around 0.22 USD/kWh** cheaper than today's cost of electricity.
7. In terms of investment cost is will cost:
    a. 150 MW of Solar PV will cost 271.5 Million USD at maximum.
    b. 50 MW of Onshore Wind will cost a maximum of 78 million USD.
    c. 175 MWh of battery will cost a maximum of 87.5 million USD.
    d. 150 MW of OTEC can cost around 2.25 Billion USD (15000 USD/kW)
    e. **The total is 2.69 Billion USD approximately**
8. The reason for the uncertainty of investment cost is because of OTEC. It is said that large scale OTEC can cost anywhere between 5000 to 15000 USD. While the maximum amount from the range has been chosen, it is improbable that the first deployed OTEC plant will be a large scale plant. So, in the situation a small scale plant is opened then the cost can vary from 16000 USD/kW to 32000 USD/kW. The costs of solar, wind, and battery are the same as in scenario 1.
9. **Jobs:** 150 MW of solar will being about 225 jobs. 50 MW of wind will bring 50 jobs. 150 MW of OTEC should bring less than 4500 jobs. This is because there isn't any global average available therefore the 500kW being made by Bluerise is said to employee 15 people. So, accordingly the amount has been extrapolated, however, this will reduce over the years.

10. In terms of land area:
    a. The Solar PV will require only 5 km^2. The Wind Energy will require 3 km^2 for onshore installations and will require 36 km^2 if it is an offshore installations and OTEC plant will require 0.0025 km^2 worth of deck area and including spacing anywhere between 40 km^2 to 200 km^2, all of this is more than available.
    b. Even in terms of potential if compared 150 MW of Solar PV at 20% capacity factor will produce 262 GWh of power and wind of 50 MW will produce 219 GWh at 50% capacity factor, both of which are within the calculated potentials for the island.
11. A few more things to note here:
    a. The numbers for installed capacity of wind, solar and battery are based on the average of 5 simulations. This means that the cost optimal system will still be reached irrespective of the change in installed capacity of Solar and Wind.
    b. Further, the model estimates that the cost of the system will be 0.22 USD/KWh in 2025, this is mainly because of the cheap cost of OTEC in per kWh terms. So one take away is that by 2040 the cost of the system in terms of LCOE will be far more affordable. However, this is improbable for 2 reasons, economically speaking the problem with OTEC is not cost/kWh but rather the investment cost which is tremendously high. Second, is that technically and commercially speaking OTEC is not yet that developed to have a 150 MW worth system in place by 2025. So, for this work we assume that the cost of the system will reach 0.22 USD/kWh by 2040 by which time we assume that OTEC will be commercial.



4.3. Step 3: Backcasting

4.3.1. Scenario 1: Simple Hybrid RE System (Wind, PV, Battery)

Technological Change

<u>What?</u>
This section deals with the main technological changes that the island will have to undergo for this transition to become a reality.

The technological changes needed for such a scenario can be looked at from the energy supply side wherein there needs to be shift from using fossil fuels to renewable energy production. This will require a large installed capacity as mentioned in point 14 of the delineation of the technical system of scenario 1 above. This will also require the introduction of close to a 100,000 electric vehicles into the transportation fleet. This will include mostly private vehicles or taxis (small sized) but also a few thousand large sized buses for public transportation. The latter is the more complicated transition because large buses require a lot of energy to run as a consequence of transporting more people, running longer hours.

<u>How?</u>

There are essentially 7 things that need to happen for this change to take place.

1. First thing that needs to be done is a 4 technical assessments; a detailed resource assessment, spatial assessment, environmental impact assessment and then finally a feasibility assessment. They form the bedrock of any project that is successfully implemented.
2. A comprehensive study on the potential of rooftop solar needs to be undertaken. A comprehensive study on the comparative cost between fossil fuels and renewable energy on the island. A Worldwatch study for Jamaica claims that the island can save 12.5 billion USD by 2030 if 90% of the electricity sector is powered by renewables.
3. Better weather forecasting models and assessments have to created and utilized so that the exact amount of energy that will be produced can be predicted with accuracy and precision.
4. 440 MW of wind turbines need to be installed. While there should be already 46.5 MW of wind turbines installed, it should be noted that 30 MW (3 MW x 10) were installed in 2012 and 16.5 MW (3.3 MW x 5) were installed in 2017 and assuming 20 years as lifespan by 2032 and 2037 they will have to be replaced. So, assuming that henceforth only 4 MW turbines are installed a total 110 units of turbines need to be installed in total. A market penetration rate of a little above 10% compared to the previous year, starting in 2018 would help reach the 440 MW target. While this penetration rate dictates a linear trend of installed capacity, it should be noted that this will never happen. But it gives an indication of the task at hand and how difficult it may get.
5. Similarly for Solar PV 910 MW needs to be installed. While currently there is 17 MW already installed assuming a 20 year lifespan it will have to be replaced by 2035-2037. Therefore, assuming a smallest 150 W_p panels, to installed 910 MW Curacao would require to install 4,550,000 units of solar PV panels. To match this high an installed capacity a 19% annual penetration rate, as compared to the previous year, starting from 2018 would be needed. However, considering the easiness of installing PV panels it might be more appropriate to install as and when a fossil fuel power plant shuts down.
6. Fossil fuel power plants need to shut down eventually. There are currently 138 MW worth of fossil fuel power plants installed across 4 power plants. Apart from the New Dokweg plant the other 3 plants are old and can technically be shut down anytime now. While a rate of 7% decrease annually, compared to the previous year and starting from 2018 would help reach the target of by 2040. However, it doesn't work like that. A plant would generally be shut down in entirety. In this situation it would be beneficial if there was 1 plant closing in 2025, then 2030, then 2035, and then finally 2040. Obviously, the New Dokweg plant shuts down in 2040. This will help with the transition immensely as it helps pace introduction of intermittent renewable energy and also help pace the introduction of batteries into the system.
7. Finally, we need to talk about transportation as of 2040 there will be a need of approx.
   a. 96,000 EVs in the system. And currently there is absolutely no market for it. So assuming a start in 2020. Within 20 years, 96000 vehicles need to be converted from ICEs to EVs, at a rate of 4800 vehicles per year. It should be understood that a niche technology such as EVs will follow a S-curve for diffusion. Assuming a 15

year lifespan for a vehicle and that there are equal number of vehicles that are 1 year old, 2 year old and so on, then we can assume that 1/15th of all vehicles are decommissioned every year. Currently there are 87000 vehicles that means 5800 vehicles are discontinued every year and new vehicles are bought. This value is greater than the number of vehicles that need to convert to EVs each year. Therefore, in theory, this offers a very simple and easy solution to achieve this. A comprehensive study on how to create an EV market on Curacao needs to be undertaken as this will be toughest challenge for the country.

Why?

It must be noted that only the resource assessment and the spatial planning can be done beforehand by the government and the EIA and Feasibility Study is project specific and generally is conducted by the company interested involved in the project. However, an EIA must be mandated by the government and private companies do not always do it voluntarily. This is because EIAs can be time consuming and can cost a lot. Along the same lines, performing the resource assessment and spatial assessment beforehand is beneficial for 2 reasons, reduces transaction costs of the project and also quickens the administrative process of getting the project into operation.

A specific mention of small scale PV Is mentioned simply because this scenario is land intensive. It requires more land than the entire area of Delft city. Therefore, for islands, it makes sense to first concentrate on rooftop solar and community solar; the remaining can come from large scale solar projects.

A cost comparison is paramount because everything is based on cost. Curacao does not have a whole lot of money in its budget and therefore, there is a need to understand that the transition will save money for the government as mentioned in point 10 and 11 from section 4.2.1. This is also useful to make the public understand the need and therefore making sure that the political parties remain true to this commitment.

Everything else is build investor confidence because they look at penetration rates for EVs, PV and Wind along with the removal rate of fossil fuel and it develops a sense of assurance that the government is serious. The most important, personally, is to mention the decommissioning rate of fossil fuels.

Who?

Energy Companies, Ministry of Economic Affairs, Ministry of Energy (when created), independent agency that checks the energy market, and Aqualectra

Societal Changes

What?

This section deals with the main cultural and behavioural changes that the island population needs to undergo. The island population is currently ill informed and therefore less bothered by the how they get their energy. However, the fact that the energy is not regular is a constant point of annoyance for the public and the businesses. So, the changes that need to happen are that there needs to be a higher acceptance of renewable energy/sustainability and also recognition of the ill effects of the fossil fuels being used. This is important because there shouldn't be public resistance to the transition as seen in Aruba. The chances are smaller at Curacao because of the large land area available but an informed electorate also helps the government make more aggressive moves, if required. Further, to counter the brain drain people should remain on the island work towards improving their country. In terms of accepting EVs the fear of not being able to travel the distance should be removed. The consumers should embrace the concept of becoming their own energy producers.

How?

There are a number of things that can be done. This section will deal with the activities that need to happen but not from a government institution standpoint. That will be covered in the structural changes section. There are essentially 4 points to be made here:

1. The population needs to be better informed about the advantages of Renewable Energy Systems and EVs; specifically targeting the issue of range anxiety for EVs.
2. More information on the ill effects of the fossil fuel power plants and ICEs.
3. Information on potential of job creation helping reduce the brain drain on the island
4. Better understanding of the economic benefits of switching to Renewables and EVs.
5. Creating a 1 stop webpage to know it all.
6. The population needs to get more politically involved in the sense that they should demand knowing and understanding the complete impacts of all policies that are to be implemented by the government.
7. Catch people early in schools and universities. This will be dealt with in educational change.
8. People should be more entrepreneurial and create their own businesses working towards the energy transition.

Why?

All of this will help improve the acceptance of renewable energy systems and EVs. Hopefully, this will also help reduce the fear of unemployment and costly renewables due to the transition. It can seen from point 12 of section 4.2.1. that this transition has the potential of employing more people than the fossil fuel industry. Further, this has the potential to galvanize the political attitude towards RETs and EVs and make the policies remain largely consistent between changing governments.

Who?

The people of Curacao, All schools, universities, Curacao government, NGOs, unions, local associations

Structural Changes

The structural changes that will be discussed in terms of the required institutional changes, governance changes, regulatory changes and infrastructural changes

Institutional Change

What?

1. Creating supporting institutions relevant to the energy sector
2. Changing the portfolios of existing institutions to potentially suit the requirements of the transition
3. There should be a more extensive data gathering methodology. There is severe lack of data from the demand side sectors, especially transportation.
4. Educational institutions play a far more relevant role in the transition
5. Reducing the number of people that leave the island to help reduce the brain drain.

How?

This can be achieved be initially setting up the following departments:

1. Creating the Dept. of Energy and Power, therefore removing this portfolio from the Department of Economic Affairs and the Bureau of Telecommunications and Post.

2. Creating an institution to monitor progress of the government initiatives, policies and in general the transition and finally, creating independent regulator with an expertise in the energy sector that is not the telecommunications and post bureau.
3. Further, it is also not a bad idea to have an organization similar to the Social and Economic Council (SER) of the Netherlands within the government that helps organize participatory work for the government and manage the transition specifically.

Also certain organizations need to have their portfolios altered to meet the need:

1. The role of Bureau of Telecommunications and Post should be reconsidered. It should either be downsized to what it is supposed to handle telecommunications and post or expanded by looking into incorporating more ICT into the energy infrastructure (smart energy sector).
2. Further, Aqualectra should be more involved in maintain the electric storage infrastructure of the island and the transmission grids, thereby handling balancing of the supply and demand of electricity on the island. And working on the balancing of the grid and this can only happen when there is better forecasting of what the supply because of the intermittent nature of the technologies that going to be used. As mentioned in the previous section also.
3. Finally, the CBS should have a more broadened portfolio and should handle all data related to the island. Maybe work with international organizations to understand the key indicators related to the energy sector that needs to be reported on. And also supply a comprehensive energy balance for the country. All this data should be public and extensive.

The education institutions should play a pivotal role in the transition by reducing the brain drain that is predominant in the country:

1. They should get into formal Memorandum of Understandings with universities abroad to provide the expertise in research and professors for the university. This can also include research collaborations with the 4TUs, thereby taking advantage of being a part of the Kingdom of Netherlands and the EU.
2. They should work with international educational networks like the ISCN to not only include sustainable practices in operating their universities but also to develop new programs that educate the youth on sustainability, renewable energy and electric mobility.
3. They can potentially also provide professional training programs created and conducted in collaboration with regional and international organizations that the government has become a part of.
4. Create study programs that teach about energy transition, transition planning, sustainability, renewable energy
5. Start extensive research on the energy sector

<u>Why?</u>

Any new creation of institutions or change in roles of current institutions is being done to streamline the roles that the government needs to play in the transition. It also helps with increasing investor and bank confidence on the island, therefore potentially reducing risk perception. This also helps create the required institutional capacity to properly regulate the energy industry.

The requirement of the changes in educational institutions is to mainly address the brain drain issue that the island faces. After which is helps address the severe lack of research on the island and most importantly it makes use of the advantage of being part of the Dutch Kingdom/EU.

Governance changes

What?

The required governance changes are angled towards improving transparency to the public and world and most importantly trying to answer the question how to improve investor confidence so that private investments (Foreign Direct Investments) are made by more companies.

1. The government should take a more transparent, participatory, predictable, and stable approach to governance, thereby improving investor confidence and global perception.
2. The government should work on empowering the citizens through more information and communication and involving them in decision making.

How?

The government should do the following with the view to alleviate investor scepticism and help provide a more reliable perspective of the country to attract investments:

1. Joining the required regional and international networks to potentially increase research capabilities, receive expert advice on the transition, get help in managing the transition, getting help in creating the required work force in terms of training programs. Most importantly meeting potential companies from the supply chain of the renewable energy industry which is important. Examples of these networks would be CARICOM, IRENA, IEA, etc.
2. Plan long term by creating vision documents and roadmaps and declaring intentions/goals/targets.
3. They should keep all the stakeholders informed to reduce market anxiety, preferably create policy with their participation (this includes involving the local population in the process). This is also where an organization like SER (mentioned in the previous section) is beneficial.
4. They can arrange such workshops and conduct surveys and opinion polls on an annual basis within the public and the private sector, to understand their grievances and changing things accordingly.
5. Tackling transparency can be achieved by creating a single point (website) for everything energy related (as mentioned in the how section of social changes). This website should have documents on the process involved to establish a RE project in the country, among other things.
6. In general the population on the island should be more informed about sustainability and the energy transition and the benefits of it, this is where having a comprehensive policy package interconnecting all departments of the government will help. This will be able to talk about large size benefits.
7. To tackle the massive barrier of capital cost of RE the government should work with the relevant international agencies like World Bank, IMF, Standard and Poor to improve macroeconomic stability and credit worthiness. This is of course beyond all the other steps mentioned in this process.
8. The government should play a leading role in this transition by public procurement policies thereby raising awareness also.

Why?

It should be noted that every activity mentioned here contributes to improving trustworthiness of the country. It reduces risk perception, which has the potential for a less interest rate on the loans lent for projects on Curacao. It reduces transaction and capital costs for the project.

Regulatory Changes

What?

There are only 3 main changes required; the regulations should be predictable, stable (yet dynamic enough to incorporate exogenous changes), and most importantly transparent and secure. There should be regulatory help to incentivize people from leaving the island.

How?

This is interconnected with the good governance section.

1. This can greatly be facilitated if the country created a National Energy Plan with the involvement of all stakeholders.
2. This should be supplement that with a sustainable energy transition roadmap (as mentioned in the previous 'how' section).
3. Further, this would be benefited by performing a detailed resource assessment on the island for the relevant renewable energy technologies and perform a spatial analysis and allocate certain areas just for renewable energy instalment (just like they have a certain area allocated for export based industries called the e-zone). This will go a long way in reducing red tape and reducing transaction costs. The previous 3 points should ideally represent a highly planned transition.
4. Incentivize renewable energy through price based policies at least initially, if required move to volume based mechanisms but eventually when there is a certain competition in the market then introducing auctions. Currently, renewable energy is incentivized through Power Purchase Agreements (PPAs) for large scale projects and Feed in-tariffs (FiTs) for small scale projects much like what is being done currently. This is important because these two mechanisms are the most trustworthy support schemes today. Also, provides capital and revenue support for the companies.
5. Removing barriers like the Sun Tax or at least reducing it. The FiT was working too good, and potentially lead to the overheating of the small scale PV market, by that there are more interconnections than what Aqualectra could handle. However, this Sun Tax has killed the market and therefore, should be revised to bring the small scale PV market under control and not stop it completely.
6. The PPA and the process to get a PPA needs to be more standardized and less ad hoc. This helps in reducing transaction cost for companies wherein they spend less time assimilating the information and less time negotiating the right PPA.
7. Eventually a more dynamic FiT regime needs to be incorporated which annually revises the Price and maybe move from a fixed price FiT to a Premium based FiT in the late future. This will help reign in expenses but works on dynamic electricity pricing through spot markets, so this is a something that needs to be researched into further into the virtue of setting up a spot market.
8. Tax incentives should also be given to any company or individual who wants to set up a RET plant. This helps reducing the upfront cost of the project and also transaction cost because no filling of taxes is required.
9. This can also be achieved by introducing fossil fuel disincentives through taxing carbon or the use of ICE vehicles but this is complicated so should be used as a last resort in the long term. However, In general, if the market takes notice of the opportunity for RETs and EVs on Curacao then taxing Carbon may not be required. This is a last resort to help disincentivize the fossil fuel industry on the island.
10. Banning the sale of ICE cars by 2030 and banning ICEs vehicles altogether by 2040. This will have to happen because otherwise transitioning to 100% EVs becomes a pipe dream

11. The transportation sector change needs to be immediate and aggressively pursued through similar price based incentives (Tax incentives, direct purchase subsidies and many others) as mentioned above for RETs. The advantage here is that there is a lot more price based incentive to be given provided across the supply chain and the use of the EVs. Example: Parking subsidies.
12. A floor price should be eventually introduced when there is high penetration of RETs. And there should also be a cap on the maximum price per MWh of RETs.
13. Promote policies that encourage entrepreneurship are required because this is a simple way of making sure educated young people remain on the island
14. Maybe even provide a grant to aspiring students to help them with financing their studies abroad under the condition that they return to work on the island for a couple of years.
15. Mandate compulsory energy audits for businesses and industries to improve data collection and enabling implementation of targeted policies for different sectors.
16. Finally, the most important of all is to use all this policy and create a legal framework that can help the relevant parties to successfully avail the justice system when deemed necessary.

Infrastructural Changes

What?

1. Reconsidering the role of the ISLA oil refinery initially and then shutting it down by 2040
2. Introducing EV vehicle supporting infrastructure
3. Introducing storage capabilities to balance the grid
4. The grid needs to adapt to the penetration of high amounts of intermittent RE.
5. Introduction of supportive installed capacities because of the introduction of intermittent sources of energy through batteries and vehicle to grid strategies

How?

Initially the refinery should look at increasing its exports as it will lose its local market and then around 2040 the refinery should be closed. Over these years because of improvements in the refinery and the refinery essentially losing its local market a lot of people are going to lose their jobs (around 1000) so this is when the training programs become very essential.

The grids should have increased capacity. There needs to be certain technical standards the grid should meet and also there should laws and regulations (or grid codes) that ascertain the performance of the grid. Also, future technical research needs to be done into this as this is one of the most crucial aspects of the transition. The effect just penetration will have on the grid, the required grid capacity, etc need to be researched. Most importantly the distribution grid needs to be studied because it will be the most affected due to bi directionality and V2G strategies. As some point introduction of smart grids will also be required to maintain everything in balance efficiently.

Storage can be introduced probably using similar incentive mechanisms like the ones used for renewable energy technologies. This should make use of the fact that there is a stable fossil fuel production to some extent until 2040. Therefore deployment can be more gradual and steady. EV infrastructure will have to be made alongside with EV penetration of the market. This can be introduced in public parking spots and eventually in old gas stations. From Dean's thesis, it is understood that battery needs to be included only when there is close to 70% Renewable energy penetration before that the amount of fossil fuel is sufficient to balance the grid. But of course actual implementation should be more gradual therefore a study should be carried out.

Who?

Distribution companies, EV companies, Ministry of Economic Affairs, Ministry of Transport and Urban Planning, Aqualectra, CBS, and BnTP

Market Structure

What?

1. Introduction of more completion along the supply chain of the electricity market is required
2. Controlled Vehicle to Grid Strategies should be implemented as it will help balancing the grid

How?

This can be done if they just adhere to the Policy document for Electricity Supply 2011-2015 which they have already created but have failed to implement. This document will need to be updated to include vehicle to grid strategies and smart grids. However, there should be an intensive study performed on the benefits of unbundling their electricity market for such a small economy. Maybe a lot of the issues can be solved by privatizing the utility company.

Who?

Ministry of Economic Affairs, Ministry of Energy, Aqualectra, Independent Regulator

4.3.2. Step 4: Timeline of Implementation – Scenario 1

In this section the transition pathway towards a 100% renewable energy system will be discussed.

This follows the what, how, who and when pattern and answers the question 'when'.

One thing that is particularly clear is that for SIDS a purely market driven approach is improbable to give satisfactory results. Therefore, there is emphasis on the population being more involved and informed, which provides the government with the required support to aggressively pursue a transition which will clearly require making tough decisions. This also justifies the reason for the section that answers the question 'how' deals predominantly with plausible government actions.

The strategy of implementation consists of 4 main steps. Namely:

1. Establish (E)
2. Educate (E)
3. Expand (E)
4. Review (R)

This is called the E^3R strategy. Before each step is described please note that while the process on paper seems linear. None of this is actually linear and every step needs to be revisited every few years.

That said the **first step** involves stepping up the required local institutions, getting actively involved in the required regional and international organizations to be a part of a larger network (not only the government but also the educational institutions). This is the first step amongst all because this is probably the easiest of things to do, this helps compensate for the brain drain and the lack of expertise on the island, this helps establish the base institutions that need to be strong and possess a strong influence on the island to create a perception of seriousness within international actors therefore increasing the potential of investments. As stated by an IEA report called Deploying renewables it provides a secure investment environment and creates the required legislative framework.

The **second step** is to educate. This is supported strongly by the international and regional organizations that the islands institutions should be a part of by now. This is equally important because this step not only refers to educating the public at large which is off paramount importance because this lends legitimacy to the actions taken by the government and again adds to creation of strong institutions and improves the perception of good governance, but also refers to educating the government and helping the government manage this enormous task. This is because there is a lack of understanding within the decision makers of the island regarding how this transition actually gets implemented. This creates the required academic foundation upon which such a task can be undertaken

The **final step** is to expand. In this step all the work in the previous two steps should come to fruition. And the island should be seeing an expansion in investments and actors interested in the island energy system. The market growth should be accelerated, while maintaining policy costs. Most challengingly, this step needs to manage the penetration of large amount variable renewable energy within the market.

However, all these steps have to be executed alongside a robust follow-up and feedback mechanism, basically a review mechanism that happens annually to make sure that there are lessons learned, based on which adaption and revision of everything necessary takes place.

<u>2017-2020 (Establish)</u>

Goal: Create institutional base, streamline policies, no EV penetration, low RET penetration; wind penetration holds steady, solar PV will make nominal gains 10- 15 MW (based on past performance and distrust of government after introduction of Sun Tax)

1. Establish the Ministry of Energy and Sustainability
2. Establish an independent regulatory for the energy industry
3. Establish an institute that can help coordinate this transition by being involved with the required stakeholders in the government and otherwise. Thereby being able to coordinate policy between various ministries and communicating a robust interconnected picture.
4. Establish the right networks (regional and international). This should be done by the government and also the educational institutes.
5. Establishing the required MoUs with universities abroad for knowledge exchange and research
6. Establish a National Energy Policy
7. Establish a Sustainable Energy Transition Plan
8. Establish streamlined price based incentive policies for RE Technologies, Batteries, and EVs like PPAs and FiTs, while removing the sun tax (or reducing it), tax incentives
9. Downsize the portfolio of the Bureau of Telecommunications and Post
10. Establish a firm participatory methodology for governance
11. Start working on establishing the required infrastructure like introducing storage, and EV charging points/stations and improving the grid. This will be a continuous process which will happen all through this transition period until 2040.
12. Establishing a robust data collection agency that is improving the mandate and strength of the CBS.
13. Establish a regional commitment for EVs

14. Step up the relevant study programs about renewable energy, energy transition and planning. Maybe even endeavour towards setting up a MSc. program on the island.

(2020-2025) Educate

Goal: Perform Technical Assessments, Educate required stakeholders, Low EV penetration phase, Moderate PV penetration phase (at least 100 MW because of utility scale solar), moderate Wind penetration (at least 100 MW)

1. Educate the government on the intricacies of the transition because even they are investing it and change in market structure, introduction of EVs, eventually shutting down the oil refinery are all big steps and therefore this is also linked with establishing the right regional and international networks.
2. Educate the government in better ways of governance.
3. Educate the public by setting up the right educational programs, training programs and also through involving them in the decision making process
4. Create a one stop web portal for everything energy transition and sustainability related
5. Perform the required resource assessment, spatial analysis, environmental impact assessment, feasibility tests and allocate land for renewable energy technologies
6. Comprehensive study on potential of rooftop solar and a cost comparative study on the use of fossil fuels and renewable energy on the island.
7. Promote policies that encourage entrepreneurship
8. Maybe even provide a grant to aspiring students to help them with financing their studies abroad under the condition that they return to work on the island for a couple of years.
9. Mandate compulsory energy audits for businesses and industries to improve data collection and enabling implementation of targeted policies for different sectors.

At this point it should be noted that a strong political and cultural commitment should have been established for transition.

2026-2040 (Expand)

Goal: Follow-up, review, adapt plans, high penetration of EV, Wind, Solar, and gradual increase in Battery

1. Create and expand EV infrastructure
2. Expand renewable energy infrastructure in terms of required batteries, solar and wind establishments
3. Work on expanding number of actors in each market
4. Disincentivize fossil fuels through taxes
5. Ban sales ICE vehicles
6. Ban ICE vehicles and use fossil fuel for energy production of course as mentioned before there is an exception for the use of oil products for other purposes like lubricants, for cooking etc.
7. Shut down the oil refinery

A couple of things to note here are that these things happen at different moments of the time period for this stage and not all at once at the beginning at 2026, for example shutting down the oil refinery happens only in 2040 and not before that. And further, these things being down by the government are subject to many things, therefore around 2026 there will be a determination made if these actions are still to be taken.

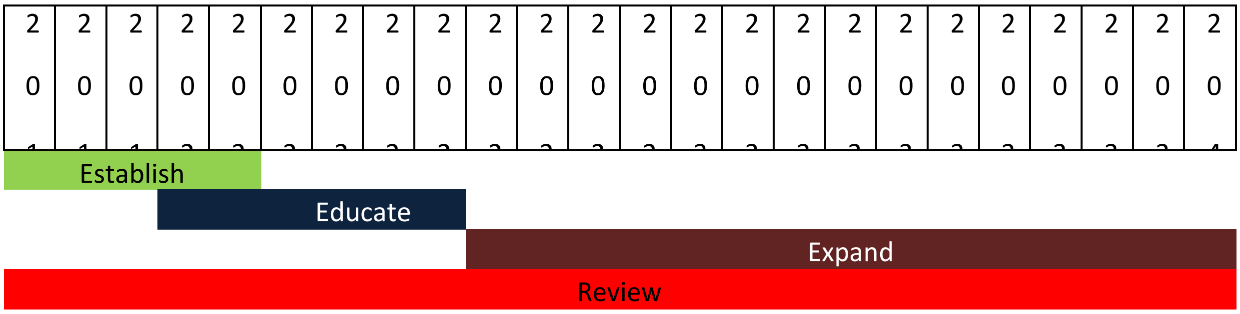
Review

Based on the literature the review process needs to answer these 5 questions essentially to seem legitimate

1. What will be responsible for monitoring the progress?
    a. This should be done by CBS and the agency in charge of coordinating this transition
    and they should answer the subsequent 3 questions.
2. What new information will be required to adapt the scenarios?
3. Who should be involved in re-evaluating the pathways?
4. What policies need to be adjusted to meet the new pathways?

How often should a review process take place? This has be an annual review, thereby providing sufficient data on the energy sector on a yearly basis to conduct robust research.

1. There is nothing to this than the process being reviewed every year. Things that need to be checked are:
    a. Installed capacity of wind, solar, and batteries.
    b. EV market – **<u>the toughest market to establish</u>**.
    c. Regulations and their impact on the energy transition plan
    d. Talking to stakeholders every year to understand grievances
    e. Create documentation on lessons learned
    f. Adapt and renew the transition path based on lessons learned.



4.3.3. Scenario 2: Ocean Hybrid System (OTEC, SWAC, Wind, PV, Battery)

This will follow the same format as the previous scenario, a backcasting analysis talking about what, how, who and then a pathway discussing when.

The advantage of the analysis of this scenario is that everything from the previous scenario holds true even for this scenario. So, here only the differences will be addressed.

Technological Changes

<u>What?</u>

There are 3 main technological changes that need to happen beyond what is already mentioned, 2 are related to efficiency improvements and 1 with renewable energy technology.

1. <u>Substitution of Old Technology</u>

There is a need to use the latest technology available for pronounced energy efficiency gains. This kind of substitution will be seen mainly in the cooling sector, and the lighting sector. This is excluding the energy efficiency gains made by substituting ICEs to EVs in the transportation sector.

2. <u>Upgrading existing Appliances/Technologies/Machinery</u>

This requires the embrace of new modern appliances that are more energy efficient. The difference between this and the substitution is that in this the technology that is used remains the same just that it is more efficient and in the previous section the efficiency improvement is gained by changing the entire technology. This section is the reason why energy demand data is important. If there is energy demand data for each sector and that further sub-divided into most energy consuming aspect of that sector then there can be targeted policies enacted to reduce demand.

3. **Introduction of Base Load Renewable Energy System**

In the 1st scenario all the RETs were of the intermittent nature. The difference in this scenario is the addition of a base load RET. This will enable a much lower land area requirement and therefore make the transition more realistic at least from this one aspect. This is because there would be fewer numbers of installed units of solar PV and Wind energy.

How?

Apart from what has been mentioned in terms of assessments and the study in the 1st scenario, the following activities need to be done:

1. 150 MW worth of installed capacity of OTEC is required. In the coming couple of years a 500 kW OTEC plants will be installed on the island. However, after that still 150 MW will need to be installed because of the lifetime of the OTEC plants assuming to be 20 years will get over around 2040. Based on current scenario, let us assume that only from 2025 does OTEC really starts getting installed. Then 10 MW per year will have to be installed to meet the 150 MW mark by 2040. In other words, starting at 500 kW from 2025 to 150 MW by 2040 requires a market penetration rate of 46.3% compared to the previous year. While this seems a lot one should remember that this means going from 500 kW in 2025 to just 3 MW in 2030. This is good because there needs to be a gradual scaling of the technology otherwise the chances of success is limited. However, because the technology is only economically viable in larger scales. So, a balance between gradual scaling and economic viability is required.
2. Success of the 10 MW SWAC and 500 kW OTEC plants at the airport and installation of testing and research OTEC plants.
3. Encouraging the development and success of the concept of Curacao as a centre of excellence for OTEC. The Ecopark is a good example
4. This system also requires 150 MW of Solar PV to be installed which at a capacity factor of 20% will produce 263 GWh of electricity annually which when compared to the potential estimate of rooftop Solar PV, it can easily be deduced that large scale Solar PV may not even be required. Currently there is 17 MW of rooftop solar PV installed, that means starting from 2018 onwards if 6 MW of Rooftop PV is installed then that is sufficient. And if historical trends are any indication, then this is going to be fairly simple. This will require a market penetration rate of 10% starting at 17 MW in 2017 to 150 MW in 2040.
5. The required installed capacity of wind energy in 2040 is 50 MW. However, by the end of the 2017 the installed capacity of wind energy on the island would have already reached 46.5 MW which is 3.5 MW short of the required target. However, assuming that a wind installation has a 20 year lifetime, any and all installations from today will not function in 2040. So, the island will require investments but not aggressively as in the case of OTEC, solar and batteries. This is not to mention that currently there is only one company owning all the 46.5 MW of wind energy and at some point in the future the island will want there to be competition in the market and not let one company have a monopoly over entire wind energy supply.
6. The current lighting bulbs need to be changed to LEDs
7. The current cooling sector needs to be shifted to Sea Water Air Conditioning.
8. Therefore, a comprehensive study on how such a massive change in the cooling sector is possible needs to be studied. It has the pre-requisites at least; which are enough difference

in water temperature between the surface and at a depth of 1000m and a densely populated area so that the infrastructure costs are less.

9. There should be transparency of operations and with the results of OTEC research to maintain confidence within the government. This research can be conducted in places like the ecopark.

Who?

Energy Companies, Ministry of Economic Development, Ministry of Energy, Aqualectra

Societal Changes

What?

Apart from what was mentioned earlier there needs to be a campaign to help people understand the benefits of energy efficiency and conservation. Further, there should be a larger emphasis on sustainability/eco-friendly behaviour as a whole instead of just the energy sector; this is because you need even more from people now, as a lot of energy efficiency measures depend on the end user. Making sure that a rebound effect is not felt due to increase in efficiency measures.

How?

The how is similar to the how of the cultural changes part under scenario 1. They need to get more involved in the political process to understand what is exactly being planned in terms of the energy transition. Further, be better informed with the help of information from NGOs and local, regional, and international institutions. But these are also points that can fall under institutional change.

However, in this scenario knowledge diffusion and awareness of energy efficiency needs to be made a priority.

Who?

Energy Companies, NGOs, Citizens, Unions, Government of Curacao

Structural Changes

Institutional Changes

What?

In terms of local institutional changes there isn't anything new apart from what is already mentioned under Scenario 1.

How?

1. An increase in the portfolio the institute that is coordinating the energy transition because now the institute has to figure out how get a technology from demonstration phase to complete commercialization.
2. Paramount to join international organizations because they can provide a platform for all the relevant stakeholders throughout the supply chain of the OTEC industry to get together in one place and share their experiences.
3. Involve local/regional/international experts, research organizations and universities by letting them use the OTEC testing plants for further research and publications

4. Creating a research, development and innovation fund that helps promote ocean energy related research

Regulatory Changes

What?

All the regulatory changes that were mentioned under scenario 1 hold true even here. However, there needs to be more emphasizes on energy efficiency regulations and research development policies.

How?

1. Implementing better grid codes and standards like increasing the voltage of transmission and distribution lines
2. Tightening building energy standards and codes to help create new buildings with zero energy designs
3. Implementing minimum energy performance standards
4. Utilizing energy labels for appliances, equipment, and lights
5. Incentivizing the usage of highly energy efficient equipment
6. Eventually banning equipment, and appliances below a certain efficiency level
7. Public Procurement policies should be considered to lead by example
8. Incentivizing people to remain on the island by improving employment opportunities
9. Funds to help people retrofit their houses thereby reducing energy consumption should be implemented
10. Once better data about industrial activities are available there is a need for targeted policies to reduce the energy demand
11. Implementing policies that help OTEC (Innovation) that range from policies to help build human capital (through training programs), provide financial support (through PPAs and other funding), coordinating research, development and the required logistics
12. Streamline the process of getting permits, certificates, and other relevant paper work. This will help quicken the process and help reduce transaction costs for companies.
13. Financial requirement will be high to implement OTEC so a comprehensive understanding on how it can be financed needs to be achieved

Infrastructural Changes

What?

Apart from the previous mentioned (in Scenario 1) infrastructure changes like batteries, grids, and EV infrastructure, closing of oil refinery, and fossil fuel power plants.

The one main infrastructural change that comes into play of this scenario is that drastic changes need to be made to the buildings in Curacao.

How?

There are two main activities to consider here:

1. Retrofitting needs to be made a priority and aggressively needs to be implemented. This includes the required changes to the buildings to accommodate Sea Water Air Conditioning amongst other things like improving insulation of the walls.
2. New Buildings should be constructed using zero energy design techniques and principles,

therefore international architectural firms should be solicited for help and knowledge diffusion.

<u>Who?</u>

Mainly the Curacao government, independent regulator of the energy sector, and Aqualectra

4.3.4. Step 4: Implementation timeline for Scenario 2

As mentioned earlier this will answer the question regarding by when all these changes need to happen.

Similar to Scenario one the E^3R strategy will be used to explain the implementation timeline.

<u>Establish and Educate (2017-2020)</u>

Goal: To establish the right foundation upon which the transition can happen, 10-15 MW of solar PV,
500 kV of OTEC, 10 MW of SWAC.

1. Implement all energy efficiency related policies standards, labels and codes for the grid, appliances, machinery and buildings
2. Incentivize usage of highly energy efficient equipment
3. Consider using public procurement policies to help encourage energy efficiency and renewable energy capacity increase
4. Funds to help perform research, innovate and retrofit a person's house
5. Implementation of policies that can help incentive OTEC (specifics mentioned in the previous section)
6. Incentives to help improve the human capacity on the island, thereby reducing the brain drain
7. Streamlining the administration process to be followed to set up a new OTEC/SWAC project
8. Establishing more robust international and regional networks that can help create the local expertise required on the island to manage OTEC and SWAC but also help the country interact with companies through the supply chain of the OTEC and SWAC industry.
9. Better data collection is paramount.
10. Increasing the portfolio of the agency coordinating the energy transition to help accelerate the growth of OTEC from a demonstration phase to a commercial phase.
11. Getting in touch with architectural firms specializing in zero energy design
12. Understanding how OTEC testing plants can be created and used
13. Educate the government on how OTEC projects can be realized
14. Financial requirement will be high to implement OTEC so a comprehensive understanding on how it can be financed needs to be achieved

<u>Educate (2020-2030)</u>

<u>Goal: Informing people, educating the government, Low OTEC penetration (5-10 MW), High SWAC penetration</u>

1. Setting up small scale OTEC test labs that should be open to research and testing for foreign universities and researchers
2. Comprehensive study on the feasibility of SWAC and implementation process on the island
3. LEDs start penetrating the market
4. Retrofitting of houses start, new houses will be made using zero energy designs.
5. Inform the public of OTEC and SWAC and its benefits
6. More in-depth research needs to be performed on offshore OTEC
7. Research on scaling OTEC within the time frame is required
8. A comprehensive strategy to implement SWAC
9. Financial requirement will be high to implement OTEC so a comprehensive understanding on how it can be financed needs to be achieved
10. Research and Testing of OTEC will continue on so as to understand

Expand (2025-2040)

Goal: Follow-up, review, adapt plans, Increase penetration of OTEC, SWAC, and Efficiency Programs

1. There should be commercial penetration of OTEC by this time. It need not be a large scale penetration but commercial penetration should have begun
2. Implementation of the SWAC implementation strategy
3. All efficiency programs are being executed
4. Based on previous lessons learnt there are adaptations of plans and strategies
5. Banning less efficient equipment and appliances

Review (2018-2040)

Based on the literature the review process needs to answer these 5 questions essentially to seem legitimate

1. What will be responsible for monitoring the progress?
    a. This should be done by CBS and the agency in charge of coordinating this transition and they should answer the subsequent 3 questions.
2. What new information will be required to adapt the scenarios?
3. Who should be involved in re-evaluating the pathways?
4. What policies need to be adjusted to meet the new pathways?
5. How often should a review process take place? This has be an annual review, thereby providing sufficient data on the energy sector on a yearly basis to conduct robust research.

There should be an annual review of the progress being made by the island on all its initiatives such as OTEC, SWAC, Efficiency gains.

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4.4. Conclusion

To conclude this case, this section will connect the research objectives and research questions with the analysis performed. The objective of this thesis was to present pathways with implementable actins to achieve the vision of a 100% renewable energy island.

Under the guidance of the Backcasting framework created by Jaco Quist and Robinson the research started with developing a thorough understanding of the current energy scenario and the factors that affected the energy system. It was clearly seen that currently only 1% of the total primary energy used on the island was of renewable in nature. Further, it was realized that the energy infrastructure on the island was way beyond its lifetime and nothing was being done to salvage the situation yet. Further, it was realized that there was lack of awareness within the public for the necessity of a transition and mainly a severe lack in structural support required for such a transition to take place. And these two aspects become paramount because if there is an aggressive energy efficiency strategy or utilize the full distributed generation potential that needs to be employed then you need to public to play an active role in it. And if you want to use large scale changes then you a strong institutional and regulatory (structural) foundation to be able to attract investments, reduce the risk perception of the island within banks, attract talent and many other things. Further, a very large impediment in the form a solar tax was recognized that has essentially stalled any progress decentralized Solar PV was making on the island. It should be noted that there severe lack of consistent data for the energy demand side which was a hindrance.

Then there was a determination made on what the potential of various renewable energy systems would be and it was clear that because of favourable environmental conditions and more land area available to use there was sufficient RETs potential. However, the clear winners in this situation were offshore wind and OTEC. This technical potential was reaffirmed by comparing the current electricity price with the LCOE of different RETs. However, it should be reiterated here that the bigger problem with RETs are not the LCOEs but rather the high investment costs. This can however be tackled by making the necessary structural changes.

There were two scenarios created that established 2 different technical systems to achieve the vision of 100% renewable energy by 2040. The first vision dealt with mature renewable energy technologies like PV, Wind and Battery. Further, building on the fact that currently there are no policies in place for improvement of energy efficiency and the public lacked awareness, it was assumed that the electricity consumption would increase at a 3% rate considering economic growth and the complete electrification of transportation. This led to a doubling of electricity consumption by the 2040. The technical system that was developed by Dean's model based on cost optimization had two important takeaways; one that the system can be economically feasible eventhough there is a large amount battery technology used and two, that there was only 10% land area required, and while this doesn't seem much in term of a percentage by 10% is 44 km^2 and that is a lot of land. Therefore, this system may not be implementable due to land constraints. However, this will not be the case if by then floating structures for RETs are commercialized. In the second scenario two main things changed, one was the usage of a base load RET for electricity production and the second the implementation of an aggressive energy efficiency gains program. It was established that the technical system was economically feasible and also did not require a lot of land area. However, the impediment of this scenario was that OTEC which is still in the demonstration phase needs to be commercialized and also that a efficiency program that reduces consumption by 50% as compared to the base line case (scenario 1), at a 3% rate of efficiency gain.

Now both these scenarios were put through the backcasting step and the four questions of what, how, who and by when were answered, with respect to the changes required. The differences between the two scenarios are that, in the first scenario technical feasibility is actually easily established and the scenario relies heavily on institutional and regulatory changes to achieve the vision, so basically a more political desire. A social awareness is also helpful in providing inertia to the political process. The sector that is going to be challenging is the creation of the EV market and shifting to an Electric Transportation market, so this needs to be studied better and more in detail and therefore pursued more aggressively. In contrast, the 2nd case adds to the interventions spoken of in the 1st scenario by requiring a larger societal role in bringing about the efficiency gains and a more drastic requirement of research, utilizing the relevant networks and building human capacity due to the necessity to commercialize a new technology and the lack of expert knowledge. It should be noted that the only way the aggressive efficiency gains is possible here is trough implementation of SWAC, so a comprehensive study on that should be performed.

In terms of implementation timeline, based on the activities required an, establish, educate, expand and review (E^3R) strategy is proposed. This encompasses all the activities that need to be done in both the scenarios. However, there is a difference between when each phase of the strategy is initiated. The 1st scenario is a bit more relaxed and it is a more linear implementation strategy which less overlapping of the different phases of the strategy. However, in the 2nd scenario because of the need of a more actively societal role and a more aggressive plan to commercial OTEC, there is a sever overlap of the different phases of the strategy. And it can be recognized that the education phase is of paramount importance in this strategy because of need to commercialize and make the population aware.

Both the scenarios have their own challenges, like the land use issue for the 1st scenario and the commercialization of OTEC in the second scenario. But one thing is clear that both the scenarios can be incredibly helped by a serious institutional and regulatory change. And if these changes are made then, it will improve investor confidence, reduce the risk perception within financial institutions therefore get cheaper loans, will reduce transaction costs, and administrative burdens and all of this will help not only reduce RETs costs but also increase penetration. Finally, it makes sense that in a small island which doesn’t have the advantage of scale, the institutions, the regulations and the politicians need to play a far greater role than in general.

5. Grenada

The State of Grenada, henceforth referred in this document just as Grenada until and unless otherwise specifically differentiated, is located in between 12.07° North 61.40° West, a 161 km north of the Venezuela, in the Eastern part of the Caribbean. It is a tri-island state consisting of the main island Grenada and 2 dependencies namely Carriacou & Petite Martinique, which are smaller in size too (Government of Grenada, 2013). They together have a total land area of 344 km^2 and a total population of 110,152 people in 2014 (Ochs et al., 2015). Approximately 6,000 -7,000 people stay in Carriacou & Petite Martiniqu (Statistics Department, 2011), occupying a land area of 34 km^2 and 2 km^2 respectively, while the rest stay on the main island of Grenada, which is 308 km^2 (Government of Grenada, 2013). To be more specific, the main island of Grenada has 6 parishes (provinces) and close to 1/3rd of the population living on the island of Grenada stays in the capital St. George (Espinasa et al., 2015). Out of all this land area 85% is basically forests or agriculture land and only 15% is inhabited by people (Government of Grenada, 2015). But, this 15% might increase in the future because a population growth of 0.54% is expected per year (IRENA, 2012).

Historically, this small state of three islands was first ruled by the French and then the British. Grenada got its political independence from the British in 1974 (Government of Grenada, 2013). Since then it is a constitutional monarchy, with a Prime Minister and Queen Elizabeth II as the Head of State, represented on the island by the Governor. It has a parliamentary style of political system, consisting of a total of almost 8 parties but only 2 major parties. The two major parties received above 99.5% of all the votes, put together, in the last election (Wikipedia contributors, 2016c).

Grenada has a GDP of 1.5 billion USD (Purchasing Power Parity, PPP), which translates to a GDP per capita (PPP) of 12,231 USD. This is probably because their urban population is only a merger 36%. Their major industries in 2015 were food and beverages, textiles, light assembly and tourism (Ochs et al., 2015). Tourism in 2011 contributed 24% approximately to the GDP of Grenada. It should come as no surprise that even Grenada is predominantly a service based industry. In 2011, services contributed approximately 79% to the GDP, industries contributing only close to 16% and 5% by agriculture (nutmeg and sugarcane, mainly) (IRENA, 2012).

Following this introduction, the next section will try to provide context to the energy sector of Grenada through describing the current energy supply and demand statistics, the main local stakeholders, performing a PESTEL analysis, and finally concluding with calculating the potential of RETs on the island.

5.1. Strategic Problem Orientation

5.1.1. Energy Supply

Grenada imports close to 93% of its primary energy in the form of petroleum products such as Kerosene, Diesel, Gasoline, and LPG. The remaining 7% is produced on the island through combustible renewables, waste, solar PV (Espinasa et al., 2015; REEGLE, 2013). In terms of combustible renewables Grenada makes use of wood for cooking, sugarcane bagasse and nutmeg leftovers for energy (REEGLE, 2013). The use of 1st generation biomass like wood for cooking makes sense because close to 65% of all population stays in rural areas. The diesel is predominantly used for electricity generation and some in transportation. The gasoline is used completely for transportation (REEGLE, 2013).

According to Espinasa et al. (2015), Grenada's annual amount of primary energy used on the island was 6221 TJ. That means 5785.5 TJ were imported as petroleum products and 435.5 TJ was produced on the island through combustible renewables, waste and PV. The island does not export any energy so the aforementioned amount will be directly used or lost in some form on the island.

In terms of the electricity sector, Grenada produces almost all its electricity using diesel. There is a single diesel power plant in the main Grenada island of capacity 45.9 MW, Carriacou has 3.2 MW and Petit Martinique has 0.5 MW installed capacity; additionally there is a backup generation worth 2.8 MW at St. George's University. This brings the total installed fossil fuel capacity to 52.4 MW. There is a very limited installed capacity of approximately 1 MW of Solar PV installed across the 3 islands and one 0.08 MW wind energy installation. Interestingly, the electrification rate on the island is 99.5% (IRENA, 2012; NREL, 2015; SE4ALL, 2012).

There were reports by GERNELEC, the sole private utility on the island, about installing 1-2 MW of wind energy by 2016 and also around 940 kW of solar PV however they have not yet materialized but are still being worked on.

In terms of future projects, Grenada is very actively pursuing a 15-20 MW geothermal plant. It is using expertise from the Japanese and the Australian governments. While there are reports of it being 2 projects each of 15-20 MW, currently the government and the utility seem to be focused on just the first one and has performed its 2nd pre-feasibility study and has secured funding for the next steps (NowGrenada, 2015, 2017).

5.1.2. Transmission and Distribution

There are currently 2 transmission lines of 33kV capacity each (Hewitt, 2015) and 12 distribution lines of 11 kV each (Espinasa et al., 2015). These lines pass through 2 substations; one at Queen's Park and the other at Grand(Espinasa et al., 2015; Hewitt, 2015).Further over the years the GRENLEC, the sole utility provider has managed to reduce transmission and distribution losses to only around 8% in 2013 and was the lowest 2012 with 7.5% (Espinasa et al., 2015), which is below average of 12.5% for the Caribbean islands (Ochs et al., 2015).

5.1.3. Energy Demand

The demand side will deal with the electricity sector specifically and then the final energy consumption by all the sectors.

GRENLEC, the sole actor involved through the entire supply chain of electricity sector, as of year **2013 generated 708 TJ (196.7 GWh) of electricity. It consumed 22 TJ (6.1 GWh) by itself and the remaining 686 TJ (190.5 GWh) was sent to be consumed by 45,765 domestic, commercial and industrial consumers. The total amount consumed was 175.8 GWh (633 TJ) reflecting the 7.5% transmission losses mentioned in the previous section. The commercial sector accounted for 55% of** the electricity consumption having 5968 registered customers. While the residential customer having 39762 customers accounted for **39% of the consumption. The industrial sector with 35 registered customers accounted for 3% of the consumption and the remaining 3% is accounted for by street lighting. The Peak Demand for the island in 2013 was 30.2 MW** (Espinasa et al., 2015; GRENLEC, 2014).

In terms of trends is can be said that there has been a decrease in residential consumption over the last 5 years, while there has been an increase in consumption in the commercial and industrial sectors. The decrease in consumption at the residential sector may be due to increased conservation or efficiency gains but may also be explained through current global economic situation (GRENLEC, 2014).

In terms of total final energy consumption in 2013, the island consumes 4492 TJ of energy out of which 41% is consumed by the transport sector, 31% by the residential sector, 23% by the commercial sector, 4% by the industrial sector and the remaining 1% by others .

The transportation sector consumes the largest share of overall energy due to the high and growing penetration of motor vehicles in Grenada and the importance of the tourism sector. The number of vehicles increased from 15,000 in 2000 to over 26,000 by 2009. The penetration of SUVs is high, with 27 percent of vehicle stock contributing to high per-vehicle consumption. There are 2 things unknown over here, most important how they define transport sector here, whether it is only road transport and the second being the more recent figures and the trend in the last 8 years. Therefore, if the same annual increase of 1200 is maintained then the numbers of vehicles have increased to 34,400 vehicles. But this linearity may not hold true if you look at the trend in unemployment which was at 25% in 2008, 33% in 2013 and seem to have reduced to 29% in 2015, youth unemployment is around 41% and also the percentage of people staying in poverty Grenada which increased to 37.7% in 2008 (Caribbean Development Bank, 2014; IMF, 2016a; SE4ALL, 2012).

Two interesting things to note here, the efficiency of the electricity market can be attributed to it being handled by a private actor and the second being that one of the reasons the transport sector consumes so much is because the cars are old and inefficient. Also at least 25% of the cars are 2nd hand cars on the islands.

Further, if the electricity sector and the trends are observed we can see a clear correlation between electricity consumption and the GDP growth rate. Only in the last 2-3 years has consumption increased again. This is due to improved agriculture sector and tourism sector (Espinasa et al., 2015; GRENLEC, 2014; REEGLE, 2013).

There have been projects preciously that have been aimed towards efficiency improvements. Like in 2007 there was drive to shift from incandescent lights to CFLs. 133, 253 bulbs were replaced by visiting 23, 205 households. This means that at an average there are 5.5 bulbs . Further, in 2015 GRENLEC along with Govt. of Grenada started a pilot program to test the benefits of different LEDs bulbs over the current High Pressure Sodium bubs used for public lighting. This changed 42 street bulbs to LEDs consisting of 3 different kinds of LEDs, of 14 units each. They showed an energy saving of 50% at an average (GRENLEC, 2014, 2016).

5.1.4. Energy Policy, Vision, Plan and Law

Summary of the National Energy Policy 2011:

This section is heavily derived from Government of Grenada (2011) and (Grantham Research Institute on Climate Change and Environment, 2015).

The Government's objectives for shaping the energy sector in Grenada, in order to "ensure access to affordable, equitable, and reliable energy sources and services to drive and secure national development, and to improve the quality of life for all of its citizens" is laid out in the National Energy Policy. The GNEP is based on seven core principles: Energy Security, Energy Independence, Energy Efficiency, Energy Conservation, Environmental Sustainability, Sustainable Resource Exploitation, Rational Energy Prices, and Energy Equity and Solidarity, including with future generations (Government of Grenada, 2011).

The Policy further sets a specific goal for renewable energy, which is to provide 20% of all domestic energy used for electricity and transport by 2020. It states various implementation measures to encourage energy efficiency and conservation in energy generation, transport and buildings sectors. However, it does not include specific targets. In particular, the GNEP calls for a set of specific projects to be co-ordinated by the Government by 2020:

1. Complete feasibility and construct a 20MW geothermal plant **(currently being pursued aggressively, 2 feasibility studies have been conducted, funding has been arranged for the next stage, a geothermal bill is being discussed)**
2. Construct an additional 20MW geothermal plant **(highly unlikely to happen by 2020)**
3. Construct a 2.5MW wind turbine for Carriacou **(recently stopped the process of tendering a 1.4 MW wind project because of recent implementation of the Electricity Supply Act 2016)**
4. Achieve 10% electricity generation by wind & solar PV **(Currently, 2 MW worth PV is installed, which equates to around 2% of electricity generation)**
5. Establish vehicle fuel efficiency standards **(no progress towards this)**
6. Achieve 20% market penetration with hybrid and electric vehicles. **(GRENLEC has been testing 3 EVs for the last year)**

It also demands the establishment of the necessary international structures, including a National Energy Commission representing relevant stakeholders that would "review the achievement of the policy targets, receive comments from stakeholders, etc and feed this information back to government, recommending solutions where necessary".

Finally, it offers a layout of a 10-year Grenada Energy Development Strategy (2010-2020), which provides for adoption of energy specific legislation such as Energy Efficiency Act, Geothermal Bill **(draft ready, begin discussed)**, and revision of the Electricity Supply Act. The proposed Energy Efficiency Act includes the following provisions:

As of today, the government had not passed legislation to make the measures outlined in the GNEP legally binding. There are other goals also as illustrated in the roadmap below:

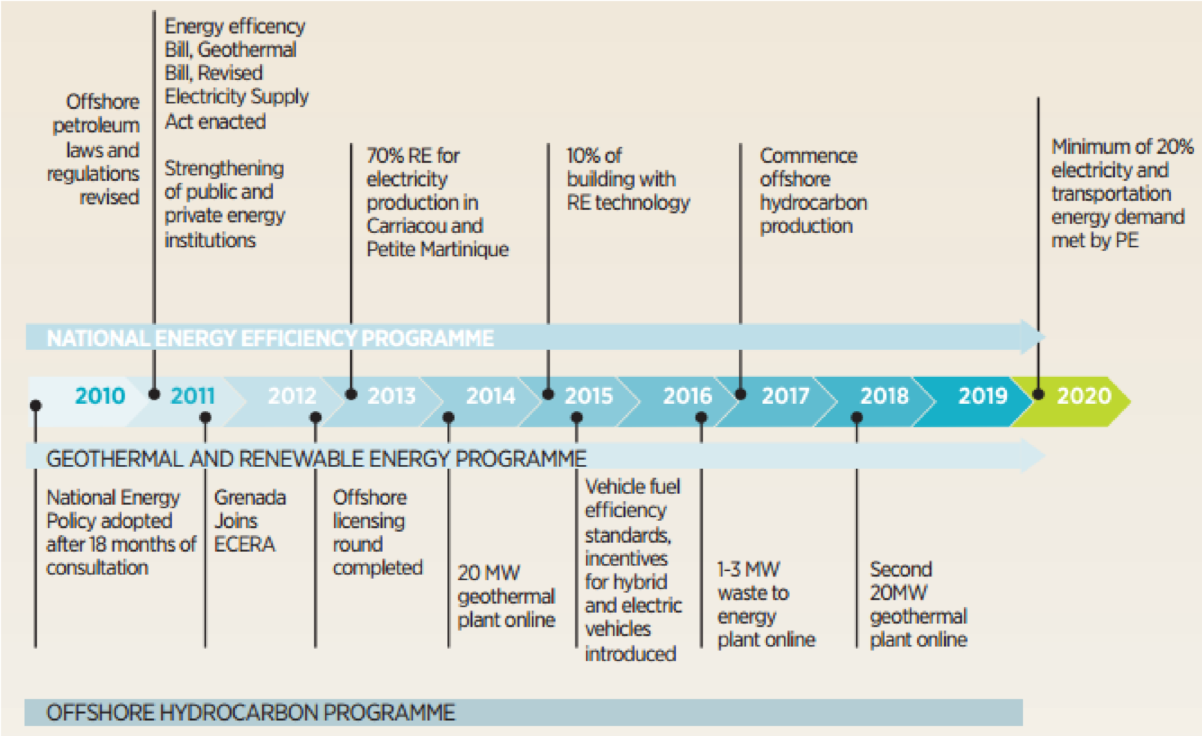


Figure 28. Grenada's Energy Roadmap 2020

Summary of the Grenada Vision 2030

As a supplement to the Grenada National Energy Policy (2011), the “Grenada Vision 2030” lays down the proposal to establish a 100% renewable energy target for both the electricity and transport sectors for 2030. As a first step to determining the pathway towards this objective, a ‘100% renewable energy showcase study is to be conducted in co-operation with the German government and a consortium of specialised companies. The Grenada Vision 2030 consists of four major projects, three focused on development of utility scale generation from geothermal, wind and waste-to-energy sources, and one on distributed solar. They are expected to require relatively little capital investment, given the small size of the economy and energy demand.

It should be mentioned that while there is a lot of mention of Waste to Energy, there seems to be limited potential as demonstrated by calculations in Energy Potentials section under Biomass.

Summary of Electricity Supply Act (ESA), 2016 and Public Utilities Regulatory Commission Bill (PURC), 2016

Mainly, there are 3 points to be discussed here (Brennan, 2015; Grantham Research Institute on Climate Change and Environment, 2015):

1. The ESA 2016 annuls the sole generation license GRENLEC had until 2073 and allows new Independent Power Producers (IPPs) to enter the market. Licensing preference will be extended to producers who choose RETs.
2. The PURC creates a commission to regulate the electricity market, by setting rates, overseeing compliance with rules and regulations, setting ethics rules and setting penalties for non-compliance.
3. Eventually, the some of the commission’s functions will be transferred to the Eastern Caribbean Regulatory Authority (ECERA) based on an anticipated treaty signing with the Organization of Eastern Caribbean States.

These two pieces of legislation were passed by the Govt. of Grenada in August 2016

5.1.5. Stakeholders

As mentioned before in the Curacao case there is 7 groups of stakeholders that are relevant for an energy transition.

However, this section will deal only with the most relevant stakeholders for the industry currently (Espinasa et al., 2015; Government of Grenada, 2011; IRENA, 2012).

There are 3 government ministries that are involved.

First, Ministry of Finance, Planning, Economy, Energy and Cooperatives is a government that in charge of overall national energy policy and setting regulation of import and sale of oil products.

The second is Ministry of Communications, Works, Physical Development, Public Utilities and ICT which oversees the electricity sector and in the absence of a regulatory commission carries out all regulatory functions.

And finally, the Ministry of Agriculture, Forestry, Fisheries and Environment which is involved in planning and implementation of renewable energy sources. This ministry is also important because it distributes solar powered water pumps to the agriculture sector.

There is also the Department of Energy and Sustainable Development which comes under the purview of the Ministry of Finance and Energy, which is responsible for the energy and electricity market. It leads to the development and implementation of renewable energy policy and promotion of new and efficient technologies.

In terms of private companies, there are mainly two the Grenada Electricity Services Limited (GRENLEC) and Grenada Solar Power Limited (GRENSOL). The former holds the license to generate, transmit and distribute electricity on all three islands until 2073. The latter is a leading solar energy company that is responsible for 300 kW of rooftop solar PV on the island. It has a special contract with GRENLEC to do so.

In terms of research collaboration the government has gotten into a MoU with St. George's University and T.A. Marryshow Community College has the responsibility to retrain technicians to install and maintain RETs.

According to the energy division website of the ministry of finance there are other stakeholders mentioned like Chevron, SOL EC Ltd, Petrocaribe Grenada Ltd, Seek Solutions, Caribbean Sun Energy Ltd, and Caribbean Bunkers Grenada Ltd, however, a lot of these seem to have a relationship with shipping and aviation industry or are not that significant (Government of Grenada, 2009).

It is still unclear as to who is responsible for selling the fuels that are not related to the electricity sector on the island. Therefore, also it is unclear as to how the transportation market is structured.

PESTEL

PESTEL	Factors Affecting RE
Political	• Criminal and Civil cases East Caribbean Supreme court the highest authority • No independent regulator of the energy market yet • High amounts of bureaucracy • The state of Venezuelan politics because they get their oil products from

	there • Working very closely with various international institutions to get funding and expertise on various energy efficiency and renewable energy projects • No Ministry handling the transport sector
Economic	• **GDP per Capita** 12,231 USD (2015), this means by historical trends there will be continuous growth in energy demand. • **Economy** Food and beverages, textiles, light assembly and tourism • **Cost of electricity –** Residential – USD 0.28/ kWh Commercial – USD 0.29/ kWh Industrial – USD 0.24/kWh This is generally not so low and is around USD 0.40/kWh • **FiT rate –** Two methods of compensation: 1. Paying a fixed amount of 0.45 XCD 2. Paying a variable price based on fuel costs of that month. • The Economic state of Venezuela • Making use of international financial institutions to fund the transition • The economy until 2021 is estimated to grow at a rate of 2.7% based on IMF calculations • Lack of Access to capital because of perception of high risk investments • World Bank Ease of Doing Business rank went from 133 to 138 • Credit Rating from Standard and Poor is SN – which means that they have defaulted on thei credit and there is little hope of paying back • Huge amounts of money is spent on disaster management and reserved for emergencies
Social	• No evidence of large population interested in transition • Technical (Engineering) education is sparse • Recently started 1 training program in collaboration with T. A. Marryshow Community College (TAMCC) • Research Collaboration between the government St. George's University • Main incentive to improve energy efficiency is monetary • 29% unemployed in 2015 and 37.7% living in poverty in 2008, this serious hampers the potential for distributed generation potential • Population growth rate is estimated at 0.5% annually
Technological	Has been dealt in detail earlier.
Environmental	• **Land Use:** ▪ 15% used for inhabitation ▪ 85% for Forest cover and agriculture ▪ Not mentioned if any of this forest cover is protected • **Average Temperature** Around 29^{o} C • **Average Wind Speed @ 50 m** 7.6 m/s • **Direction of Wind** NE to SE • **Sun hours per day** 9 (approximately) • **Solar Irradiation in 2015** 2000- 2120 kWhr/m^2/year • **Temperature difference** between surface water and at a between of 1000m is 27^{o} C • **Present in the Hurricane Belt – Hurricane Emily and Ivan destroyed nearly**

	90% of all infrastructure on the island
Law	• National Energy Policy 2011 • Sustainable Energy Roadmap for 2020 • Grenada Vision 2030 – Electricity and Transport sector to be 100% renewable energy • Electricity Supply Act 2016 • Feed in Tariffs • PPAs for large scale Renewable Installations which needs to gotten through GRENLEC but after the ESA 2016 not sure who is responsible • Tax exemption for RE technology imported • No Energy efficiency law • No Transport law • PetroCaribe Agreement which mentions that fuel will be purchased from Venezuela's PDVSA for the next 25 years, signed in 2006 • Signed and Ratified the Paris Climate Deal committing to reduce emissions by 30% by 2025 compared to the 2010 emissions

5.1.6. Energy Potentials

All assumptions and methodologies henceforth are the same as for the Curacao Case and hence are not repeated.

Solar PV

Global Horizontal Irradiation for Grenada = 2000 kWh/m^2/year (IRENA Renewable Readiness report considers a potential of 2120 kWh/year)
Total available land area = 17 km^2 = 17,000,000 m^2
Resource potential = 34,000 GWh/year
Panel Efficiency = 18.5%
Spacing Factor = 5
Technical Potential = 1258 GWh/year
6.6 times the 2014 electricity consumption of 190.5 GWh

Rooftop Solar PV

There are 42,213 domestic electric connections and 6,560 businesses and industries electricity connection. Therefore, there are 24,426 usable roofs in total. That is a total of 610650 m^2 of usable roof space.

Resource Potential = 1221 GWh/year
Technical Potential = 226 GWh/year
This is 1.2 times the 2014 electricity consumption

Wind Onshore

Using the same Vestas 3MW V90 as in the case of Curacao for sake of accurate comparison
Wins Speed at 50m = 7.6 m/s
Wind Speed at 80m = 8.08 m/s
Power at 80m = 0.7MW
Spacing Factor = 0.08 km^2
Number of Turbines = 12.35
Power Density = 12.35 x 0.7 = 8.65 MW/km^2
Potential for Installed Capacity = 147 MW
Resource Potential = 8.65 x 8750 x 17 = 1288 GWh/year

Technical Potential = 1288 x 0.40 (Capacity Factor) = 515 GWh/yr
This is 2.7 times the 2014 electricity consumption

Wind Offshore

The depth of the ocean reaches 60m at a distance of 10 km from the shore. Therefore, it is assumed offshore turbines are only installed between a distance of 5 and 10 km from the shore. This holds an area of 652 km^2 but not all the space can obviously be used, so it is assumed that only a third of that area is usable, which is 217 km^2. Now using the same details and assumptions as in the Curacao case:

Spacing Factor = 0.78 km^2
Number of Turbines = 1.27 turbines
Power of 1 turbine = 1.68 MW
Power density = 1.27 x 1.68 = 2.13 MW/km^2
The resource potential = 2.13 x 8760 x 217 = 4049 GWh/yr
Theoretical Potential = 4049 x 0.40 = 1620 GWh/year
This is 8.5 times the electricity consumption of 2014

Geothermal Energy

Geothermal prefeasibility studies were done on the island of Grenada in 1981 and again in 1992. These studies revealed a medium enthalpy resource on Mt. St. Catherine, several small thermal springs in ravines radial to the central volcano and numerous relatively young phreatic explosion craters. Additionally, the sub-sea volcano “Kick-em-Jenny” lies only 8 km off Grenada's north coast suggesting that the zone between it and central northeastern Grenada may hold geothermal potential. **Grenada is estimated to have a geothermal resource potential of 1,100 MW. GRENLEC in recent years has performed 2 pre-feasibility studies in collaboration with Japan and New Zealand and have made a conservative estimate of 50 MW potential at least**. They are working towards starting a 20 MW plant soon after which they also want to start around 20 MW geothermal plant. The prefeasibility studies show a potential of a 4 to 8 km^2 well area which a temperature of 200 to 290^o C.

To perform my own calculations the data is currently not available.

Biomass Potential

As of 2015 Grenada generated approximately 46,000 tonnes of waste. Out of which 44.6% is biodegradable and 19.5% is non-biodegradable and the rest is recycled.

So using 20,500 tonnes of biodegradable waste, we get 2,256,760 m^3 of biogas which can produce **4.5 GWh of electricity using the same numbers as in the Curacao case. This is 0.023 times the 2014 electricity consumption value.**

Using the 8970 tonnes of non-biodegradable waste by the **incineration method 1.1 GWh of electricity can be produced and using the gasification method you can produce 1.8 GWh of electricity, which are 0.005 and 0.009 times the 2014 consumption value, respectively.**

OTEC

The difference between the surface temperature and the temperature of the water is 27^o C. So, this in itself proves the tremendous potential OTEC. However, the only downside is that Google Earth says that the depth of 1000 m is only reached at a distance greater than 20 km from the shore, which said there is 1982 study which claims that this depth can be reached within the 1st 10 km.

Battery Storage (V2G)

There were 26,300 vehicles in Grenada in 2009, an increase from 15,000 in 2000. Assuming a similar increase in the remaining years, today there can be as many as 35,000 vehicles approximately.

So, if all of them were to become electric then the battery storage potential assuming a Tesla Model 3 with a 60 kWh battery would be **0.25 GWh storage capacity.**

Energy Efficiency Gains

- **Lighting**

In terms of street lighting LEDs are around 50% more efficient than the current HPS lighting used. Therefore, considering that today street lighting uses 5.28 GWh, by shifting the bulbs to LEDs the consumption can reduce by 50% to 2.64 GWh.

For lighting inside buildings, based on the average number of lights in a household being 5.5 approximately 6, it is calculated that currently there are approx. 275,000 bulbs out of which 137,500 are CFLs and others are all incandescent. LEDs are 50% and 80% more efficient than CFLs and Incandescent lights respectively. Based on the data in the energy consumption section we can say that an incandescent bulb consumed 0.22 MWh/year of energy. That means 137,500 incandescent bulbs consumes 30.2 GWh and if we replace this by LEDs then we can reduce consumption to 6 GWh. While 137,500 CFL bulbs consume 19.6 GWh and changing them to LEDs will reduce the consumption to 9.8 GWh by 50%.

Therefore, a total reduction of 36.64 GWh can be gained just from using LEDs. This is a 20% reduction of the current usage of 175 GWh

- **Heating, Ventilation and Air Conditioning (HVAC)**

There is no heating required. This section will mainly talk about the AC part of this. Currently 50% of all electricity is consumed by the cooling technology, which is assumed to be a traditional air conditioning system. Therefore, this section will talk about 2 possibilities for efficiency gains:

First, is the use of a **geothermal HVAC** system for households, which have a **70% reduction potential**. Currently, **91 GWh is used for cooling and a 70% reduction leads to reduction of 63.7 GWh to a consumption of 27.3 GWh**.

Second, is the use of **Advanced Air Conditioning** which can give a **30% reduction, 27.3 GWh reductions**.

The World Energy Forum gives a more generic way claims that modern efficient HVAC systems used for cooling buildings have the potential to reduce consumption by 60-78%. So, considering 60% we can say that 54.6 GWh is reduced and the consumption drops to 36.4 GWh. This is a reduction of 30% from total electricity consumption today.

There are other ways also to increase efficiency gains like colouring your roof by a lighter colour reduces electricity consumption by cooling, changing your windows, insulation and utilizing Zero energy designs. These are not calculated for now.

- **Grid**

If GRENLEC can manage to reduce their grid losses from 7.5% to 6% like most developed nations then it can supply an additional 2.85 GWh (currently 14.25 GWh is lost in transmission) of electricity for the same installed capacity. This is 20% reduction of losses.

- **Transport**

For reduction in energy consumption there are many things that can be considered like using advanced tyres, inflating the tyre to the right pressure (3.3% fuel economy improvement), using traffic planning and management, improving vehicle fuel efficiency, and using technical methods to double the fuel efficiency.

However, this work will deal with the efficiency gain by substitution effect of changing from an ICE to an EV. An electric vehicle is at least 3 times more efficient in terms of tank to wheel efficiency therefore; from a current usage of 1842 TJ it will reduce to 614 TJ.

5.2. Future Vision and Scenarios

The timeline is bounded by the year 2040. Even though Grenada wants to transition their electricity and transport sector to renewables by 2030, this research deems it to be improbable. For the reason that currently there are no EVs being used today and getting people to adopt EVs can be monumental task.

It should be noted that there is a World Bank Calculation, The GNEP calculation and the CARICOM/WorldWatch calculation that speaks of electricity consumption either doubling or becoming 2.5 times the current value by 2027 or 2030. For this to happen the electricity sector would have to grow at 4% to 7% annually. But, considering the location of Grenada and it's tumultuous economy, it seems unlikely for the electricity sector to increase at that rate.

Considering that for Grenada the electricity sector has historically followed the same pattern as that of the economy. This research first talks about the economic growth of the country. The IMF predicts that until 2021 Grenada will grow at an **annual average rate of 2.7%.** Again considering that it is located in the hurricane belt, we assume the same average annual GDP growth rate of 2.7% until 2040.

The population is assumed to grow at the same rate of 0.52% yearly to reach 126,000 inhabitants by 2040.

There the transportation sector because of the growth of the tourism sector will double by 2040, going from 26,000 in 2009 to 50,000 in 2040. This will increase electricity consumption by a 1000 TJ.

5.2.1. Scenario 1: PV, Wind, Battery

Electricity Consumption without transportation: following the same economic growth pattern the electricity consumption will be 1343 TJ
Electricity Consumption with Transportation: 2343 TJ by 2040.
Installed Capacity of Solar PV: 380 MW
Installed Capacity of Wind: 183 MW
Installed Battery Capacity: 3.18 GWh
Total Land Area Required: 21-23.5 km^2 which is approx. 6.4% of the land area.
Total Jobs: 661 jobs compared to the 232 employees in GRENLEC.
Total investment: 2.6 Billion USD, which is 111.5 million USD/year, which is 7.4% of GDP compared to spending annually 15% of GDP on oil imports

5.2.2. Scenario 2: Geothermal, PV, Wind, Battery

Using the previous case as a baseline for this case we assume that without any efficiency gains the electricity consumption NOT including 100% EVs is 1343 TJ

However, considering that there are electricity efficiency measures implemented by 2020; then it is assumed that there is a 1% annual efficiency increase until 2040. This means a 50% reduction in electricity consumption compared to the projected electricity consumption for 2040 in the base case (1343 TJ) to 646 TJ.

Including the electricity consumption due to 100% EVs the total electricity consumption for 2040 is 1646 which is a 32% reduction in overall consumption compared to the projected 2343 TJ in the baseline scenario.

Comparing the consumption value of 1646 TJ to the consumption values presented in Noortje's thesis we can see that our 2040 consumption value is 40% lower. Therefore the assumption is that the total installed capacity can also be 40% less and that will be sufficient to meet the electricity demand for 2040.

Installed geothermal capacity: 90 MW; Land Area: 0.03km^2/MW; Jobs: 1.7/MW; Cost: 4000 USD/kW

Installed Solar PV: 90 MW

Installed Wind Energy: 30 MW

Installed Battery: 107 MWh

LCOS: <0.22 USD/kWh

Total Land Area: 9 km^2 = 2.6% of total land area available

Total number of jobs: 303 at an average compared to 232 employees in GRENLEC

Total Investment: 623 million USD = 27.1 million USD/year = annually 1.8% of GDP

5.3. Backcasting

5.3.1. Scenario 1: PV, Wind and Battery

5.3.1.1. Technological Change

What?

1. Implementation of renewable energy in large quantities for the scale of the island instead of fossil fuels
2. Implementation of close to 50,000 vehicles of different sizes.

How?

1. An extensive study on the potential of rooftop and community based Solar PV
2. An extensive study on the possibility of vehicle to grid technology and the required market design for that.
3. Better wind and solar forecasting models, therefore enabling a more balanced grid.
4. Implementation of 330 MW of Solar PV. At a rate of 24% per year starting 2018. This requires the installation of 2.2 million panels. The increase in utility scale solar PV should happen in accordance with a plan to remove fossil fuel generation.
5. Implementation of 183 MW of wind energy. Currently there is no wind energy installation. The 1.1 MW plant to be set up for Carriacou has been put on hold by GRENLEC, for now. So assuming that the plant comes by 2019 then to reach 183 MW in 21 years a penetration rate of 27% will be required. Assuming that at an average the unit size in the future will be 1 MW then 183 units of wind turbines will be installed.
6. The fossil fuel power plants should be shut down completely by 2040. The advantage here is that until the recent electricity act was passed GRENLEC in itself had a target of 100% renewable electricity by 2030. However, they did not speak of any particular plan that they wished to follow. In general, that means a linear decommissioning at the rate 37% for 23 years. However, that will never happen, so the suggestion is first to decommission the 3.2MW plant and the 0.5 MW plant in Carriacou and Petit Martinique by 2025. After which, shut down half the large diesel plant on Grenada by 2035 and then shut down the entire plant by 2040. This strategy keeps the fossil fuel energy as back up until 2040.

7. Finally, 50000 vehicles have to shift to EVs by 2040. Currently, there are 3 being tested by GRENLEC, nothing is commercially available. This requires a linear penetration rate of 50% starting in 2018. This is improbable. Considering a 15 year life span and assuming that 1/15th of all cars get decommissioned and both each year then 1700 cars get decommissioned every year and new cards are bought. Therefore, there should be target to get at least 50% of the transportation fleet to electric by 2030. And the last 50% in the last 10 years.

Who?

Energy Companies, Dept. of Energy, Ministry of Finance and planning, GRENLEC

5.3.1.2. Societal Changes

What?

1. Public acceptance of renewable energy needs to increase
2. Public should start embracing the concept of becoming prosumers
3. People should become more entrepreneurial, thereby reducing the brain drain
4. Should learn to accept EVs and smaller vehicles instead of SUVs.
5. Should become okay with the idea of controlled charging

How?

1. More information about renewable energy should be made available and given through a single webpage
2. Consolidation of all the information regarding the benefits of RETs and EVs in terms of cost, health benefits, and jobs should be seriously dispersed.
3. Schools and colleges and universities have to play a more active role in educating students about renewable energy
4. The population should want to be more interactive with their government
5. For people living in the rural area the government and NGOs should take extra effort to disseminate information
6. Demonstration projects of controlled charging should be established and slowly the word needs to be spread

Why?

1. A better informed populace can take matters into their own hands and take charge of the transition if they want (like seen in a few developed nations Scotland, Netherlands, Germany etc)
2. They can also force the government to take action now especially because they are a part of the Paris agreement and it has been ratified by the government
3. The also provide the government with the support to take bolder action on the subject
4. Controlled charging becomes necessary because of over production from PV and Wind sources, and instead of curtailing their production; through controlled charging some of the excess electricity can be used to charge the EVs

Who?

GRENLEC, Govt. of Grenada, NGOs, the people of Grenada

5.3.1.3. Structural Changes

Institutional Change

What?

1. Set up relevant institutions to support greater penetration of renewable energy
2. Expand capacities for existing institutions
3. Data collection needs to be made a priority

4. Educational institutions need play a more critical role in developing vocational skills and reducing the brain drain in this sector
5. Institutes that aid renewable energy research should also be established

How?

1. Setting up an organization to deal with everything sustainable energy, make sure the roadmaps that are made, the goals and targets are achieved
2. The Grenada Bureau of Standards must increase capacity to be able to set standards and benchmarks for renewable energy equipment that are required.
3. The Meteorology department in conjunction with the organization for sustainable energy should have their capacity increased to be able to assess and perform a detailed resource assessment, spatial planning and EIAs for the island, maybe even involve the educational institutes in this. Also importantly should work with the poor to help understand how they can transition to renewable energy.
4. There should be a department that looks into how to create an entrepreneurial environment for the people of Grenada.
5. The educational institutes need to create bachelors and master's program for everything related to the energy sector and in general relating to the economy of the island for example set up business development courses or hotel management courses.
6. They should also get into MoUs with regional organizations and international universities to help with providing job training in RETS and also perform advance research in the field.
7. This can also include entrepreneurship courses for students.
8. Educational institues should incorporate sustainable practices in their operations and on campus thereby potentially increasing awareness within the youth and spreading the word
9. The dept. for sustainable energy that was suggested in the 1st point of this section should also look into different business models to encourage RETs penetration, especially in rural Grenada.
10. Universities should conduct workshops and lectures and campaigns towards sustainable energy in conjunction with GRENLEC and NGOs.
11. The department of statistics under the ministry of finance needs increase its capacity to collect all information regarding the energy sector. Especially the demand sector as information on that is limited and that is of utmost importance for efficiency measures and conservations measures.
12. Set up a Ministry to handle everything transport planning and traffic related.

Why?

1. This extra step of setting up a specific department for sustainable energy is taken to provide an extra layer of reassurance to investors because currently the RETs penetration has been limited, even though there is a vision document for 2030, a roadmap for 2020 and a national energy policy
2. The entrepreneurship helps with the brain drain and the lack of interest from international investors.
3. Universities can build a bottom-up movement if done right, which is essentially for a transition. The people need to be proactively involved. Also, knowledge doesn't always translate to action therefore hopefully instil leadership within the youth and that will translate to action
4. There is no government organization that looks into the transport sector and there should be one.

Who?

Meteorology department, Grenada bureau of standards, department of statistics, ministry of finance, educational institutions, NGOs, GRENLEC

Governance Changes

What?

1. Improve transparency to the people of Grenada and the world through reducing the red tape and having information readily available
2. While politically Grenada is considered to have a largely predictable and stable government; the problem lies with the government not being proactive enough.
3. Improve risk perception and investor confidence
4. Empower the population of Grenada

How?

1. There should be a massive effort to consolidate all information to a single source point. The department of sustainable energy can be of use here
2. Setting up regional and international networks within organizations that consist of solar pv, wind energy, batteries and EV companies and thereby promoting the island and it's intentions and the resources
3. Reduce red tape by have a single document that details all the procedures
4. Take an effort to spread the information in rural Grenada also, who maybe do not have access to internet.
5. All stakeholders should be constantly consulted and informed of changes being made to the energy legislation and policy
6. Like the private sector assessment that was undertaken in 2012, similar efforts should be made for the energy industry to address stakeholder issues constantly.
7. Work with the Grenada Development Bank and other organizations to help receive concessionary financing for the poor so that they can also transition to RETs.
8. The government of Grenada because of being severely affected by hurricanes is severely indebted already with a lot of financial institutions therefore their credit rating is terrible and therefore the risk perception of loaning money for an investment in Grenada comes with a high interest rate on the loan which is not good because the costs for transition are already sort of high because of the lack of economy of scale. So, the government needs to really work with development banks and credit unions to manage to receive low interest rate loans and small loans for individuals interested in decentralized generation. THIS IS VERY IMPORTANT FOR GRENADA
9. The government should try and play a leading role through public procurement policies however; this should be looked into considering the debt the government already owes.
10. Work with the World Bank to reduce the number of days to open business in Grenada and climb up on the ease of doing business ranking

Why?

All of this is done very simply to reduce transaction costs of the project, reduce the risk perception, reduce the interest rate on the loan, thereby decrease the capital cost of the project

Who?

Government of Grenada, and Grenada Development Bank

Regulatory Changes

What?

1. Regulation to help the poor transition
2. Regulation should be predictable, secure, transparent, stable and long term.
3. A legal framework needs to be established
4. Regulations for transport sector need to be established
5. People should be incentivized to stay

How?

1. The taxes on business should be reviewed as that was stated as the biggest impediment for doing business in Grenada. It makes sense that they have high taxes because they have large debt which they need to pay back. But, if the tax stalls economic activity then maybe it should be reviewed.
2. While there is an import tax exemption for RETs, this should be extended to the Balance of Plant equipment also
3. The VAT tax levy on fuel and electricity prices in Grenada should be removed for people producing energy through renewable sources
4. FiTs and PPAs through tendering is the most popular form a support scheme in the world today however Grenada’s case has shown little progress even with these schemes in place. This could be because of the fact that GRENLEC was early supposed to be the sole electricity generator or that people are poor on the island or because it is not easy to attract a IPP because of the risk perception. However, only last year did the government unbundle the generation side of things, so they should wait for 2020 and until then if still the progress is not satisfactory then the government should introduce Quotas on GRENLEC and utility suppliers.
5. Public loans guarantees should be introduced initially at least for the rural population and then their scope can be extended. The idea is that they probably can still have credibility to guarantee small loans.
6. The government should convert all the policy they have mentioned into law thereby creating a strong legal framework for the transition
7. They should introduce a rural renewable energy bill that deals with transition in rural Grenada.
8. Land acquisition is a major problem there and therefore after the resource assessment, the spatial mapping and the EIA is performed the government should block certain sq. km of in the most resource intensive locations for renewable energy deployment. This will go a long way in reducing costs of the project
9. Hopefully, once the independent regulatory is established the processes for support schemes and incentives will get streamlined.
10. The department of entrepreneurship should suggest policies that help the youth stay in the country
11. Grants to students can be issued, thereby financing their study abroad but then they would have to come back to the country to work
12. Real time pricing should be introduced for the electricity and transport market should be introduced.
13. Energy Audits should be mandated therefore enabling collection of demand side data
14. Transportation sector for EVs needs a bunch of policies in it’s favour. It has be price based incentives for consumers to purchase the more expensive cars.
15. Government vehicles, then company/business vehicles, and then taxis are the way to develop a strong understanding within the community for EVs

Why?

It should be understood that there are different schemes for different stages of the transition and therefore everything is done to support and incentivize the transition.

Who?

GRENLEC, Independent regulator, Govt. of Grenada, energy companies

Infrastructural Changes

What?

1. Introducing EVs supporting infrastructure

2. Grid adaptability
3. Introducing capabilities to balance the grid better

How?

1. Increasing the capacity of the grid so that it can better handle bi-directionality and high penetration of intermittent RE.
2. Perform a study on how to introduce V2G strategies to balance the grid better
3. Then improve the codes and standards of the grids on the island
4. Storage in the form of batteries should be introduced and can be incentivized similarly using price based mechanisms. Further, batteries will be required only towards the end of the transition after 70%
5. Study on system integration should also be performed to handle high Variable RE penetration
6. Market design should also be researched in the case of 100% renewable energy and V2G schemes and therefore the relevant infrastructure should be introduced accordingly. Real time pricing should also be introduced as a by-product of V2G and EVs.

Why?

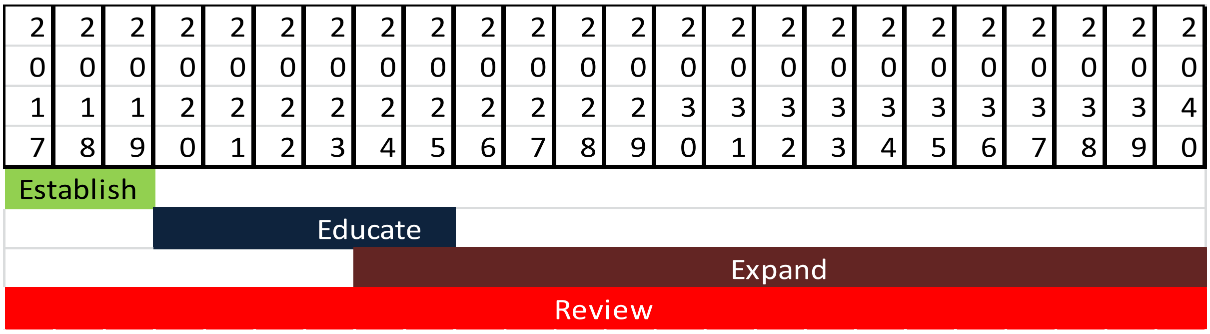
These are important infrastructural requirements to supplement a transition and it cannot be done without it.

Who?

GRENLEC, Govt. of Grenada, Energy companies, energy regulator, EV companies

5.3.2. Step 4: Implementation Timeline

We are going to use the same E3R strategy over here too. The difference will be that the education part will start earlier and not a lot of time will be spent on the establishing part because a lot is already done and the rest can be fairly simple to do.



The **first step's – Establish - goal** is to establish all the relevant institutions and step up the relevant network connections. Grenada already has the policies in place and most of the institutions and they have recently unbundled their generation. But an increase in renewable energy penetration is expected for Solar PV and the 1.1 MW of wind energy at Carriacou is also expected to become active.

The **goal of educate** to carry out all the research that is required to be carried out and based on the review of the previous year's change policies. The expectation is that there will be 50% RE penetration in the electricity market b 2025.

The **goal of expand** is to keep reviewing the policies and great a dynamic policy environment that reacts to the market and its actors. So, reviewing becomes essential here. By 2030 80% penetration is expected for electricity market and 50% penetration for the transport market.

I will rewrite this section with all the relevant changes under their respective strategy headings.

5.3.3. Scenario 2: Geothermal, PV, Wind

For this part we only discuss the changes that are not a part of the changes mentioned under section 6.4.1. because we assume that all those changes are still necessary and required for this scenario.

5.3.3.1. Technological Change

What?

1. There is a need to substitute all the old operating technologies in different fields. So, that can be substituting CFLs with LEDs, for example. Or getting better cooling systems like using geothermal cooling or advanced cooling systems.
2. Updating currently less efficient technologies to their more efficient version is also necessary, like in the case of household appliances, industrial equipment etc
3. Introduction of baseload technology into the energy mix

How?

1. Currently there the government and GRENLEC are already looking very seriously into 40-50 MW of Geothermal energy, while they are behind schedule they are still working towards the construction and both the plants should be ready around 2025. After which point they will require 40 MW more of installed capacity and considering it takes 6-8 years for a geothermal plant to get constructed, and assuming that they construct only 20 MW plants even in the future, then latest by 2025 they should start constructing the 3rd plant and then by 2032-33 they should start the process for the last geothermal plant.
2. However, a better way of planning this transition would be to substitute the fossil fuel plants with geothermal energy.
3. Study the potential for Geothermal Cooling systems and start a trial project with a few demo systems by 2020.
4. More important start looking into efficient cooling systems to replace the current outdated, presumably, conventional systems.
5. Expand on the LED programme to start with changing all their public lighting to LEDs first and then get industries, businesses and then last individual households involved.
6. There is a requirement for 90 MW of solar, which can be managed at an annual penetration rate of 17.75%.
7. There should be a comprehensive study on decentralized PV and its potential because of the limited land area available it is beneficial to try and fill up as many roof tops as possible with PV systems
8. 30 MW penetration of wind energy is required. Assuming that the 1.1 MW plant at Carriacou is constructed by 2020. There will be a need to install the rest in the 20 years. This can be done at a penetration of 18% annually.

Who?

Energy companies, GRENLEC, Ministry of Finance, Department of Energy

5.3.3.2. Societal Changes

What?

1. Emphasis on the benefits of energy efficiency and conservation measures
2. All around information about sustainability and eco-friendly behaviour
3. Making sure a rebound effect does not take place.

How?

1. In terms of the process this is not going to be very different from scenario 1. The people need to be more involved and informed sure websites and information campaigns.
2. The bigger trouble here that needs to be overcome is that more knowledge doesn't necessarily translate to action therefore, a more grassroots approach in terms of community

outreach programmes, participatory workshops at educational institutions and work places, should be organized.
3. The need for private transportation needs to be reduced and a more public transport mentality needs to be inculcated.

Why?

This is cruicial in this scenario because we require a 36% reduction in total energy consumption by 2040. And while that does not look tough, Grenada is not really an affluent country and it has much bigger challenges than energy transition and therefore, this can take a back seat sometimes.

Who?

NGOs, Civil Societies, GRENLEC, Govt. Grenada, Educational institutions

5.3.3.3. Structural Changes

Something worth nothing here is that to a very large extent anything and everything that needs to be done structurally to improve energy efficiency and install geothermal energy is already mentioned in their national energy policy. The government is just slow at following through on it or hasn't followed through on certain sections of the energy policy at all. So, it might seem like reiteration but that doesn't change the fact that these changes still need to be done.

Institutional Change

What?

It is the same scenario 1 everything now also includes energy efficiency.

How?

1. Establish an energy efficiency unit/department that will be incharge of creating EE strategy, standards, regulating consumer and supplier activities.
2. This will require an increase in human capacity and expertise within the government for energy efficiency. The expertise can be received through training workshops with the international and regional bodies
3. Establish relationships with local/regional/international organizations that can aid in energy efficiency research and implementation. This can also be beneficial when certification is required, so maybe use a regional organization for energy efficiency certification of equipment and appliances
4. Establish relationships with companies along the supply chain of geothermal energy.
5. Creating an energy efficiency fund within the government would be beneficial.
6. The statistics department should be given more power to be able to collect more data from the energy demand side of the industry, there is severe lack of information.

Why?

1. Increasing bureaucracy within the government is not necessarily bad because sometimes not having enough people makes the government not prioritize elements which are important.
2. Because of the lack of human capacity and expertise on the island asking help from local/regional and international organizations is paramount.
3. Economic incentives to a large extent work well to drive consumers towards energy efficient technology

Regulatory Changes

What?

In terms of what changes need to happen they remain the same as scenario one apart from the need to add energy efficiency regulations

How?

1. Better codes and (minimum performance) standards for grids to enable bi-directionality, reduce losses, improve chances of V2G becoming reality.

2. Creation of a national plan and supporting this with concrete legislation for energy efficiency increase. This should have national targets and sectoral targets (however, the latter can only happen if sectoral data on energy consumption is available in detail)
3. There should be legislation to help with retrofitting current buildings and also improvements in codes and standards to incorporate renewable energy in buildings. This will help not only with the efficiency aspect, but aid the transition through decentralized energy.
4. Making energy auditing mandatory for every sector, maybe the energy efficiency unit can be in charge of this also
5. In general, there needs to be better codes and standards for buildings, appliances, equipment,
6. There should be incentives for large consumers, residential consumers, commercial consumers and the public sector
7. Further, there should incentives given to the utility to increase efficiency also
8. Energy labels should be introduced so that consumers can make a decision on whether they want a more efficient product or the less efficient one.
9. Get the geothermal exploration and drilling bill passed and create a roadmap for increase in installed capacity of geothermal energy, this helps with the investors understandind the seriousness of the government in pursuing geothermal energy
10. Streamline the processes and administrative requirements to start the drilling and exploration, this will help reduce delays in the project and reduce financial burden
11. There should be a separate study on rural grenada and there should be equitable incentives for them as well to incorporate energy efficiency measures.

Who?

Geothermal companies, Govt. of Grenada, GRENLEC

Infrastructural Changes

What?

The only major infrastructural change that needs to happen here different from scenario 1 is the need to make buildings more efficient.

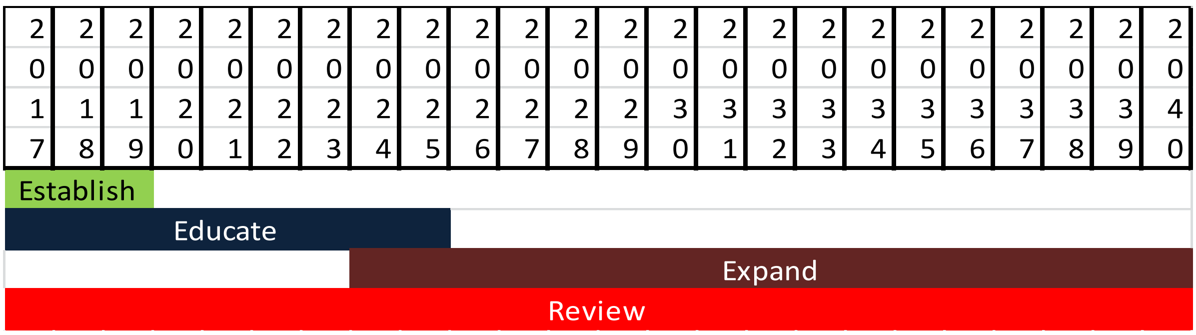
How?

1. The building codes can require people to install rooftop solar PV.
2. There are be changes required in terms of ventilation, and materials used for construction
3. A study on how V2G can be made a reality should be carried out
4. Introducing geothermal cooling for buildings and a study on how that can be made possible.
5. Zero energy designs should be used for any new buildings that are constructed

Who?

Architecture firms, the govt. of Grenada, GRENLEC

5.3.4. Step 4: Implementation of timeline



The difference to the scenario 1 is the extension of the educate timeline. The reason for this is because there is a requirement to improve on energy efficiency. And currently there are no experts on the island for the same. So, the understanding is that with the establishment of the energy efficiency unit there is also a lot of training that comes along with it for its employees and not to mention while there is an understanding that one can improve cooling efficiency by changing the demand side technology, one should also look into supply side geothermal based technologies for cooling and that requires some research.

2017-2019 - Establish
Goal: Establish all the relevant and required institutes, establish the geothermal bill and construct the first 20 MW geothermal plant, set up the 1.1 MW wind plant

2017-2025 – Educate
Goal: Perform research on geothermal cooling systems, understand energy efficiency increases and the requirements for that to happen, 20 MW of Solar PV is installed, the 2nd 20 MW geothermal plant is installed, 5 MW of wind energy.

2025- 2040 - Expand
Goal: by 2030 another 5 MW of wind energy is established, 20 MW more solar PV, sales of ICEs are stopped by 2030. After 2030, the rest of it happens by 2040.

5.4. Conclusion

In conclusion, it can be said that Grenada as an island has somehow managed to perform decently well bureaucratically but has failed in capitalizing on that. From the section on the strategic problem orientation we can see that more than 90% of the energy is from fossil fuels and most of the non-fossil fuel energy is also used for cooking purposes. In the demand side of things, transport consumes most of the energy, followed by the residential sectors, then the commercial sector and then the industrial sector. They have a fairly efficient grid system thanks largely to the private utility comapny Grenlec.

They have an energy policy from 2011 in place which talks about wanting to reach 20% of all energy consumed by electricity sector and the transport sector from renewables by 2020 and a 100% by 2030, they have a roadmap for 2020. The policy talks about all the relevant issues of the transport sector and the electricity sector and how to improve energy efficiency. However, that is all there is. Beyond that there is limited progress made. No improvements in the transport sector, there isn't even an govt. agency that looks into regulating the transport sector, no efficiency improvements, there has been progress made in installation of renewable energy technologies for electricity production like solar PV but beyond that there is nothing more. GRENLEC has stalled all renewable energy projects currently until they understand the implications of the new electricity law which unbundles the generation side of the electricity sector. Beyond this a very large population of grenada is poor so that hampers a lot of information dissemination and in general transitioning because the technologies are capital cost intensive. And large scale renewable energy is complicated because of the risk perception of the island and also because it already has lots of outstanding loans that it has to repay. This is probably due to it being present in the hurricane belt.

Further, on calculatin the potentials it should be noted that geothermal, wind and solar PV where the most feasible, and this also happens to be true in terms of cost. Therefore, there were two scenarios created which spoke about the energy consumption value for the future of 2040 and the energy mix of installed capacities that will meet them. The first scenario was full of solar PV, wind, and batteries and no energy efficiency gains, while the 2nd scenario had geothermal, PV and wind and batteries; along with energy efficiency gains. This is interesting because 1 is full of intermittent sources of energy while the other has a base load technology to it and has energy efficiency to add to it. Further, it was noted that the investment cost per year would be 7.5% and 2% annually, respectively, as compared to 15% annually spent on fossil fuel imports. The 1st scenario had the disadvantage of requiring large land area which may not be feasibile in small isalnds, therefore the 2nd scenario is the better one in terms of land area, percentage of GDP.

On answering the following questions, what, how, why, who and by when, regarding changes for each scenario. The following was concluded about the 2 scenarios, they have most of the established required institutions and structural support. The first and second scenario needs a specific unit to look into the sustainable energy regime on the island and most importantly a department that handles the transportation sector. The 2nd scenario in addition requires a unit to handle energy efficiency. However, all of this will require to build human capacity and expertise on the island therefore utilizing help from regional organizations is paramount. In terms of technical feasibility since both the scenarios use mature technologies, there isn't a lot of problems or need for research. There is a need to research potentials of various technologies and there is a need to study how vehicle to grid can become a reality and what kind of market structure and pricing mechanism is needed for that. So, this has to do with a lot of research on the demand side and also there is requirement for a lot of data collection for the sector also. The biggest contrast between the 2 scenarios is the fact that energy efficiency and conservation cannot happen without active societal role. Therefore, the role of the consumer is amplified in the 2nd scenario. And this need to improve energy efficiency and make the consumers place a larger role becomes more difficult because of the large population of people living in rural Grenada. In the 1st scenario because of the lack of movement with penetration of solar and wind, there is a may come a requirement to use quotas obligations and then letting the generation and the utility decide how they want to meet those obligations. But most importantly both scenarios can be achieved by 2040 using the E3R strategy.

One of the major challenges for both scenarios is the need for finance to make this transition happen. Grenada will have to work towards that specially through maybe Grenada development bank and credit unions. There is also a land issue for the first case, which needs to be looked into and handled. But it should be noted that in all strategies the govt. plays a pivotal role because initially they need to provide a secure investment environment and then look at maintaining that environment while giving both capital and revenue support and yet have a dynamic policy to be able to react to negative consequences.

6. Cross Case Analysis

This section will compare the 2 cases using the 4 steps of the methodology.

6.1. Strategic Problem Orientation

Let's look at the differences using the PESTEL method, as that seems to be the most structured.

- **Political Factors**

	Curacao	Grenada
Government Style	Parliamentary	Parliamentary
Political Jurisdiction	Part of Kingdom of Netherlands and the EU	Independent
Political Stability	Constantly changing government	Stable Government
Institutional Support	Ministry of Economic Affairs	Ministry of Finance – Energy

for Electricity Sector		Division
Transport Sector	Ministry of Traffic, Transport and Urban Planning	-
Independent Energy Regulator	Bureau of Telecommunications and Post	Being set-up in the near future. Currently Ministry of Communications, Works, Physical Development, Public Utilities and ICT is in-charge

Table 11. Overview of Essential Political Factors for the 2 SIDS

Politically, both Grenada and Curacao are parliamentary in nature. But there are two big differences; one being that Curacao is still a part of the Kingdom of Netherlands, and therefore a part of the EU. Two, Curacao is politically perturbed seen by the constant changes in government, whereas Grenada has largely a stable political climate. However, this constant change in government in Curacao seems to have limited effect on RE penetration in the electricity sector because in the last 7 years 25% of the electricity sector has come to be powered by RETs. This can be correlated to the stability that is brought into the economy by being a part of the Netherlands/EU and also because of the 2 decade experience that Curacao had previous developed in Wind Energy. This experience is a consequence of what is stated as the 'influence of individual champions' by Philip David Morgan Ince (2013). In terms of institutions that aid Curacao has no specific institution to regulate the energy sector, the ministry of economic affairs takes care of it, and they have an independent regulator of the energy market but it is handled by the Bureau of Telecommunication and Post, which does not instil confidence. Curacao does have a transport planning department but their effectiveness can be questioned because of the lack of transport policies. While Grenada on the other hand has an Energy Division under the Ministry of Finance that handles energy, efficiency and sustainable development. The effectiveness of this division can be questioned because it has failed to implement any efficiency policies and the progress towards RETs has been limited, as seen by the energy balance of Grenada. However, there is no institution for the transport sector. Grenada has recently passed a law to establish a commission that will act as independent regulator of the energy market and eventually a few of the functions will be shifted to the Eastern Caribbean Regulatory Commission. Governmental institutions serve multiple purposes like establish vision and mission, establishing policies, monitoring and reviewing progress, collecting relevant data, establishing relevant indicators but they become very important within the context of SIDS because a strong institutional setup helps indicate seriousness to outside investors and thereby increase investor confidence.

- **Economic Factors**

	Curacao	Grenada
GDP/Capita	20,126 USD (2014)	12,231 USD (2015)
Economic Sectors	Oil Industry, Tourism, Financial Sector	Tourism, Agriculture
Credit Ratings	A-/A2-	SN
Ease of Doing Business Rank	-	138/190
Cost of Electricity (Avg.)	0.35 USD/kWh	0.27 USD/kWh

Table 12. Overview of the different Economic Factors

Economically, clearly Curacao is far more affluent than Grenada in terms of GDP per capita. This implies that the people of Curacao are in a better position to potentially use decentralized energy generation to transition. This is possibly because of the dependence on various sectors for economic growth like the oil industry, the financial sector and the tourism sector. While Grenada predominantly depends on the tourism, and, a little, on the agriculture sector both of which are seasonal. This is not to mention that they are still recovering from the 2004 and 2005 hurricane attack coupled with the financial crisis of 2008. In terms of credit worthiness, which relates to the country's ability to repay loans or how worthy the country is of receiving a loan, of the two countries Grenada is in terrible shape with a ranking of "SN", which implies that they are unlikely to pay back loans(Global Credit Portal, 2017; Now Grenada, 2014). While on the other hand Curacao is at "A-/A2-"which is not bad, it reflects a stable outlook, which is important; this is partly thanks to the Kingdom of Netherlands helping Curacao (Caribbean News Now, 2016; Global Credit Portal, 2017). In terms of GDP growth both countries have been slow. Grenada partly because of being tragically affected by hurricanes over a decade ago and then couple that with the financial crises. While Curacao it is because of political instability. IMF predicts a better future in terms of GDP growth for Grenada over Curacao (IMF, 2016a, b). In general, cost of electricity is generally very high in the Caribbean and is stated as an impediment to doing business (Arnold McIntyre et al., 2015). Grenada generally has very high electricity rates, like 0.34 USD/kWh in 2015 (Espinasa et al., 2015; NREL, 2015) while in Curacao also it is high even though there is a refinery on the island. Currently, because of the low oil prices the cost of electricity has also reduced. In terms of ease of doing business, an ranking system developed by the World Bank based on 10 indicators, Grenada is ranked 138/190 countries and has been doing badly (World Bank, 2017) but it hopes to do better because of a series of regulatory changes in the last year. While Curacao is not even ranked by the World Bank, however, they are conducting their own study based on the World Bank Methodology (COSME, 2015). If looked more deeply into the Ease of Doing Business ranking for Grenada, it will be noticed that Grenada performs decently when it comes to indicators like starting a business and getting electricity access and enforcing contracts, however, in the remaining 7 indicators, especially in paying taxes, getting credit and dealing with construction permits category, Grenada needs to improve (World Bank, 2017). Specifically when it comes to taxes; because it has been recognized as the biggest barrier to private investments, even, by the Organization of Eastern Caribbean States survey in 2010 (Whitehead et al., 2013). Not to mention, Grenada also spends a lot or at least keeps a lot of their budget for disaster management while Curacao has not this requirement. This relates to the energy industry because now it can be said that doing business in Grenada is not really looked favourably upon and that there are little chances that private banks will fund them and even when the development bank funds them it may not be as concessionary as they would like it to be. That said, in general, it may be easier to transition in Grenada because the economy is not so reliant on an oil refinery.

- **Societal Factors**

	Curacao	Grenada
Unemployment Rate	12%	29%
Poverty Rate	25%	40%
Urbanization	89%	35%
Rural Living Population	11%	65%
Energy Courses	Energy Minor	-
Vocational Training	-	Yes, in Collaboration with GRENLEC
Energy Research	University of Twente (mainly)	St. George's University
Outreach	-	Through components of internationally funded efficiency programs GRENLEC – the utility company

Table 13. Overview of the Societal Factors in the 2 Islands

Societally speaking Curacao is more affluent than Grenada. That means, the unemployment rate in Curacao is just 12% compared to 29% in Grenada. The poverty rate in Curacao is close to 25% while in Grenada is it closer to 40%. Most interestingly, close 65% of the population lives in rural Grenada compared to 10% in Curacao. This is important because it can be inferred that it is probably easier to spread the information in Curacao than in Grenada (We are Social and Hootsuite, 2017) and also because of this the people of Curacao can probably more afford the transition at an individual level than in Grenada. There is a brain drain issue in both the islands. However, the fact is that Curacao at least has a minor, with their bachelors program, on energy is a little encouraging; while Grenada has no such thing. On the other hand Grenada has an institute that handles vocational training while Curacao has no such arrangement. GRENLEC is working with that institute to make it more renewable energy friendly. Further, the Govt. of Grenada has tied by with St. George's University of Energy research, it must be stated that this university doesn't specialize in energy studies but rather is the only university that performs scientific studies (IRENA, 2012). Further, Grenada has previously gotten help of international organizations to fund better lighting options and solar water heaters which include a component of spreading information on the subject and also GRENLEC has an active community outreach program (Carpio, 2010; GRENLEC, 2014; SE4ALL, 2012). So, it is assumed that they have some understanding of the energy use, while Curacao has nothing of that sort. However, University of Twente in the Netherlands is performing good energy research on Curacao. How much of it is being used is unknown.

- **Technological Factors and Energy Sector**

	Curacao	Grenada
Primary Energy Use (TJ)	128939	6221
Fossil Fuel (%)	99	93
Renewable Energy (%)	1	7
Finale Energy Consumption (TJ)	47083	4491
Transport Sector (%)	60	41
Residential Sector (%)	-	30.5
Commercial Sector (%)	-	23
Industrial Sector (%)	-	3.5
Other (%)	-	1.5
Electricity Sector (%)	6	15
Air Conditioning	45-50%	50-60%
Installed Capacity (MW)	185	52.4
Renewable Energy (%)	25	2

Table 14. Overview of the different Technological and Energy Sector Related Factors

Grenada's primary energy use in 2013 was 93% imported fossil fuel used in diesel generators to produce electricity, in the form LPG and kerosene for cooking, and in the form of gasoline for vehicles. And the remaining 7% constitutes of 1st generation biomass and solar PV. The first generation biomass is used for cooking in rural Grenada. While in Curacao 99% of primary energy use is fossil fuel, used similarly as used in Grenada but Curacao has an oil refinery which also uses some of that primary energy, and around 1% is renewable energy in the form of onshore wind and rooftop solar PV. Both their transport sector is 100% fossil fuel. While Grenada has a very normal consumption pattern, wherein, 40% is consumed by transport sector, 32% by the residential sector, 23% by the commercial sector and 4% by the industrial sector. Curacao on the other hand, has a transport sector that consumes 60% of all energy (Niel Gardner et al., 2013). And there is no information on how much is consumed overall by other sectors. This consumption could predominantly be because of 2 reasons; one because of very high numbers of tourists that come to Curacao and the send because of the non- regulation of the transport sector; for example, there are no regulations checking quality of vehicles being imported into Curacao. Not being in the hurricane belt helps with extending the tourism season a little longer than in Grenada. Another point worth discussing the amount of electricity consumed by the air conditioning system, in Curacao is apparently consumes around 60-65% of all electricity consumption in the residential sector and 30%

in the commercial sector (Caithlin Ann Marugg, 2016; van Eldik, 2015), whereas in Grenada the overall consumption by the cooling system is around 50-60% (IRENA, 2012). Of course, the overall percentage even in Curacao is around 50%, the point here being twofold: One, cooling systems used are highly inefficient consume the most amount of power and two, potentially, the other reason the air conditioning system in the residential sector consumes close to 65% of power is also because of poor insulation of the buildings. Lastly, in terms of installed capacity and consumption Grenada is almost 4 times less than Curacao. Currently, 25% of installed capacity for electricity production in Curacao is renewable, while in Grenada it is closer to 2% today. This is striking because on paper Grenada is far more prepared for the transition than Curacao is, by virtue of having certain institutions, having a utility that wants to transition, having a vision, roadmap, and policy.

- **Renewable Energy Potential**

Unit: TJ/yr	Curacao	Grenada
Utility Scale Solar PV	5940	4530
Rooftop Solar PV	930	815
Onshore Wind	5875	1854
Offshore Wind	39557	5832
OTEC	2880×10^6	-
Geothermal	-	27,750

Table 15. Overview of all relevant Renewable Energy Technology Potentials on the two Islands

In terms of potential of renewable energy, both islands are similar to an extent. It boasts a lot of potential for solar PV and wind energy as it is expected. In terms of baseload renewable energy, the islands boast different sources; Curacao has great potential for OTEC, while Grenada has for Geothermal. Both lack any substantial potential for waste to energy, biomass/biogas, or hydropower, which is unfortunate. These sources are baseload renewable energy and are mature technologies, so they could have been used substantially in the transition as they would also been relatively cheap. There are other technologies also like Solar Thermal, wave, tidal which have little potential or are too expensive and their learning curve doesn't seem steep enough (solar thermal). But beyond all this, the main reason is to limit the technological scope of this research. Now looking deeper into the solar PV and Wind Energy section, we can say that rooftop solar PV has only limited potential (that said, it is believed that the calculation performed for this research for rooftop solar is conservative) and therefore large scale PV will also have to be considered to meet the transition needs. In terms of off shore and on shore wind; Curacao has low potential for conventional offshore wind energy, while Grenada has a very large potential. This is because of the depth of the ocean exceeding the 60 m mark very close to the shore in Curacao. However, this is the reason why Curacao is a prime location for OTEC while Grenada doesn't really have the potential for land based OTEC at least. The depth of 800 to 1000 m of the coast of Grenada is at a distance of greater than 20km. In terms of on shore wind the only limiting factor (as in the case of utility scale solar PV) is the land made available for installations.

- **Environmental Factors**

	Curacao	Grenada
Temperature (°C)	29	29
Solar Irradiation (kWhr/m²/yr)	2027	2000-2120
Available Land	50% - Unprotected, inhabited land area	85% - Forest Cover and Agriculture Land
Wind Speeds (@50 m)	9.5 m/s	7.6 m/s
Direction of Wind	NE to SE	NE to SE

Hurricane Belt	No	Yes

Table 16. Overview of the Environmental Factors on both the Islands

Both are in the same region so have similar temperatures, and seasonal patterns. They are warm all year long. The temperatures do not vary over the year a lot. They both have vast sums of land available and unoccupied. Grenada has only 15% of its land occupied the rest is used for agriculture or is a forest area. Similarly Curacao has also around 50% of its land area just covered by forest and it is not protected forest land. The stark difference, and the main one that matters, is the fact that Curacao is outside the Hurricane belt of the Caribbean, while Grenada is within the Hurricane Belt. This leads to a lot of the resources in Grenada being diverted towards disaster management. This also leads to the cost of the loan increasing for any and all investment in Grenada. As inferred from the high wind energy potential, it can be said that there is a good healthy and consistent wind speed.

- **Legal and Policy Factors**

	Curacao	Grenada
Energy Policy	Electricity Policy	Electricity/Transport/Efficiency Policy
Sustainable Energy Vision	No	100% RE by 2030
Sustainable Energy Roadmap	No	Yes
Policy for Small Scale PV	FiT – 0.15 USD/kWh Sun Tax – 9 USD (Residential) 18 USD (Commercial)	FiT 1 – 0.17 USD/kWh (fixed) FiT 2 – 0.09 USD/kWh (Variable) Based on avg. avoided fuel cost in prior year
Energy Efficiency/Conservation Targets/Policy/Laws	-	-
Sustainable Transportation Targets/Laws/Policy	-	100% renewable by 2030
Tax Benefits	No Import Duty for RETs	15% VAT exempted for anyone investing in RETs
Highest Judicial Body	The Dutch Supreme Court	Eastern Caribbean Supreme Court

Table 17. Overview of Legal and Policy Factors of the 2 Islands

Curacao has one electricity policy paper wherein it discusses opening its market and unbundling but hasn't yet implemented it. However, it does have a FiT for small scale solar PV which was doing really well, but due to (what the author assumes, over heating of the market) they introduced a monthly solar tax which pretty much stalled the entire penetration small scale solar PV was projected to have. In terms of large scale production of renewables the interested IPP is supposed to negotiate a PPA with the utility. While on the other hand Grenada has a FiT installed, and until recently only the utility company was allowed to install large scale electricity systems but that has been changed last year. Grenada, has a National Energy Plan, A 2030 Vision, A 2020 roadmap for sustainable energy, has an independent regulator recently commissioned. They have a Geothermal Bill circulating and which will be voted in parliament soon. However, they have a problem most of the times converting their vision in policy document to actual laws. Lastly, one of the biggest advantages for Curacao is that, the highest judicial court is the Supreme Court of Netherlands which provides a resounding assurance to a lot of investors; whereas, Grenada doesn't enjoy any such privilege.

It is astonishing that Curacao with limited structural support and intermittent governments has had a 25% penetration of renewable energy in the electricity sector, while Grenada with much of the same structural support (maybe even more) has only managed around 5% penetration of installed capacity. One of main reasons for this is because Curacao is one of the pioneers of wind energy in the region, Aqualectra in the early 1990s installed wind turbines and they ran for over a decade and a lot of experience was gathered by that. It helped propel Curacao's interest in renewable energy. This supported by being in the EU and potentially have mainland Netherlands backing has led to them having such a high penetration of wind and now even solar (well at least until 2015). This can't be said for Grenada, they have started testing with renewable energy only in the last 5-10 years. GRENLEC is willing to transition but is taking is slow with small scale solar PV but only accepts a certain amount every time. Further, there is a lack of capital available for the island which makes it difficult to finance renewable projects which require high upfront costs and in Grenada because of the small size of the projects the project is even more expensive because of high fixed costs. Though from Curacao's experience, it maybe hypothesized that political instability (at least the form Curacao has) need not necessarily be a deterrent to projects provided you have a company and a utility/government willing to negotiate. This also states the advantage of unbundling your supply side of the sector. Therefore, reading this we can draw parallels to literature review wherein these two islands face a lot if not all the issues mentioned in the literature.

6.2. Future Energy Scenarios

Year: 2040	Curacao		Grenada	
Scenarios	1	2	1	2
Energy Demand: Electricity + Transport (TJ)	5625	2700	2343	1646
Annual Energy Efficiency Gain	-	3%	-	1%
Required Installed Capacity (MW)	1350	350	563	210
Solar PV (MW)	910	150	380	90
Wind Energy (MW)	440	50	183	30
Battery (GWh)	7.65	0.175	3.18	0.107
OTEC (MW)	-	150	-	-
Geothermal (MW)	-		-	90
No. of vehicles	96,000	96,000	50,000	50,000
Jobs Created	1700	5000	661	303
Land Area	25-30 km^2	8-10 km^2	21-24 km^2	9-10 km^2

Table 18. Overview of 4 different Scenarios Created for the 2 Islands

Based on these factors and potentials, there were 2 future scenarios made for each of the 2 cases. The first scenarios in both the cases are based on completely intermittent renewable energy sources (Solar PV + Wind Energy) along with battery storage. While the second scenarios in both the cases introduced a baseload technology into the energy mixes, thereby reducing the need for batteries and intermittent RES. Further, the 2ns scenarios also introduced energy efficiency gains because of which there were drastic reductions in energy demand in the future. There were 3 common assumptions in all 4 scenarios. They were that the transportation sector would transition to a 100% electric, the usage of oil products of things apart from electricity production and transportation would not be discussed in this transition and that the target year for all 4 scenarios to achieve the 100% RE vision is 2040.

Henceforth, the 1st scenarios of both the cases will be discussed together and the 2nd case for both the scenarios will be discussed together.

The technology selection for the 1st case was driven by the fact that in terms of renewable energy technologies which have potential on the islands wind and solar are the most mature technologies today deployed. This is important for cost of the system but it is also important to help get loans for projects. Banks are generally hesitant to loan money for projects that have a high risk. There can potentially be 9 types of risk relevant to investment in renewable energy (Ecofys et al., 2016), and two out of them are technical and management risk, and country risk. The latter is generally high because of also social risks, administrative risks, unstable policies and generally erratic economic development, so by choosing mature technologies about which the banks have a lot of knowledge is useful to at least reduce the risk of the project, a little. This affects the interest rate levy on the project, which directly affects the cost of the project. This was also supported by the immense potential the two technologies have on islands. However, the problem lied with the fact that expensive battery storage had to be incorporated to balance supply and demand. This made the system expensive, however the prices are still comparable to the current electricity costs. The other problem stands at the fact that because of the expensive battery it was cheaper to install excess wind and solar before even thinking of installing battery. This lead to severe over production and therefore, a lot of produced electricity was dumped. This leads to complications. Now the question is how to reduce this over production. Looking at literature one way is to curtail the electricity produced when there is going to be over production. The other probable way is to have controlled charging of the deployed EVs. This has been shown to reduce the amount of electricity dumped. Of course, there are also other ways based on literature, like creating a common grid between nearby islands or in a more futuristic sense maybe this electricity can be used to produce Hydrogen for Fuel Cell based vehicles. However, the last two questions are outside the scope of this work because we talk about SIDS being energy self-sufficient and fuel cell cars are the next step in vehicular transition and will happen only after EVs. Now what is more probable for this research is the possibility of curtailing production and using controlled charging for EVs. In the former situation, the understanding of how to compensate electricity generators who have established RE plants but are not being used will need to figure out. Therefore, what is a better solution is using a controlled public and home vehicle to grid applications. This has shown compelling results in Aruba, wherein more than 90% of the electricity that would have otherwise been curtailed can be utilized. The results should be transferrable to Curacao and Grenada here simply because of the geographical likeliness. One of the last problems with this scenarios was the need for waste amounts of land. In Curacao you need almost 44 km^2 of land (assuming the transition is purely land based) and to give a comparison the land area of the city of delft is 24 km^2. Similarly, even in Grenada there was a requirement of about 22 km^2. While in percentages they are not a lot, that doesn't change the fact that it is still a large requirement for small islands.

The technology selection for the 2nd case was driven by wanting a base load technology that had immense potential. Therefore for the case of Curacao the OTEC technology was utilized and the case of Grenada Geothermal technology was utilized. The first positive impact that this had was the reduced impact on land use. The second impact was that the overall system cost in terms of LCOE is cheaper than the 1st cases and therefore on paper better. This also reduced the dumped energy to a large extent, that is based on literature up to 87% of RE penetration can be sustained and will be completely used to power the system. Only beyond that will the dump start. However, the main differences between these scenarios are also the main downside of these scenarios. The OTEC technology proposed to be used for the Curacao case is an immature technology which is in its demonstration stage, this means very high capital costs and limited financing options because loan will be difficult to get. This also by virtue has limited knowledge pool available to work with. The Geothermal technology proposed for Grenada is a mature technology but still has a very high capital cost. The advantage here is that there are financing options and a vast pool of expertise willing to help like the Japanese and the New Zealanders are helping Grenada now with the research and implementation of the Geothermal plant. Both scenarios addressed implementing energy efficiency to reduce demand of electricity by 2040. The difference only lies in the rate of efficiency gains annually. Curacao states there needs to be a 3% reduction annually to get to the target reduction of 50% by 2040 compared to the scenario 1 projection of what the electricity demand will be in 2040; while this is 1% for Grenada. This is predominantly got to do with the rate of increase in electricity in the 1st scenario for both cases without energy efficiency gains. The annual efficiency gain percentage is based on how much would bd required to reduce consumption by 50% by 2040. This may seem a lot but looking at the efficiency gain potentials calculated one can imagine that this is possible. Even in literature it is mentioned that a 2-3% annual gain can be achieved (and this is without efficiency gain by the substitution effect of ICEs to EVs).

6.3. Backcasting analysis

The Backcasting analysis mainly spoke about the what-how-why-who regarding the changes required to reach our scenarios. Here too, scenarios 1 of both cases will be compared together and scenarios 2 will be compared toward of both the cases.

- **<u>Scenario 1 – both cases</u>**

Let's talk about the most important common aspects and different aspects in these scenarios. It is important to note here that all changes across the 2 cases have been done for some if not all of the following reasons:

1. Improve investor confidence on the island
2. Reduce risk perception regarding the island
3. Improve potential of getting loan at low interest rates for projects on the island
4. Assure predictability and stability of regulations and policies
5. Ensure there is societal drive for transition therefore making politicians stick to plans
6. Support renewables deployment through capital and revenue support; by
7. Reduce transaction costs, therefore reducing capital costs of the project
8. Provide PPAs/FiTs with desirable prices

It should be noted that the last 3 points also aide with points 1 to 4. As it can be seen this is mainly dealing with economics and finance of the project.

Most common aspects for the 2 scenarios lie in the technological, societal, infrastructural and governance changes that need to happen. And these are for obvious reasons because they technologies being used in both scenarios for both cases are identical. And there are no efficiency improvements that are seen in this scenario. So the technological changes are required based on which the same infrastructural changes will be required, and to facilitate all of this you need better but the same kind of societal awareness and changes. Even in the transport sector the sales of ICEs will need to be banned by 2030 and all ICEs by 2040. There is no evidence to suggest that the market will be capable of doing this on their own until they are pressurized into it.

Lets start discussing the main differences by talking about the infrastructural change of having to reconsider the role of the oil refinery at Curacao while nothing of this is required for Grenada. The established oil refinery is a way of life and therefore makes it increasingly difficult for garnering public support to close the plant even though at the government level it is discussed always. Therefore the plant's role should be reconsidered for up until 2040, by that I mean reduced in capacity and scope. Then what is the next step needs to be studied further but hopefull by 2040 RETs will be wider spread and will not require much thought to shut the plant.

The next differences mainly lie in the institutional and regulatory sections of the structural change required. In terms of institutional and regulatory changes as mentioned while discussing the Strategic Problem Orientation that it seems almost like Grenada is a step forward in those terms. However, in terms of RE deployment the situation is opposite. Curacao currently has more penetration compared to Grenada. So, the important differences in what needs to be changed is that in Curacao there needs to have a department of energy which looks into all the energy needs of the island under which there are committees looking into various technologies for implementation. The transport department needs to take a more active role in infrastructure planning and transitioning to EVs. The CBS should be more aggressive with data collection. Apart from this the mainly require an independent regulator of the energy sector which has the expertise in this sector and is not filled with personnel form the telecommunications bureau. In terms of policy they should create a National Energy Policy which integrates the processes that already are being used and the instruments already being used. Then create a roadmap with set targets. They can use this. Then they need to turn all this into legislature and vote on it. Which also making sure that they reduce the solar tax and rather give tax incentives. Further, resource mapping, spatially mapping of resources is of utmost importance and is will help reduce transaction costs. These policy instruments are also common for Grenada. As will a standardized PPA agreement. However, none of this works if both the islands do not aggressively participate in international networks to set up the right relationships and the right educational programmers for vocational training and also studying and research. But what Grenada needs to do is also allow IPPs to supply power and if that doesn't spur Renewable energy penetration even after all the networking, then the government of Grenada should switch to Renewable Portfolio Standards as a mean to make GRENLEC transition.

However, Grenada needs a few extra institutions and policies because of 65% of their population living in rural households, close to 40-45% being poor, the unemployment rate being close to 29% and the youth unemployment rate being close to 40%. Grenada requires an institution that works separately with the poor and the unemployed to figure out what their needs are and how best to transition them. This can be done by providing more vocational training or entrepreneurial skills to start their own business. For this to work Educational institutes will have to create MoUs will foreign Universities to help with providing them with education. In general the education programmes need to be more attuned to need to the economy.

Scenario 2 – Both Cases

This is where there are more differences than similarities. The base-load technology needed to be implemented in Curacao is OTEC and in Grenada it is Geothermal. And because of one being a demonstration phase technology and the other being a mature technology there are obviously differences in implementation. Another addition to these scenarios is the introduction of energy efficiency gains. While the what is similar the how is going to be drastically different.

In terms of energy efficiency the difference lie in the fact that SWAC will be introduced at Curacao however Grenada will have to really on Geothermal reverse heat pumps or advanced AC units. Therefore because one is supply side strategy is can be implemented by the government by changing building codes and standards and working on retrofitting houses. The change to a geothermal reverse heat pump or advanced AC is more a demand side change similar to change in light bulbs. So this needs to done through the education program and workshops by making them aware of the potential economic benefits of efficiency gains. In Grenada this can be a part of the GRELEC outreach programme. GRENLEC would do it if the government puts them under efficiency standards.

In terms of OTEC and Geothermal, the differences are that Curacao will require a fund to spur innovation and research now, they will require to establish loan guarantees and grants to move

OTEC from the 500 kW Demonstration plant to a commercial plant in the next decade. Further, their involvement with companies in the supply chain of OTEC and financial institutes becomes important because they need more and more attention given to their island with regards to OTEC so that funding issues are not faced which will be a problem for a OTEC plant because capital costs are really high. So, having a committee within the energy department handle this specifically is worth exploring. However, currently the even the government is under informed about OTEC therefore first after setting up the OTEC Committee, the committee should involve itself with all the stakeholders involved and understand the technology so that at least the govt. is not apprehensive of utilizing the technology. This also the case where Curacao should take full advantage of being a part of the Netherlands and asking them for help in terms of negogiations and attracting investments for OTEC. This is not required in Grenada; Geothermal is a mature technology, it needs to go through the same process of getting capital and revenue support and things should be fine. More importantly they have a law specifically for Geothermal which is being discussed now, so should be voted on soon. This will increase the confidence of investors into Geothermal in Grenada.

6.4. Implementation Strategy

The common implementation strategy that can be used for all 4 scenarios is the E^3R strategy. Even though both cases have different starting points and each scenario has different end energy mixes. The interesting thing to be noted is that the strategy remains the same.

First you **Establish** all the required institutes, agencies, policies, networks, roadmaps so that this provides the initial boost of confidence to the investors and various energy companies.

Then you E**ducate** the population and the investors and the government in certain cases. So for example: in scenario 1 at this stage a good thing to research is the effect of very high penetration of intermittent RE to the system and how the system can be integrated better and what kind of pricing mechanism to have, the market structure, and how to deploy a controlled V2G system. All of this will become pertinent in 2030s when storage becomes necessary, when there is 70% and above penetration of Solar and Wind. And in the case of OTEC it helps to educate the government in itself about how a demonstration phase technology can help their transition.

Finally, once you have the institutions in place to support the transition and the polices and laws in place for investors to rely on the island works on E**xpanding** their capacity of human and technology mainly. This needs to be based on **constant Review** of how the market has taken to the aforementioned changes and policies implementation. If the market in itself is coming forward and implementing RETs as in the case of Curacao and if it is happening in the right pace then the island just needs to review and keep updating regulations to maintain that investor confidence. If the market is not achieving penetration at an acceptable rate then a change of policies are required.

What varies in these strategies are the timelines of implementation. For example: The establish phase is until 2020 in the Curcao Scenario 1 but for Grenada Scenario 1 this is just until 2019. This is because of the different starting points. And in the OTEC phase the education phase overlaps with the establish phase completely in the Curacao Case.

The interesting thing about this strategy is that if one was to take the strategy laid out by the Rocky Mountain Institute (Locke and Gerstin, 2017; RMI, 2016), and the WorldWatch Institute (Ochs et al., 2015), it will be noticed that the E3R strategy is similar to them. This is in a way a validation of the strategy being suggested.

WorldWatch	RMI	This Research
Priority Initiatives	Inclusive Plan	Establish
Policies	Act: Pro-activity of Stakeholders Utilities stepping outside comfort zone	Educate
Projects	Collaboration	Expand
Activities		Review

Table 19. Comparison of 3 Different Strategies Employed to enable SIDS Energy Transition

One main difference is that the E3R strategy places importance to the review process which the other 2 strategies do not explicitly recognize.

7. Conclusion

The aim of this study was to be able to suggest implementable actions for an energy transition based on various factors affecting the energy system in the Caribbean. This was to be done through offering a thorough mapping of the current state and various transition pathways in a quick scan manner. Therefore, a methodology reflecting something that could be utilized quickly was also to be created before the study could be started.

The Caribbean was chosen as region because of the limited literature available on these islands for transition. Therefore keeping in line with this requirement the geographical scope was further reduced to 2 islands based on a 5 parameter criteria as mentioned in chapter 3.

Therefore, the first chapter while speaking about the problem statement, the research questions and knowledge gap in the literature paves a pathway to chapter 2 that speaks about how elements of chapter 1 were realized. Chapter 2 discusses literature on future studies, backcasting, transition pathways, EPM, PESTEL, and SIDS in the Caribbean. This combined with chapter 1, establishes chapter 3 of this study which speaks about the modified methodology of backcasting to enable a quick scan. At this point, Curacao and Grenada were chosen as the two cases from Caribbean that will be analyzed. Chapter 4 and Chapter 5 utilized the methodology to establish 2 future scenarios for each case with one transition pathway for each scenario respectively. Then chapter 6 performed a cross case analysis while talking about the similarities and differences between the two cases.

The final chapter 7 is the conclusions which will be discussed through 3 steps. The first step being answer the main research question along with the 7 sub research questions; the second step will providing recommendations for what the next step for research should be; finally the third step will be the reflections wherein the limitations of this work will be discussed, along with a critique of the methodology used and how it can be improved.

7.1. Conclusion

Based on the problem statement that SIDS need to do the most to create a climate change resilient economy by virtue of being the most vulnerable and technically have the potentially to implement at least a renewable energy system as one of the solutions; they still do not lead the world in the energy transition. The objective of the research was to study and recommend implementable actions based on drivers and barriers for the region that can be taken by the various governments. Therefore the main research question that needed to be answered was:

How can islands of the Caribbean transition to reach the goal of a 100% Renewable Energy?

From the scenarios one can establish that preferring a final energy system which includes a firm energy source is plausibly the most economically beneficial. However, it should be noted that future costs are unreliable and change on a year basis therefore, even though this system sizing depicts economic favourability to utilizing Geothermal and OTEC. However, one of the most interesting hypothesizes of this research is that, if the sizing performed by the models is to be taken on face value then, economies of scale could plausibly have a role to play. Energy companies can still make use of it while installation. This is predominantly because of the required over-capacity required.

Further, islands should concentrate on reducing risk perception and increasing human capacity (reducing brain drain) and increasing awareness within the public for renewable energy. The latter is the most important because this forces political parties to stand by renewable energy and also potentially opens the doors for bottom-up initiatives with limited government help. All of this has to be supplemented by an aggressive government approach to reaching out and engaging with potential companies. Unsurprisingly, these are all well-established barriers that islands face all around the world. However, off-late because of the immense attention being given on SIDS post COP21, international organizations are more than willing to help, this consideration is also something that was lacking in literature. This is not to say that depending on each islands unique situation there isn't a difference. There are specific differences like the potential requirement of different rural energy transition policy in Grenada because 65% of the population lives in rural Grenada. Or that because of the relatively high credit rating of Curacao the island can potentially indulge in loan guarantees and grants to accelerate the transition which is not possible in Grenada.

Lastly, islands can make use of this quick-scan backcasting methodology to initiate their transition process and utilize the E3R strategy to understand what is required for a transition to start. This has been further elaborated on in section

This main question was sub-divided into 7 sub-questions. These sub-questions will be answered below:

What is the current energy scenario? This question collates the first 3 sub-questions for the research. These 3 sub-questions are:

- What is the current energy system on the islands?
- Who are the main stakeholders involved in the current energy system?
- What are the various factors affecting the current energy system that influence the energy transition?

The current energy scenario is in line with the literature. Curacao and Grenada both use fossil fuels to meet more than 90% of their total energy demand. They rely on fossil fuel imported from Venezuela. Curacao relies almost entirely on fossil fuels with 99% and 93% of the energy used on Grenada is fossil fuel. But the 7% in Grenada is mainly because of usage of traditional Biomass for cooking purposes. This clearly shows that they have a long way to be self-sufficient. The grid sees losses of close to 10-12% and around 7% in Curacao and Grenada respectively. The demand side has limited verifiable information but the split up seems to follow literature. Wherein transportation uses most of the energy on the island then comes the electricity sector and then the rest. Within the electricity sector the air conditioning contributes to more than 50% of the electricity demand.

Where these islands diverge a little from traditional literature in market structure, where it was believed that SIDS have a state-owned monopolistic electricity market structure. Curacao while less divergent has authorized IPPs for the production of renewable energy on the island. But the utility is still state-owned. Grenada also allows IPPs to supply power and has a privately owned utility. This is also the reason for the lower grid losses in Grenada. However, the transport sector is completely monopolized unfortunately.

The main stakeholders in both the situations were the government and the utility. While other energy companies (which produce renewbale energy on the islands) were involved their influence is little known. Users and NGOs were generally never involved in these decisions. Therefore, this being more reminiscent of the top-down approach utilized widely in the developed world. Though, it should be noted that the success of this is limited as seen in Aruba where the public has already started protesting against more wind turbines being used.

In terms of other factors that influence the transition, it is needless to say that the electricity tariffs are on the higher side with both countries generally having more than 0.30 USD/kWh. Also, both Grenada and Curacao spend 10% or more of the country's GDP on oil imports. The advantage that Curacao has over Grenada is that it is still technically a part of the Kingdom of Netherlands and has access to the EU market, also because of this the credit rating of Curacao is high therefore signifying a lower risk perception which enables cheaper loans. The same cannot be said for Grenada. It has dismal credit rating and therefore getting loans for large projects can be complicated. The extent to which it helps Curacao to be a part of the Netherlands is seen through the strong judiciary, because the highest court is the Supreme Court in Netherlands. It can also be hypothesized that partly because of Curacao's favorable political situation even though they do not have a form energy policy and just a few support mechanisms in place renewable energy is doing largely well. Actually better than in Grenada this has a strong vision document, a national energy policy and a roadmap to instill confidence in investors. One other main factor that separates the two countries is that Curacao lies outside the Hurricane belt while Grenada lies within the Hurricane belt. Thereby making is far riskier to invest in the Grenadian economy.

What are the potentials and cost of the renewable energy technologies?

Clearly both the islands have immense resource potential in solar and wind. And in terms of firm energy Curacao has great OTEC potential, while Grenada has great geothermal potential. The advantage Grenada has is that Geothermal is already a mature technology therefore they do not necessarily follow the traditional transition pathway where they first install large amounts of solar and wind and then move onto to Geothermal. Instead Grenada should plan extremely well and transition from the very beginning along with geothermal, much like how it is being done now. Both islands have negligible potential for Bio-based energy and hydro power. The importation of bio-fuels from Brazil is not considered because the self-sufficiency issue and also because there is little need to create regime/niche for bio-fuels when the end goal is to transition to EVs. However, it is plausible that the 100% renewable energy vision is reached faster if bio-fuels are imported and therefore requires a more serious study into it.

The costs of onshore wind and utility scale solar are comparable with fossil fuel energy these days. Therefore, it makes sense that onshore wind and utility scale solar are the first technologies to penetrate the market. However, based on Curacao's experience it can be seen that if the right FiT is provided then rooftop solar can make a quicker penetration into the market. Geothermal is slightly more expensive than solar, wind and fossil fuel technologies today. But, from Gioutsos (2016) we can see that a 20% reduction in system LCOE can be expected when Geothermal is added to the system. OTEC is still not a mature technology and therefore is expensive. However, is it still the only form of firm renewable energy Curacao has potential for and therefore the government needs to actively help the technology reach market maturity.

What does the future scenario for each island look like?

Based on a cost optimization model the 1st scenarios which include on wind, solar, and batteries; for both the cases see that over capacity is far cheaper than installing batteries to meet demand. However, this over capacity becomes an issue because of the lack of land area on the islands. Therefore, it probably makes sense for the islands to shift their energy infrastructure offshore if they want to pursue this configuration. It may also be cheaper in the long run and have less social backlash. The cost of the current mentioned configuration is also plausible as it was within today's cost of electricity in both cases.

The second scenario which includes firm energy of OTEC (in Curacao) and Geothermal (in Grenada), leads to substantially low variable renewable energy like solar and wind, and further almost negates the need for battery storage. This also leads to a cheaper electricity price as compared to even the 1st scenarios. The land area requirement also reduces by almost half when compared to the first scenarios. It is also hypothesized that this scenario will also cost less to the government in the long run.

What are the technological, structural, societal interventions that need to happen for the future to be achieved?

There are common changes that span across both the cases and all four scenarios like the need for data collection and the need for the setting up the right institutions that can plan, monitor and review the transition. There needs to be capital and revenue support through tariff based policies that can reduce the capital costs and improve investor confidence. There is a need to standardize processes to reduce administrative costs. Most importantly, there needs to be extensive societal information dissemination required through outreach programs and new educational programs and subjects in schools and universities. There is also a need to set up vocational training programs that can help the unemployed get jobs in the RE sector and help the people losing jobs from the fossil fuel sector. All of this potentially doable if the right networks of organizations are tapped into. More commonly in the 2nd scenarios both these islands need to serious start implementing minimum energy standards for appliances and equipment, most importantly issue mandatory energy audits.

Specifically, because OTEC is involved in the 2nd scenario of Curacao, there is a need to establish a research and development fund that provides grants and loans. More interestingly, OTEC should take a more systemic approach and always be built in conjunction with various other applications like it is being done currently at the Eco-park. This will enable easier funding. At this stage, Curacao should also exploit its connection with the EU for funding and develop a network of companies along supply chain that are willing to construct OTEC plants.

In Grenada, what is specifically required is a more detailed understanding of how the people in the rural part of the island (65% of the population) can be transitioned. So, a different rural development policy and extensive societal studies should be undertaken in conjunction with energy companies to help develop new financing models and business models.

However, the immediate interventions are different for Curacao and Grenada. Curacao has no concrete roadmap for transition, no proper energy policy and lacks institutional support. However pressure from the landscape (in terms of the economic crisis in Venezuela) and the 2 decade long experience in wind energy helped Curacao still achieve high penetration of renewable energy in the electricity sector. While Grenada has a roadmap in place, with an energy policy and an institution to specifically handle the energy sector however implementation and execution is slow. This is partly the governments fault also partly the fault of GRENLEC.

Finally, a study and infrastructure for Electric Vehicles need to be commissioned. A regional commitment would a go long way in intriguing EV companies to set up shop in the region.

What pathways can be followed?

Based on the literature this is government and society lead transition currently; a technology substitution pathway. To operationalize the pathways a common Establish, Educate, Expand and Review strategy is implemented. And the only thing that differences in each scenario is the time period for each part of the strategy. Because OTEC is still in the demonstration phase the period for education is longest in this. While because geothermal is a mature technology there isn't much time spent on the education part of the strategy. This strategy is in no way linear and is definitely iterative. This is established by the review process that happens once every year to make sure transition is moving forward smoothly.

7.2. Recommendations for Policy Makers/Government

A few of the most important recommendations for policy makers/the government are:

- Establish the required institutions that have the power to establish the required policies, monitor and review the transition, and collect all the relevant data.
- Create a robust participatory process for decision making that involves all citizens of the country, and the NGOs also. Not only the government and the energy companies.
- Indulge in outreach and communication programmes that help inform the citizens better
- Collaborate with relevant regional and international organizations this can help in creating the relevant human capacity by virtue of creating training programmes and relevant educational programmes. Further, this can help increase the knowledge and expertise regarding the transition on the island
- Create a robust policy package that involves all the necessary capital subsidies and revenue subsidies, which ideally first starts with tariff based policies and then moves to more volume based policies
- Give special attention to incentivizing energy efficiency gains through minimum performance standards and building codes. Initiating this process by insisting on energy audits.
- Collaborated with the relevant actors to understand and implement the transition that is needs to happen in the transport sector towards EVs.
- Focus on creating a diverse portfolio of energy technologies that have a mixture of firm energy and intermittent energy, do not focus on a future that is completely powered by variable renewable energy
- Understand the pros and cons of privatization of the energy sector and move towards more privatization. The advantages of having a private utility company can be seen in Grenada (low transmission losses and efficient services)
- Create a highly planned and predictable transition roadmap with the relevant actors
- Should enable shifting of RETs from land to offshore installations. Offshore PV, Wind and OTEC will help tremendously because of the limited land availability on islands.

7.3. Recommendations for Energy Companies

- The utilities need to stop looking at the inevitable transition as a threat but should embrace it and actively work with the government and the other actors to accelerate the transition
- Collaborate with the government to enable execution of new and innovative business models like community based energy transition
- Collect a large repository of data and make it available to the public
- Understand how energy efficiency gains can be beneficial and help implement the relevant measures instead
- Work with the necessary actors to understand the effect of introducing EVs into the electricity grid and therefore researching on system integration and more robust grid networks
- Should actively look into how offshore Renewable Energy systems can be used to aid the transition

7.1. Recommendations for Researchers

This has two aspects to it; one being the more practical recommendations and the other being the more academic recommendations on the methodological framework. This section will deal with the former. The later will be discussed in the reflections section.

- A more robust energy efficiency calculation needs to be performed considering all other efficiency gains that have not been considered in this research like improved road and traffic planning, change in the type of tyres in vehicles, different appliances and their potential efficiency gains
- A grid impact assessment needs to be performed
- Research on how system integration can be accomplished should be done soon because this will become important when there is high RE penetration
- Technical Research and research on required infrastructure for Vehicle to Grid and in general effect of 100% electric transportation needs to be performed because this will need changes in the infrastructure (and this is generally a long term investment and no one wants to again investment into it 5 to 10 years down the line).
- A comprehensive report on the cost of this transition and the jobs this transition will create. This should take into account the local costs of renewable energy technologies with the localized interest rates and not global averages as done in this study.

7.4. Limitations

<u>Technological Limitations</u>

This work mainly looks at mature technologies for transition. OTEC is the only technology that is still in demonstration phase which is considered. Biomass/Biofuels are also not considered. While on island potential is limited, this is something that can be imported. In terms of the transportation sector, biofuels have already been mentioned but apart from this it make also be interesting to see the leapfrogging potential to direct fuel cell vehicles. Fuel Cell vehicles are currently getting dwarfed by the popularity of Li-ion battery cars. Therefore, using islands as a living lab may be interesting.

Further, future technology like floating wind and PV has also not been explicitly considered. These technologies are already being deployed in different parts of the world. They are far more efficient. So, they should be considered in the long term.

Future Scenario Limitations

Apart from the aforementioned technological limitations which are also related to the limitations of the future scenarios, there are other limitations also.

Modelling: There was only 1 model used, Gioutsos (2016). This model assumes a 5% discount rate for islands, which seems to be low. Further, this model was used for the 1st scenario of both the cases because this model for this research mainly only Wind energy, Solar PV and Li-ion batteries for storage were used. This required the input of potential future investment costs of these technologies which was input at 750 USD/kW for Solar PV, 1000 USD/kW for Wind Energy and 125 USD/kWh for Battery storage. What needs to be noted is that in actuality the cost of onshore wind and large scale utility solar PV will fall much lower than what is considered but slightly higher costs were chosen because the following technologies, residential rooftop, offshore wind, floating structures for wind and solar were also kept in mind. Further, Li-ion battery costs are already being predicted to fall below 100 USD/kWh by 2030 in the Bloomberg 2017 energy outlook report.

For the 2nd scenarios for both the cases we have used approximate values based on calculations run by van Velzen (2017). So costs will be lower than what is mentioned in these scenarios. Therefore, the next section suggests using more accurate and widely used models for system sizing. Further, in this the efficiency gains calculated is also limited there are certain measure that haven't been calculated and therefore there is a potential to further reduce energy demand.

Finally, the future scenario energy demand is approximated based on assumptions of population growth, economic growth and corresponding transportation growth. All of these assumptions could potentially be inaccurate. So, the future scenario is a good indicator of possible future but to be take it at face value would be misleading.

Methodological Limitations

This methodology is meant to illustrate a quick-scan method to create a transition pathway and therefore the depth into which the pathway goes into is limited. Therefore, how to view this methodology and work is mentioned in the next section.

7.5. Reflections on the Methodology and Future Work

This is the section where the methodology is concluded. Further, in this section as and when there is point to be made regarding the methodology a corresponding future work will be mentioned, if deemed necessary. The first three points are more in general about the methodology and what this author thinks are interesting future work. After which there is a detailed critique of each step of the methodology

- This research has endeavoured to potentially create a quick-scan backcasting methodology for energy transitions. It is called quick-scan based on a singular parameter of the amount of time it takes to create the pathways. This methodology works best where there is a lot of data available.

  - Potentially something interesting to look into is how to properly define a quick-scan methodology. Should time be the only parameter that defines a quick-scan or could there be others? Currently there is no quick-scan methodology that goes all the way to creating transition pathways.
  - Further it may be interesting to combine the backcasting methodology policy packaging literature when discussing mature technologies and maybe Functions of Innovation literature when discussing technologies still in research phase.
  - Lastly, an attempt at creating a more participatory approach for a quick-scan should be made, the analysis will have more value.
- The first case of Curacao took quite some time and based on that this method would not be described as a quick-scan. However, once the entire methodology was operationalized in detail, in terms of what kind of data is required and what needs to be done for each step, then this turned into a quick-scan where the 2nd case of Grenada was completed in about 1 month.
  - A more robust literature review on island cases that have already transitioned to a 100% renewable energy like Samso, Denmark and a meta-analysis of all the studies performed for 100% transition could lead to a more specific and detailed understanding of how to operationalize this methodology further.
- It is also worth understanding where in the process of energy transitions does this work stand. This is located in the beginning of the transition process. So, one could potentially initiate the transition process by performing a quick-scan backcasting using this methodology.
- It was very beneficial to utilize the energy balance in combination with PESTEL and a stakeholder analysis to create a holistic picture of the current energy scenario. It was efficient and quick.
  - The next step which could be potentially better for communication with different stakeholders is representing these factors in a format of drivers and barriers and indicates potentially exogenous factors. This can help a stakeholder with limited expertise in the field really understand what is stopping them from transitioning.
- The importance of mapping the energy potentials cannot be emphasized enough. It helps really narrow the scope of the research and helps understand what the future can look like. However, this is probably the most time consuming part of the research and therefore utilizing a pre-existing potential calculation will go a long way in quickening this process even further.
  - That said, this research has collected all the relevant information for a sufficient potential calculation and this should more formally presented and utilized through a spreadsheet or an online tool for TU Delft.
- The present costs of RETs were beneficial only for the reason of establishing that they are cheaper than the current cost of electricity and could also potentially be used to state that mature RETs are cost competitive with fossil fuels. But this is general knowledge nowadays so there was little value added by this information. However, FUTURE costs of the RETs proved to be essential for this research as explained in the next point.

- Future Scenarios for a 100% RE vision can be complicated and if one is to stick with the most popular methodologies mentioned in the literature then this will no longer be a quick scan. Because one of the most popular methods for establishing internal consistency in a normative scenario is through GMA and that does so by expanding the scope of the scenario vastly. Therefore, the decision to keep the scenario as a technical scenario and just perform a system sizing for the potential future demand using pre-existing established sizing models helped quicken the process, narrow the scope of the scenario and most importantly help understand the economic viability of the scenario. However, this is also where there are issues. In the sense that the model utilized for this study did not have all the relevant technologies, further it assumed only a 5% discount rate for technologies while calculating LCOS, and this value could be higher. Lastly, there is limited information on how robust the grid modelling is in the model used. Therefore unable to understand if the grid performed the sufficient balancing.
    - So for the future, utilize a more commercial available and robust model which preferably lets the researcher understand and change these aspects. Eg: HOMER (it is one of the most widely used system sizing models used today)
- In terms of the Backcasting step, specifically talking only about the technological, societal and the structural changes was a good idea. However, this research probably went into more specificity than required when talking about the changes.
    - It is probably more beneficial in a quick scan to speak of large groups of changes. For example: instead of stating that a Feed-in Tariff should be implemented, maybe just mentioned that a tariff based policy should be considered initially is sufficient. Stating that capital subsidies are required to reduce the investment cost is sufficient instead of stating that tax should not be levy.
    - Further, it is assumed that a more robust literature review as mentioned above in this section would help in concentrating the changes to the most relevant aspects of the transition.
- Lastly, regarding the strategy that came out of this research for SIDS. It is believed that the strategy of E3R is robust and largely generic. The advantage of this is that the strategies used by Rocky Mountain Institute through their Island Energy Program, CARICOM in conjunction with Worldwatch institute and IRENA can all be placed within this (IRENA, 2015; Locke and Gerstin, 2017; Ochs et al., 2015; RMI, 2016).
    - This strategy and changes have not been validated. Using historical trends are not of any use in this situation because they tell you what has been achieved and this research relies on understanding what needs to be achieved. So, potentially discussing this with potential stakeholders is one way of validation and further because of the relatively small numbers of installed capacity instead of looking at past deployment percentages achieved by different countries utilizing a certain policy, maybe one can also look into whether a certain policy has enabled installation of a certain absolute MW of RETs in a year. Therefore, getting an idea of whether policy x has previously installed y MW of Solar/Wind.

Appendix 1

There are 4 types of potential that can be calculated

a. *Resource Potential*
   i. Physical Constraints
   ii. Theoretical Physical potential
   iii. Energy content of resource
b. *Technical Potential*
   i. System constraints
   ii. Topographical Constraints
   iii. Land use
   iv. System Performance
c. Economic Potential
d. Market Potential

Solar PV

Resource Potential = (Solar Irradiation * Available Area)
Solar Irradiation (Direct Horizontal Irradiation) = 2027 kWh/m^2/year (SolarGIS, 2014b)
Available Area = 22 km^2 (Assumption of 5% of total land area)
Spacing Factor = 5 (for on the ground Solar PV) (IRENA, 2014)

Resource Potential = 44,594 GWh/year

Technical Potential = (Solar Irradiation * Available Area * Panel Efficiency) / Spacing Factor
Panel Efficiency = 18.5% (Assuming an average value based on the values presented in the MSc. Thesis of Brais – 20.5% (Nodar, 2016) and IRENA (2014) – 16.5%)

Technical Potential = 1650 GWh/year

Even though this technical potential does not include a number Balance of Plant (BOP) loss, another assumption made is that the efficiencies of the Panel and BOP will only increase over the years.

Solar CSP

Resource Potential = (Solar Irradiation * Available Area) / Spacing Factor = 35200 GWh/year
Solar Irradiation (Direct Normal Irradiation) = 1600 kWh/m^2/year (SolarGIS, 2014a)
Spacing Factor = 5 to 10 = 7.5 average
Available Space = 22 km^2

Technical Potential = (Solar Irradiation * Available Area * Efficiency) / Spacing Factor
= 1126.4 GWh/year
Efficiency = function of Irradiance = 12% for around 1800 kWh/year irradiance (IRENA, 2014)

Rooftop Solar PV

Resource Potential = Solar Irradiation * Usable Rooftop Area

The calculation for usable rooftop area starts with the knowing that there are 62,000 households and 7,000 businesses in Curacao today. This provides us with a total of 24,000 usable rooftops from the households and around 3,500 usable rooftops from businesses (which include industries). Therefore, this is a total of 27,500 usable rooftops, with a total area of 687500m^2 of usable rooftop.

Resource potential = 2027*687500 = 1393.5 GWh/year
However, the efficiency of the system is close to 18.5%, therefore

<u>Technical potential = 257.8 GWh/year</u>

Assumptions:

1. 50% of households are stand-alone households therefore providing 31,000 roofs.
2. 50% of households are apartments and each apartment has 10 households, that means there is 1 roof for every 10 households, therefore this provides 3100 roofs.
3. This is a total of 34100 household roofs. But because of various blockages in terms of trees and taller buildings only 70% of these roofs are usable. This gives us a total of 24,000 roofs approximately.
4. From the business stand point the assumption is that half the roofs are usable. While even they should be given blockage consideration, the fact that industries have far large rooftops is used an averaging factor. This is an average between the limited rooftop on tall office buildings and large rooftops available in industries. Therefore 3,500 usable rooftops.
5. The final assumption is that each rooftop has an area of 50 m^2 and 50% of that area can be used for installing solar panels. That is 25 m^2. This is reasonable based on the assessment performed by Nexant for the World Bank based on the NREL assumptions that 1% of the land of the island is covered by houses and commercial buildings and 10% of the roofs of those buildings can be used to install solar panels (Nexant, 2010). However, this is a very conservative estimate in my opinion and the potential is at least double of it, which I have reflected in my analysis.

Geothermal (GT)

a. GT = Heat flow rate x Well Area x PRH x Efficiency x hrs/yr x CF [Modified from (Nodar, 2016)]
b. Two Type of GT
    i. Binary – low temp – for heating purposes – no need here
    ii. Flash – high temp - >200c – 70% of current plants – for electricity – will be calculated here (Salvatore, 2013)
c. Two ways of the plant process
    i. Uranium rich granite – radio decay - not applicable
    ii. Geothermal Gradient
        1. Natural Gradient of temperature below surface
        2. Higher temperature with deeper depth
        3. Away from volcanic areas – 25c to 30c /km
        4. Volcanic area – 150c/km (Curacao Chronicle, 2015)
d. HIP and PRH are two terms we are concerned about
    i. HIP = C_v of rocks and pore fluids x Vol. of Rocks x ($T_{reserve}$ x $T_{surface}$)
    ii. No data on C_v of rocks and pore and Vol. of rocks
    iii. Further heat gradient based on oil rigs at Aruba for the region is 20c/km
    iv. Reaching 200c would require well @ depth of 10km
    v. Which has never been done (not even for oil rigs)
    vi. PRH = 50% HIP(Curacao Chronicle, 2015; Van Wees et al., 2010)

NO POTENTIAL because a 10km deep drilling has never been done, even for oil rigs. It is not economically feasible.

Hydropower

= density x g x delta H x Efficiency x Flow rate

a. No data on delta H and Flow rate or volume of water
b. The variation of sizes and height differences around the world are so large that it makes no sense to estimate based on world data

c. No. of known dams 8
d. Mainly used for rejuvenation of ground water
e. More data for potential calculation is required

Wind Power

= ½ x Cp x Density x $(velocity)^3$ x Area of rotor [Class Notes]

Wind Speed: $U(h) = U(h_{ref}) \cdot \frac{\ln(h/z_0)}{\ln(h_{ref}/z_0)}$ [Class Notes] Note that in my calculations wind speed is denoted by 'v' and not U

a. Avail Area = 5% of land = $22km^2$
b. Spacing factor = 5D (main wind direction) and 3D (secondary wind direction) (IRENA, 2014)
c. Density of air = 1.18 kg/m3 @ 80m
d. Wind Turbine currently in use 3MW Vestas V90(assuming this as standard for all calculation)
e. Hub Height = 80 m(Vestas., 2017a)
f. Average v = 9.5 m/s @ 50 m (Hanst, 2006)
g. Wind Speed at 80 m = 10.15 m/s
h. Rotor Diameter = 90 m
i. Area of rotor = (3.14 * 90 *90)/4 =6361.72 m^2
ii. Spacing Factor = (5 x 90) x (3 x 90) = 0.08 km^2
i. Number of turbines = (1 x1)/0.081 = 12.35 turbines
j. Power Coefficient = 0.35 (assumption)
k. Power generation by 1 turbine = 1.37 MW
l. Power Density = 12.35 x 1.37 = 16.96 MW/km^2
m. Resource Potential = 16.96 x 8750 x 22 = 3264.8 GWh/yr
n. Capacity Factor = 0.50 (An average value of 0.40 and 0.60, based on wind turbine analysis done on the current wind turbines installed in Curacao (CREDP/GIZ, 2011))
o. Technical Potential = 1632.4 GWh/yr

Wind Offshore

Same formula as above

a. Max depth of water up to which it can be installed in = 60 m (Musial et al., 2016), beyond this there is a need for floating technologies.
b. The distance from shore at which depth goes beyond 60 m = 2 – 3 km (google earth)
c. Assuming that wind turbines are not welcomed close to the shore
d. Corroborating that with the fact that in the last 10 years the percentage of offshore wind turbines placed within 5 km has reduced from approx. 80 % to less than 10% is an indication of the world trend (Fraunhofer IWES, 2016).
e. Based on c and d points I would say no potential
f. But assuming turbine at distance of 2.2 km from shore we calculate potential
g. Reference Wind Turbine = V136 – 3.45 MW (Vestas., 2017b)
h. Rotor Dia = 136 m
i. Spacing factor = 7 x Rotor Diameter = 950 m = 1 km
j. Coastline = 364 km therefore assuming that the perimeter at a distance of 2.2km into the sea will also remain the same (WorldAtlas, 2016).
k. That means 1 wind turbine at a distance of 1 km from each
l. That means 364 wind turbines can be installed
m. Hub height = 150 m; Wind speed at 50 m = 10.6 m
n. Power produced over the year by 364 turbines at 10.6m/s = 10,988 GWh/year

o. **It should be noted that including capacity factor, this value will reduce by half.**

Storage

a. Fast response storage = Market Potential
b. Long term storage = Not required (assumption)
c. Short term Shortage
    i. Assuming a 0.5% increase in the number of vehicles from last year to 2040, the total number of vehicles will reach 96,000. And then assuming that all of them are connected to the grid and they can give back 25% of their charge to the grid because the Tesla 3 model (60 kWh Battery) using his super charging network requires only 10 mins to charge 25% of the battery .
    ii. Therefore the amount it can provide to the grid is 0.25*60*96000 = 1.4 GWh/day. **This is 1840 TJ/yr.**
    iii. However, the chance of all the vehicles being connected to the grid is impossible. Therefore, I assume that at a given time only 50% of the vehicles are connected. This may look like a lot but I would argue that this is still at the conservative side because today cars are parked for close to 95% of the times therefore that means 22.8 hours a day approximately. This seems a lot and also I consider all vehicles and not only cars therefore I reduce the value to 85% of the time. Even that means that vehicles are parked at least 20 hrs a day at an average. So, I finally assume that provided 96,000 vehicles are parked for 20 hours at different times. At a particular given time at least 50% can be connected to the grid. Therefore, the actual amounts vehicles provide to a grid over the year are **920 TJ.**
    iv. Lead Acid = mainly market potential
    v. Li-ion = mainly market potential
    vi. Fuel Cells = mainly market potential

Efficiency

a. Cooling
    i. Current Energy demand is 750 GWh. We know that out of which 40% is households and 60% Businesses. Further, in households 50% is air-conditioning (it is assumed that refrigeration with freezer accounts for 25% of the consumption (Cabeza et al., 2014; de Almeidaa et al., 2011; Lapillonne et al., 2015) therefore bring the air-conditioning percentage to 50) and 30% in Businesses. Therefore the total consumption by cooling is = 750*0.40= 300 GWh. Now if all of this is replaced by SWAC which claims to be around 80-90% more efficiency (Prochazka, 2012). We are looking at **energy saving** of the order of **0.80*300 = 240 GWh/ year = 864 TJ/yr.**
    ii. For every other appliance efficiency increases but usage also increases so net remains the same.
b. Lighting
    i. Currently based on the fact that 2%, 20% and 1% of electricity consumption at households, businesses and public lighting, respectively, are consumed by lighting, we can say that the total amount consumed by lighting is (750*0.4*0.02)+(750*0.60*0.2)+(750*0.01)=103.5 GWh. And assuming that they currently they are using normal bulbs with low energy savings and all of it replaced by LEDs in the future there is going to a saving of 80%. That means **82.8 GWh = 298 TJ/yr** of energy can be saved. That is an 11% saving based on today's demand.
c. Sustainable Buildings

i. The Statistics department game with 5 variants of population growth/decline until 2050. They also had estimates for 2035. Therefore taking an average of all the 5 variants, it is believed that the population will increase to 176226 compared to the 158986 people currently staying. This is a 17240 increase in the next 20 years. This directly correlates to increase in buildings.

ii. Therefore, it is estimated in Nodar (2016), which is Brais's thesis that 40-50% reduction of energy consumption can be achieved in new buildings provided energy efficiency principles are taken into account. Also, it is also possible to achieve zero-energy designs when renewable energy systems are implemented. For existing buildings one can retrofit it to increase energy savings. The Global Energy Assessment (2012) claims that a 46% saving in building heating and cooling energy use by retrofitting existing houses. But this includes implementing efficient technologies and since this research has already done that, we assume that there is still a 23% efficiency gain to be had by methods apart from technology substitution

iii. Currently houses use 300 GWh and a 23% reduction = 69 GWh = 248 TJ of saving. And in businesses is means 103.5 GWh = 373 TJ of energy savings. Therefore a total of 172.5 GWh = 621 TJ of savings (Nodar, 2016).

d. Transport

i. Comparing the tank to wheel efficiency of cars based on different fuels it is seen that electric cars are at least 3 times more efficient than any conventional IC Engine car (Eurelectric, 2015).

ii. Today, considering that the transport sector uses 10769 TJ

iii. Therefore, combining point i and ii we can say that at least 7180 TJ/yr of energy consumption can be saved. However, this calculation needs to be verified because ever estimate shows that there will be an increase in electricity consumption provided all of Europe's cars are electrified.

e. Grid

i. Currently around 14% of the electricity is lost in the transmission lines, this is called NRE (Non- revenue electricity)

ii. However in developed nations this percentage is closer to 5 -7%.

iii. Therefore, 0.14*872 = 122 GWh = 439 TJ and 0.07*872=61 GWh = 220 TJ. Therefore, a 50% saving capacity and in numbers 220 TJ can be added to the final consumption by curtailing loss. (Government of Curacao, 2011)

Ocean Energy

a. OTEC

i. $\frac{Pnet}{Qw} = \frac{\rho Cp\, x\, \eta\, x\, n}{8(273+Ts)}(\Delta T^2 - 0.3\Delta Tdesign^2)$ x 8760

ii. Q_w = Flow rate (m^3/s) = 18 m^3/s

iii. ρ = Density (kg/m^3) = 1000 kg/m^3

iv. C_p = Specific heat seawater (J/(kgK)) = 4000 J/(kgK)

v. η = Efficiency of Turbine = 0.85

vi. T_s = Surface Temperature (K) = 300 K = (273 + 27)

vii. $T_{d,800}$ = Temperature at depth 800m = 279 K = (273 +6)

viii. $\Delta T = T_s - T_{d,800}$ = 21 K

ix. ΔT_{design} = 20K

x. P_{net} = 39.8 GWh/yr for a Q of 18 m^3/s (OR)

xi. P_{net} = 4.55 MW

xii. This means that a OTEC plant will produce around 8.5 GWh/MW installed. This can also be done assuming that an OTEC plant has a capacity factor of

around 95%, which is reasonable, and you will get a similar answer of producing 8.4 GWh/MW.

i. **Apart from this it should be noted that 18 m3/s is a flowrate required for a 100 MW capacity plant.**

ii. **Now if we are to consider that the entire Exclusive Economic Zone can be utilized for installation ie that 370 km of the coast of Curacao and that only after the 3rd km onwards do we have enough depth for the temperature difference then essentially OTEC power plants can be installed in the elliptical are between 3 and 370 km of the coast of Curacao. A simple back of the envelop calculation with tell that then the available area is 474,000 km2. But of course not all of that ocean area can be used because of its proximately to Venezuela and Aruba. Therefore we assume that 33% of that area can be used for installing OTEC plants that use around 500 m2 per 100 MW plant according to Bluerise. But let us assume it takes a 1000 m2 of area.**

iii. **This implies that we have 158,000 km2 of ocean area available to install 158,000,000 OTEC plants of 100 MW capacity. This will produce 6300 PWh/year**

iv. **Now assuming that there needs to be distance of 1000 m on all sides between two plants then we reduce the number of installed power plants from 158 million to 39 million plants. This will produce 1570 PWh/year.**

b. Wave – No potential. Most potential located between 30° and 60° latitude in the two hemispheres (Schelleman and van Weijsten, 2016; van Velzen, 2017).

c. Tidal – There is no potential for Tidal energy because the difference between the high and low tides should be approximately 5 metres (NREL, 2013)and in Curacao based on forecasting up to the 7th of March 2017, the average difference seems to be around 0.5 m (Tide-forecast, 2017).

Biomass

a. Will not be calculating for energy crops and algae
b. Based on waste data; the amount of waste in 2015 was 257244 tonnes (Central Bureau of Statistics, 2017)
c. Using type and amount of waste based on Grenada (Waste Atlas, 2012)
d. Amount of biodegradable waste = 44.6% = 114730.8 tonnes
e. Amount recycled = 80357
f. Amount of non-biodegradable waste = 19.5% = 50162.58 tonnes
g. **From 1 tonne of biodegradable waste we can get around 90 to 130 m^3 of biogas**
h. **And 1 m^3 of biogas at an electrical efficiency of 35% we get 2 kWh per m^3 of biogas**
i. **Therefore based on the data that means there is a potential to produce 12,046,734 m3 per year (average) and that means electricity production of 24.1 GWh/ yr at 2 kWh per m^3 of biogas (Banks, 2009; Electrigaz, 2015).**
j. **Incineration: Has a potential to produce 125 kWh per tonne of waste. The total energy produced by this technology is approximately 6.270 GWh/yr**
k. **Gasification: The power potential of this technology is roughly 200 kWh per tonne. This translates to energy potential of approximately 10132.51 MWh per year.**
l. **It should be noted that both points j and k are based on the amount of non-biodegradable waste generated.**
m. Waste generations in any country will increase over a given period of time due to increased standard of living and rise in population. The recycling rates will affect the power generation potentials over the years since the waste that served as feedstock for power generation, will now be recycled. However, this applies to the case of

conversion of non-biodegradables to power. The power generation from biodegradables is going to increase due to increase in population over the 20 year period of the study. It was observed that waste output increased by 25% over the period of 2010-2015.

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