Department of Mechanical and Aerospace Engineering

Investigation of Renewable Power house by 2030 in Cuba using Homer

Author: Prianka Ram

Supervisor: Paul Touhy

A thesis submitted in partial fulfilment for the requirement of the degree

Master of Science

Sustainable Engineering: Renewable Energy Systems and the Environment

2017

Copyright Declaration

Signed: Prianka Ram   Date: 25/08/2017

Abstract

Cuba is an island which currently dependant on imports of oil for electricity. The oil industry is playing a crucial part in the Cuban economy. Due to transportation of oil, many people in Cuba cannot afford to pay the price of oil. This is the main issue which leads to many communities being left with little or no electricity. Initially Venezuela was committed to increase the production and expansion of the oil industry at a lower cost. Unfortunately Venezuela has decided to reduce or withdraw their commitment which will leave Cuba in a bad state, consequently new technologies are required to minimize oil dependency. The goal of this report is to determine potential renewable energy resources and its technology to reduce imported fuel for energy consumption for cooking, heating, lightening, cooking and use of electrical appliances. This thesis will place particular emphasis on how the change of renewable energy mix will be beneficial for Cuba and how this will equally reduce carbon emission. The steps towards greener energy is only possible by changing energy policy to meet a strong target by 2030 of 24% renewable energy in the electrical energy mix, which will force Cuba to work towards their aim.

Small-scale renewable technologies have already been introduced and installed in small, isolated and rural areas. To analyse the goal and challenges, a methodology chart was designed to ensure the aim of this project is met. The methodology chart starts off with researched literatures and data relating to the topic which determined what work was carried out in Cuba and what process or improvements are required. Data was collected on current energy mix and current energy sources and what potential renewable energy technologies are needed. As energy is very limited in Cuba storage technologies was also researched which would be suitable for Cuba. Based on data collection the system optimization was carried out by applying Homer (Hybrid Optimisation Model for Multiple Energy Resources) a modelling tool based on 2016 capacity information to validate the model and to determine the total energy mix with an increase in renewable energy for 2030. Additionally it takes in consideration the energy efficiency, economic viability and environmental impact. To determine the aim for worst and best results, 4 scenarios were used to determine the demand profile.

Acknowledgements:

I am truly thankful and indebted to my family and my husband for their constant support, and understanding and for motivating me positively during my academic years.

This dissertation would not have been possible without the right guidance and honest opinion of my supervisor, Paul Tuohy. I would like to thank Paul for taking time out to respond to my frequent queries and assisting me with my project topic.

Furthermore I would like to thank my classmates and my friends for their help required during this course.

And lastly I would like to thank all lectures for their time and providing us with interesting and factual information relating to this course which will be taken into consideration in future work.

Table of Contents

1. Nomenclature

Abbreviation	
AC	Alternating current
COE	Cost of total electricity ($)
$C_{ann,tot}$	Total annualised cost ($)
C_{NPC}	Net present cost ($)
E_{prim}	Total primary load
$E_{kinetic}$	Kinetic energy (Joules)
f_{PV}	PV derating factor (%)
GDP	Gross domestic Product
HOMER	Hybrid Optimization Model for electric renewables
I_S	Standar amount of radiation used to rate the capacity of PV array (1kW/m^2)
IEA	International Energy Agency
kW	kilowatt
L_{served}	Total electrical load serviced in a time step (kW)
η_{hyd}	Hydro turbine efficiency (%)
PV	Photovoltaic

P	Power output (watts)
P_{PV}	Photovoltaic (PV) array power output (kW)
P_{ren}	Total renewable electrical power output in a time-step (kW)
p_{ren}	Renewable penetration (%)
$Q_{turbine}$	Hydro turbine flow rate (m^3/s)
RPM	Spinning speed (revolution per minute)
T_c	PV cell temperature at current time step (°C)
U_{hub}	Wind speed at the hub height of the wind turbine (m/s)
U_{anem}	Wind speed at anemometer height (m)
V	Electrical Voltage
W	Watt
Y_{PV}	Rated capacity of the PV array (kW)
Z_{hub}	Hub height of the wind turbine
Z_{anem}	Anemometer height (m)
Z_0	Surface roughness length (m)

2. List of figures

3. List of tables

4. Introduction

4.1. Location

Cuba is a popular and favourite tourist island located in the Caribbean Sea. It has an area of 109,820 square kilometre land and 1,040 square kilometre water area which makes it a total area of 110,860 square kilometres [1]. It is situated between the Caribbean Sea and North Atlantic Ocean. The island is surrounded with countries of the United States, Haiti, Jamaica and Yucatan Peninsula. Cuba is a hot and a humid country with an average relative humidity of 78% (Suarez et al,2012) and due to its weather condition, solar PV, wind, biogas and hydropower will be an ideal system. The annual average temperature in summer can be up to 25◦C and in winter 20◦C. Figure 1 is illustration a map of Cuba.

Figure 1 – map of Cuba [2]

According to the central Intelligence Agency [4] Cuba has an inhabitants of 11.3 million which a proportion of 30% is rural and the remaining is an urban community. The urban community has increased in the remaining years due to better facilities received for:

- Health care
- Education
- Employment availability
- Housing benefits
- Local transportation
- Socialisation

4.2. History

Cuba has been known as the biggest sugarcane producer worldwide. From the 17th century windmill was used to ground sugar cane through wind speed which was the first sustainable technology.

Before 1959 Cuba was in partnership with the Soviet Union.

From 1959 to 1989 Soviet Union provided financial support to run the island and additionally facilitated by imported oil. This led Cuba to build it power generation infrastructure and became the highest consumer of imports.

Cuba has less pressure based on energy supply as Soviet Union and Venezuela have provided large subsidies to Cuba by supplying oil for power generation and transportation fuel. Nearly 85% of its power is dependent on fossil fuel that has been imported and partially produced in Cuba. The division is nearly half of the energy is used for power generation and the remaining is used for transportation.

In 1981 Fidel Castro emphasised strongly the importance of renewable energy system. This led to building a small-scale hydropower in 1985 which caused a step towards clean energy.

Between 1990 to 1997 was the worse time for Cuba. This was the time when Soviet Union decided to not support Cuba regarding financial assistance and oil for power generation. This caused pressure for domestic fuel production and a decline in GDP. The oil produced in Cuba has a high contamination of Sulphur and which caused damage to the operating systems to produce power [5].

During big crisis Venezuelan stepped in to support Cuba. Cuba landed in situations which cause the whole country in a devastated problem.in 2004 to 2005 the island had a blackout for several days. This was caused by power plant breakdowns.

This opened everyone’s eyes and made history for a development of the energy revolution.

The Canadian company, Sherritt, planned a program known as a power purchase agreement (PPA) to reduce electricity consumption and to expand generation capacity through combined-cycle gas turbine. If we exclude the turbine, smaller generators are installed, known as diesel generators which are highly inefficient.
As oil is used to burn for energy production which causes high operating costs and results in high carbon footprint [5].

Venezuela is looking to potentially terminate from the deal to import oil which will lead Cuba in a situation where it requires high proportion of energy subsides or try to have most energy produced on the island through renewables.

Cuba has started early to introduce renewable energy in a small scale which needs to expand to a large scale renewable energy mix which is still dominated by fossil fuel.

Cuba has experienced a drastic shift from Soviet Union to renewable energy revolution. The loss of Soviet Union connection led to many challenges and new energy policy was required to be reviewed. Cuba had no access of cheap oil to be transported which resulted in limited electricity to the whole community in 1990. This caused not only the collapse of Soviet Union but also a downfall of Cuba's infrastructure by extreme weather condition, with high frequency of hurricanes[5].

4.3. Revolution

Based on previous disastrous incidents, Cuba decided to take a step and make an energy generation. The target set, was to make Cuba's energy more efficient. For the reduction of energy demand, inefficient applications were replaced to more efficient refrigerators, fans, air conditioners and light bulbs. Payment plans were used to buy efficient appliances to make it more affordable.

Cuba is currently making slow progress in terms of power generation of approximately 1.5 GW and a small wind power plant has been established which produces another 20 megawatt. Cuba has the reputation of being the largest sugar cane producer which was used in the previous years for exchanging goods and is used as another renewable option, such as ethanol fuel [5][6].

Extreme weather condition has a big impact to the bigger generators whereas failure of smaller generators leads to no energy or limited energy to the localized areas which can be fixed easily.

It is important to find another solution to provide energy which will make Cuba independent and improve energy generations. The disadvantage of using small generator is high operating costs, high feedstock cost, and maintenance to all small generators [5].

4.4. Current

As experience from future situation it is essential to plan and consider alternatives when fossil fuel is not available. Fossil fuel, also known as the golden fuel, is an essential feedstock for electrification, building material, appliances and clothing. Many countries like Germany, Denmark and France are developing their grid into renewable energy systems. Every country and island should priorities sustainable and renewable energy resources and set these as an important clause in the energy policy. This will not only develop alternative energy resource but also show a positive impact on social, environment and economic. Many communities in Cuba do not have access to electricity due to high cost of electricity prices. When comparing the electricity price with US there is difference of 20% according to the US Energy Information Administration [7][8]. In order to experience latest technologies, communication and be up to date with and around the world, development for efficient energy micro grid is required to be improved and reduce diesel generators which are used for residential electricity and energy demand. It's necessary to improve grids to avoid history mistakes. This would be a viable solution to improve the efficiency of the micro grid and increase the supply of renewable energy resources. The reduction of transmission and will reduce energy loss. By improving mircogrid Cuba can become independent energy demand supplier and will reduce energy pressure dependency by Venezuela.

This will not improve energy supply to rural areas in Cuba but also reduce a great amount of carbon foot print for a better living environment in the present and future.

4.5. Economy

In 19th century Cuba has been known as one of the greatest sugar cane producer in the world.
Income is based on tourist attract. Most of the electricity consumption is used for refrigeration and air condition. It is important to have these luxury appliances available for the tourist to keep the tourist lifestyle a priority. Not only is it important for the tourist but also for the local community to provide them with similar conditions.

Many researchers have identified, Cuba has low involvement in the global economy and dependency on external support, especially of subsided oil.

Since 2006, the energy system in Cuba has been shifted from centralized to a more distributed structure (Kakonen et at 2014).

Additional target for a stable infrastructure is the high exposure of extreme weather conditions such as hurricanes which are the main responsibility causing damages to the microgrid system.

In order to have back up energy, 40% of distributed energy systems are produced through generators and motors with a capacity of 3 to 10 MW which is fuelled by diesel oil.

Wright also stated, the systems in Cuba needs to go under maintenance which can then change the power system by more efficient systems and improve transmission and distribution network.

By improving electricity grid and adding additional capacity through renewable energy which will strengthen economic development.

Electricity Price:

Electricity price plays a major role based on Cubans and global economy. A list or energy prices is provided from Aviso de Consumo, Union Electric which was given in Pesos and changed to US Dollar using the currency convertor travelex.co.uk

Range of electricity consumption (kWh/month)	Price per kWh (Cuban pesos)	Price per kWh (US$)
0 – 100	0.09	0.003
101 -150	0.30	0.011
151 – 200	0.40	0.015
201 – 250	0.60	0.023
301 -350	0.80	0.030
351 - 500	1.50	0.057
501 – 1000	2.00	0.075
1000 – 5000	3.00	0.113
< 5000	5.00	0.189

Table 1 – electricity prices in Cuba by Aviso de Consumo

Cuba`s economy faces many uncertainty in the electricity generation through global price cost of fuel and low quality of transmission and distribution. The trend in the table emphasis the higher the electricity consumed the higher the electricity cost will be. The price of electricity is depending on electricity demand growth, domestic fuel production, foreign investments and global marketing electricity prices in Cuba.

4.6. Aim

Electricity has become a fundamental part of our life to run appliances, lightening and heating. Initially fossil fuel was used to generate electricity for many years which everyone took for granted. The condition now is fossil fuel is running out and is non-renewable therefore it is essential to look for alternative ways to generate future energy which are reliable and available to future generation. The aim is to analyse and examine the renewable energy shift by 2030 and what suitable renewable energy technologies can be used to meet demand.

4.7. Objectives

The objective is believed that when introducing high renewable energy mix, it will promote Cuba being independent based on energy by reducing fossil fuel imports and reforms a better economic growth and stability.

Growth in clean energy is essential as in Cuba around 200,000 people do not have access to electricity for basic needs for cooking, healting and lightening which makes it socially and economic development very weak.Cuba is a potential island to make change and reform their electricity demand.

A target of 24% increase has been set by the government by 2030 for companies to move towards renewable energy.

4.8. SCOPE

The scope of this project is to determine the energy production by 2030 by increasing renewable energy in the distribution grid. Different scenarios will be introduced in the analyse section to conclude the aim. Interconnections will not be introduced in this research project but can be looked into future work. Basic environmental concerns will be discussed in the conclusion which can be analysed in future work. The study of this project is to simulate and optimize a system design of a hybrid renewable energy system for application to the island in a large scale.

The main objective for this study is:

- To determine current energy load in Cuba
- Evaluate current and potential renewable energy resources
- Model and optimize a hybrid systems by is based on;
    - Different energy scenarios
    - Financial feasibility
    - Environmental impact
    - Evaluate reliable scenarios

The selection of potential energy resources used in the hybrid microgrid system is based primarly on availability resources in Cuba.

It is determined based on the geographical location; solar, wind, hydro and bioenergy have the highest energy mix potential to be a sustainable country.

The hybrid energy system, will be combined to the microgrid, is a combination of renewables and bioenergy is used as a controlled energy source which can be compensated for the intermittences of solar and wind energy using it for electrification to reduce the installed storage capacity requirements.

4.9. Methodology

This report will summerise Cubas new renewable energy by 2030. To meet this aim the report is divided into different Sections:

Section 5 compresses Literature reviews relating to Cubas energy history to the energy revolution which started in 2006 and what is avialable today. Different renewable energy resources and technologies will be described to understand their importance and what potential it has to the decentralisation of energy from renewable energy and fossil fuel. Additionally main challenges will be discussed. A brief introduction will be given of the simulation model used in the thesis.

Section 6 will introduce the Theory of energy and hybrid systems and future summary is made for the different renewable energy technologies.

Section 7 disusses the importance of large scale grids. It is important to understnd the concept of a mircogrid and how renewable energy can increase the self-dependecy of energy. Resources from IEA is provided to understand current installed capacity of energy production in Cuba.

Many researches have stated storages are important inorder to save energy being wasted, therefore different types of storages and batteries are explained

Section 8 will provide given electricty production, consumption data for 2016 which will help to analyses and validate a software model to determine future realistic result

Chapter 9 combines all found data to validate the simulation and optimisation tool known as HOMER. This will determine why its an ideal tool and will provide results of energy generations

Section 10 is an anlyses to determine if Cuba can increase its renewable capacity to a total of 24%.

Section 11 will conclude the aim and furter improvement and work will be given for a better sustaibale energy development in Cuba

5. Chapter 2:

2.1 Literature review

The Literature review will look into many different energy aspects in Cuba to determine the total electricity supply by 2030.

Chapter 2 has been divided into subheading to understand the background electricity history and knowledge to determine the aim.

Cuba has been known as an interesting country for an energy history which was discussed in introduction. Islands like Cuba is struggling to be energy independent as interconnections are not shared with other countries to a better import. Cuba is relying on energy been transported to the island in the form of fossil fuel to operate diesel generators. Additional there is no access to financial assistance to develop energy systems. Developing an environmentally sustainable energy with low carbon emission can be a challenge that needs to be tackled and has been everyone’s interest in the recent years. Cuba has already started working to become a renewable energy revolution which has been a very slow progress. Cuba is an important island which needs to takes this inconsideration as we all are living currently in an unsustainable environment which needs to be improved as soon as possible to reduce global warming and slowing reduce fossil fuel dependency. The listed concerns will drive us to increase renewable energy development and improve energy policies. From 2006 Cuba has shown great interest to increase energy efficiency by using LED light and efficient appliances for cooling, heating and refrigeration.

Chapter 2 has been divided into subheading to understand the background electricity history and knowledge to determine the aim.

- Issues and challenges of electricity in Cuba
- Cuba energy development
- Energy consumption in 2016
- The grid and renewable energy resources
- Why is it important to increase renewable energy and develop large scale systems
- Introduction of Homer

2.1.1 Issues and Challenges

Due to history and challenges in the energy sector, makes Cuba an interest case to be researched on as it is being recognised as a sustainable development model. Living planate has stated, Cuba is one of the few countries which have a low carbon emission of 1.8 global hectares per head. The low carbon emission is based on low energy consumption.

Based on the world energy trends[1] for non-OECD countries energy demand rose by 2.3% in 2015.

To develop a sustainable and efficient mircogrid 4 aspects needs to be considered:

1. Extreme weather conditions
2. Economic crisis
3. Energy dependency by Valenzuela
4. Fossil fuel decline

Cuba energia is an important renewable energy research organisation. They look into issues and challenges relating to energy in Cuba. They have stated, for Cuba to have enough electricity to meet demand from mainly renewable energy, access to technology and funding is required. Their role is to look into available technology access by carrying out assessments which could affect environment, social and economic. These concerns can be resolved quickly if US embargo lets technologies and supply to be shipped to Cuba and receive financial support. Investments are equally limited in getting foreign investments. Currently Ministry and state councils are in the process of changing their policy by making renewable energy as a priority and provide funds to technologies which will support Cuba's rise in energy and economic. An additional concern for a slow progress in Cuba as public opinion is not welcomed. Another downside for Cuba to improve as a nation.

Many researches and experts have stated Cuba need to develop a strong policy which includes the nationals target to run their country in a better structure. By making renewable energy and its target of reducing carbon foot print can increase the share of nation`s energy mix and provide electricity to the whole community with a lower cost.

Most investors still are not ready to invest in Cuba due to it previous energy histry. It is important to forget what has happened previously. There are a lot of opportunities available in Cuba for the development of sustainable energy.

This report will discuss current and potential renewable energy resources and technologies, additionally the new energy revolution, policy and energy demand and supply by 2030.

ISSUES	CHALLENGES
Financial crisis	Bigger photovoltaic
energy efficiency	Safer wind turbines
Energy fuel for heating and cooking	Storage battery technologies
Limited access to technologies	Technology development costs

Table 2 – Issues and challenges in Cuba

2.1 Cuban energy development

Cuba faced a strong energy challenge which makes an interesting research project. Many countries have their own fuel to run the grid and provide electricity to the whole country. Whereas Cuba is depending on imported fossil fuel to run diesel generator, previously from the Soviet Union and currently by Venezuela. The main characteristic is the Cuban power sector with high electrification rate and low consumption rate.

Cuba is highly depending on fossil fuel. In 1958 Cuba used to exchange their sugar cane for oil with the Soviet Union. This allowed half of the community to have access to fuel and electricity at a reasonable price.

Cuba realised in 1970, imported crude oil was not enough therefore started to increase domestic crude oil production of oil which became stable in 1990. The construction site is near the coastal areas which produce low quality oil. The oil produced domestically contains a high quantity of sulphur which could have been used to produce asphalt and would lead to an additional business venture. Due to shortage of fuel, the domestic oil needs to be used to operate diesel generators for the production of electricity. Due to the increase of domestic production of fuel oil in Cuba, almost 50% is produced and the remaining is imported mainly from Venezuela.

To increase renewable resources and supply this to grid, planning, suitable technology and finance plays an essential role therefore Cuba needs to accept foreign investors to get in partnership for a greener electricity grid. It is important to meet the basic needs for the community for example: clean water, lightening, refrigeration, air conditioning.

In 2009 Cuba has organized to develop renewable energy revolution by creating groups of:

- National group for renewable energy source
- Energy efficiency and cogeneration
- Vice ministry for renewable energies
- Ministry of basic Industry[26]

It is the role of local government to motivate and introduce renewable energy systems to the community, school and industry. Awareness of how important it is to think further and have alternative routes which will not affect the future generation. Renewable energy will benefit of using energy from clean resources, reduce carbon dioxide being emitted and have alternative energy to operate our daily appliance and technologies to run the nation and our daily lives.

2.2 Energy consumption in 2016

Research and investigation made by Mira, Hanna and Jyrki stated off-grid small scale electrification has been installed successfully in remote areas and has provided electricity to nearly 35,000 people in Cuba.

It is now the time to move into large scale renewable energy which requires full work in the sector of productive and service.

2.3 Renewable energy resources

Introduction:

Energy is very much a big fundamental of life to operate different functions and potential to tackle and grown economic and job opportunity growth from planning to manufacture to production. For analysis, different types of renewable energy systems will be determined for the need of electricity in smaller islands like Cuba.

Renewable energy is an energy source which is available most of the time depending on weather conditions compared to fossil fuel. Fossil fuel is not a source that can be found immediately. It is a natural source which has been made many decades. This black gold energy is now depleting, therefore new ways needs to be researched and looked at to find available resources which has a greener effect to human and the surrounding.

Sustainable technologies help to determine potential solutions in efficient and reliable energy resources and reduce subsidize oil. Renewable energy has a greater impact in off grid system which needs to be shifted to a larger scale system and connect to the grid. This will surely change in the future as Cuba is ready and making the effort to change its energy condition. The change of energy started in 1981 when Fidel Castro realised the shortage of energy to the whole community in Cuba. Fidel C. decided to develop an energy plan to introduce small scale hydropower and look into additional renewable energy to increase electricity supply.

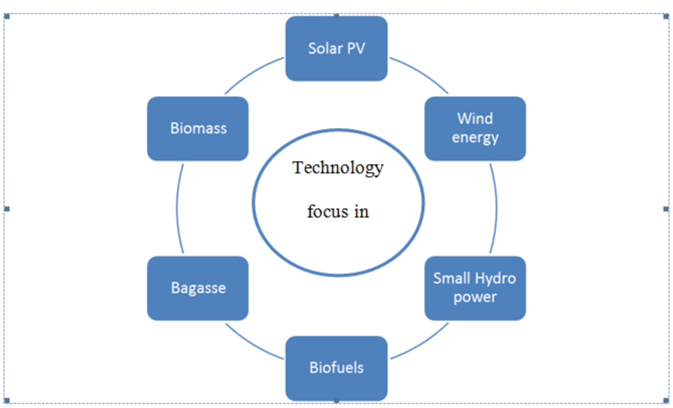


Figure 2 – Technology focus in Cuba

For the main renewable energy resource, solar, wind and biomass the electricity generation should be concentrated on the central of Cuba.

2.2.1 Solar Photovoltaic (PV)

PV is an effective renewable energy system which provides electricity from sunlight. As Cuba is located in the geographical area which makes the country hot and where the solar energy generation is extensive throughout the year this will be an ideal system to be introduced in large scale. Nearly 1800 kWh/m^2 per year of solar radiation is received (Carbonell Morles). This is sufficient to operate solar PV system to produce electricity. Currently the Cuban government has already developed PV systems in small scale which provides essential needs to heat water for residential and commercial consumers with the total capacity of 3.9 MW. Currently a total capacity of 1.8 MW of solar PV systems is installed in Cuba off-grid due to high global electricity prices and lack of feed-in remuneration for solar electricity. The aim of the government is to develop PV systems in a large scale and connect this to the mircogrid will help to promote renewable energy to all areas in Cuba, which are big and small cities and equally to rural areas. By 2030 a total capacity of 100 MW will be added where 90 MW will be connected to the national Grid. (Suarez et al, 2016)

- Electricity price for PV

The figure below is a clear indication, the cost of solar PV will be reduced in the coming years which will make it more capital feasible for countries with lower funding options

Figure 3 – PV pricing by greentechmedia

(https://www.greentechmedia.com/articles/read/solar-pv-module-price-reach-57-cents-per-watt-in-2015-continue-to-fall-thro)

For small scale PV systems, it is a very cost effective system compared to large scale. It is determined by improving material and efficiency cost the system will become economic viable and reduction in price. PV systems do have their disadvantages which are:

1. High set up cost
2. Regular maintenance is required
3. Replacement costs are expensive
4. When material is broken or send to landfill for disposal, this will be not environmental viable due to toxic material used to catch photons from sunlight to converts this to electricity.
5. Future Solar PV system planning is already in progress to build further solar system. The map below is an indication where the construction of solar PV`s will be built. Reference: https://www.cubastandard.com/?p=16321

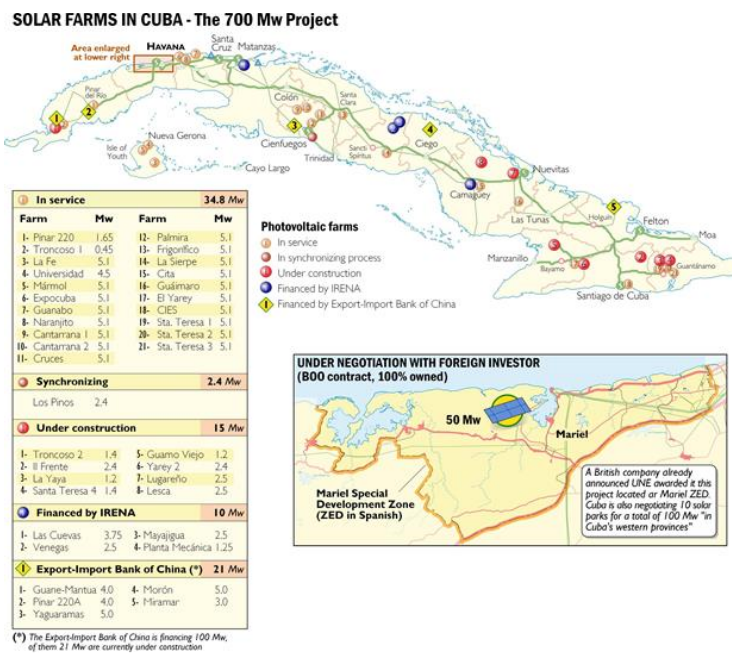


Figure 4- current and future solar farms by Cuba standards

2.2.3 Wind energy

Wind energy in Cuba is relative new and has large potential to be introduced to generate electricity. Cuba has more than 4850 windfarms which need to be maintained and be used to be connected to the grid for further electricity contribution (Suarez et al, 2016). Currently three wind farms with the total capacity of 7.2 MW and an average annual electricity energy production of 3.0 GWh. The fourth wind park is under construction process which will have the capacity of 4.5 MW.

It has been confirmed to constructed windfarms of 500 MW capacity negotiated 3 areas in the northeast of the country by 2020. At the moment the specialists of the company of engineering and projects of the UNE (INEL) study the characteristics of the turbines of 2.0, 2.3 and 2.5 MW (these last two with technology Siemens) and at the beginning of 2017 we hope to initiate the negotiations and the visits of specialists.

Generally interest in wind farms has increased due to its clean and cheap energy production. Introducing more wind farms in Cuba will increase electricity generation through renewables.

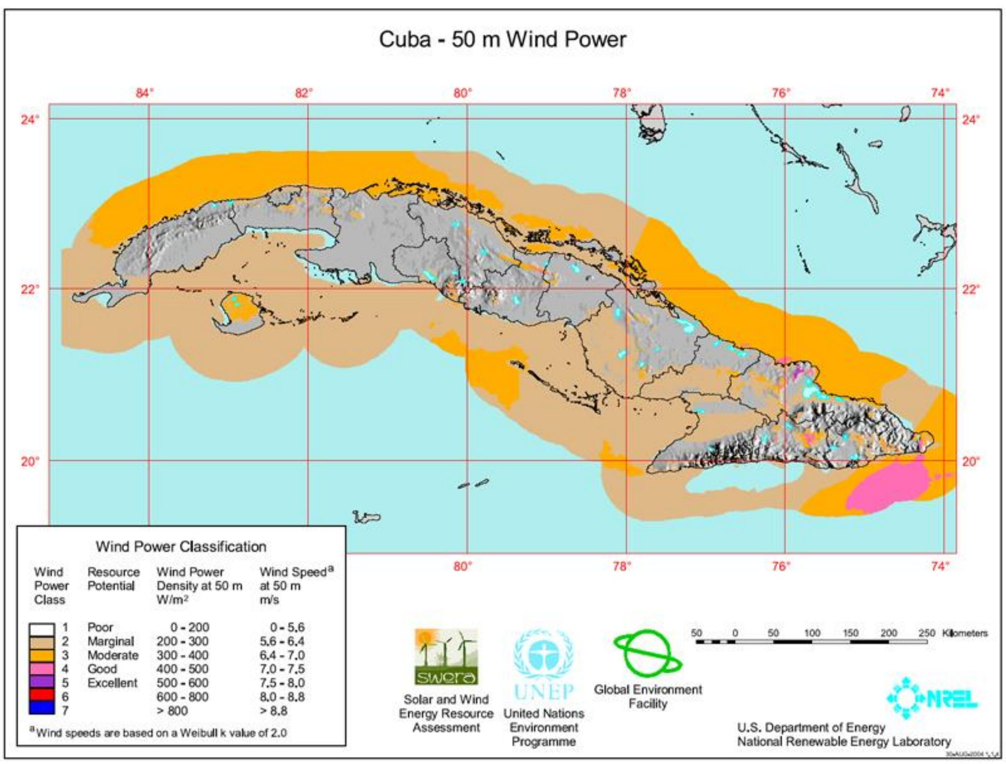


*Figure 5 – Potential wind speed to build wind farms by US NREL(*Reference: http://www.blog.thesietch.org/wp-content/uploads/2007/07/windmapcuba.jpg

Bioenergy

Cuba`s main renewable energy source is biomass which is a domain to the foreseeable future. Sugarcane is the main feedstock. Before the energy revolution, sugarcane was exchanged to buy fossil fuel from the Soviet union and became at the same time the biggest sugarcane export business which reduced after the loss of partnership.
Fuel wood and charcoal are other main biomass sources in Cuba. The total energy produced from biomass can be up to 2 Mtoe (Suarez et al, 2016). In rural areas, wood is used in stoves and open fire as an energy sources for heating.
Cuba has a program for the use of forest biomass that includes the installation of gasification plants connected to the internal combustion engine to produce electricity in the selected areas (Morales et al, 2014).

Biogas can be used by extracting energy from animal farms, agricultural waste and food processing. Suarez analysed nearly 370 million m^3 per year. It can be used for the production of electricity, heating, lightening and cooking. Cuba has 198 biogas digesters and 11 biogas plants (Suarez et al, 2012).

Havana energy and ZERUS S.A. are in a joint venture to produce bio power from bio waste. Havana energy owns 49% of its share and the remaining by the Cuban company. 5 bioelectrical plants with a total power generation of 300MW from bio-waste.

Bioenergy will be the major contributor as a renewable energy source in the future to the energy supply.

Hydropower

Hydropower is another renewable energy potential. This was the first available renewable energy system in cuba. Hydro power has proved to be a reliable energy resources in isolated and rural areas and can be expanded off and potentially on grid. For the best electricity generation it should be situated near the deep sea area. Ocean thermal energy conversion (OTEC) which is a system which creates energy from water depth of 1000 m and needs a temperature of 5◦C or less.

5.1. Modelling tool – Homer

Homer (Hybrid Optimization Model for Electrical Renewable) is an computerised optimization modelling tool which can help to evaluate and analyse energy design based on different energy mix from renewable energy and other fuel source. Homer is an electrification tool which has been developed by the technical homer energy company, known as the US national renewable energy. It can evaluate capacity and total maximum produced on off-grid and centralised grid which are connected for various technologies and appliances. A mix of appliances can be added to the evaluations which are generators, Solar PV, wind turbines, hydropower, biomass, storage capacity and including batteries. Additionally it can determine total cost of installing and operating the system over its life span. The tool is useful as it also determines different design option based on technical and economist merit. The micro power system generates electricity and heat for the service of peoples demand. It helps to combine electrical and storage technologies at low voltages. Examples of micro power systems are:

- Solar batteries
- Wind diesel systems
- Grid connected natural gas micro turbines

This will be a challenging decision to determine the ideal option in the Homer optimizing tool. The three principles used to determine evaluation based on data submitted are:

1. Simulation of data – it analyses long term options based on required location and timescale. Additionally determines the idealist of the system combinations used and the electrical plus thermal loads. The advantage in the simulation process is providing an estimated total capital and instillation life cycle cost.

2. Optimization - The aim of optimization is to determine the best possible system configuration based on minimum operating and instillation net cost. It can be single or mixed energy technology components. The decision for optimization depends on many factors of:
    - Number of Solar PV systems
    - Numbers and size of wind turbines
    - Addition of hydropower system
    - Numbers of storage batteries
    - Use of ac-dc converters
3. Sensitivity analysis – The analysis includes different sets of optimisation analysis and forms different sets of results. To receive optimal results, different data sets are added which includes:
    - fuel prices
    - total capital cost for instillation
    - interest rates to pay of loans
    - hourly data from optimisation
    - resource data from renewables

In the homer modelling tool, economic tool can be used which plays part in the simulation process. It is integrate with the optimization analysis to determine the cost of the system configuration.(http://shodhganga.inflibnet.ac.in/bitstream/10603/34708/12/12_chapter3.pdf))

To understand the homer simulation process, varies calculations are used to determine the optimum system combination. The cost in the tool are real capital costs in Dollars,$, which are updated frequently. It does not determine the first year of return cost due to start up off instillation. Calculations are made based on lifetime costs of batteries and generators. The equation used for each component at the end of project lifetime is:

$$S = C_{rem} \frac{R_{rem}}{R_{comp}} \qquad \text{Equation 1}$$

Where:

S = Salvage value in $

C_{rem} = replacement cost in $

R_{rem} = remaining life of component in years

R_{comp} = lifetime of the components in years

Secondly the total net present cost:

$$C_{NPC} = \frac{C_{ann,tot}}{CRF_{i,R_{proj}}} \qquad \text{Equation 2}$$

Where:

C_{NPC} = cost of initial lifecycle cost of a system

$C_{ann,tot}$ = total annualized cost in $

R_{proj} = the project life time in years

i = annual interest rate at lowest

CRF = capital recovery factor

To determine the cost of energy the next equation will determine if the system will be feasible in economic and cost perspective:

$$COE = \frac{C_{ann,tot}}{E_{prim} + E_{def} + E_{grid,sales}} \qquad \text{Equation 3}$$

Where:

COE= cost of energy system in $

E_{prim} = total primary load

E_{def}= total deferrable load

$E_{grid,sale}$ = total cost of energy sold from grid in $

CRF = capital recovery factor

Equation 3 is the most important equation which is used after all simulations have been completed. It determines the average cost in kilowatt hour which is used in Homer during optimisation stage.

The cost if energy system (COE) and cost of initial lifecycle cost (NCP)

This will help to determine the ideal sustainable and renewable energy system mix in Cuba by 2030 and beyond

6. Theory:

This chapter will introduce the basic concept of energy systems, hybrid renewable energy systems followed by different types of technologies.

6.1. Energy systems

There are many definitions for energy systems. To understand the concept of energy systems, these two words will be split to understand the basic concept. In physics the meaning of energy means of in the process of completing work. Energy can be in many forms: potential, kinematic, thermal, chemical and electrical. Energy can also in the form of heat.

Systems was defined by Churchman, who was a philosopher and scientist, in 1968 which is known as two or more objects are combined to work together to determine a result.

6.2. Hybrid systems

Cuba is highly fossil fuel dependent and to reduce the imported subsidised oil to the island from Venezuela it is essential to increase renewable energy for avoiding energy shortage and energy dependency from other countries. Many countries already have introduced to increase renewable energy to their national grid such as solar, wind, bioenergy, geothermal and hydropower to increase supply for increasing demand and reduce carbon emission for a sustainable country. The other benefits of using renewable energy is the low life cycle cost but high investment capital cost. Many renewable energy sources have a higher rate of intermittence than non-renewable energy source (Mishra et al, 2016).

Hybrid energy systems are proven to be an efficient way of combining renewable energy system for the production of electricity including storage components to provide increased system efficiency and a more balanced energy supply (Fhamy et al, 2014).

6.3. Renewable energy

Photovoltaic energy

Photovoltaic PV cell is a system made by semi conducting material which generates electric power by a current and voltage when sun radiation shines to the cell. When the cell absorbs sunlight it raises an electron to a higher energy stage from the solar PV cell to the external circuit. In the circuit the electron release energy through vibration and moves back to the initial solar PV cell.

6.4. Bioenergy

Biogas

Biogas is produced by decomposing organic material with the absence of oxygen through anaerobic reaction in a closed system or through fermentation of biodegradable material e.g. sugar. Biogas will consist of methane and canon dioxide with a small contamination of moisture, hydrogen sulphide and siloxanes.

The breakdown of organic materials will have 4 key steps (Abbasi et al, 2012):

- By the process of hydrolysis, the material contain large protein macromolecules, fats and carbohydrate polymers are broken down into amino acids, long chain fatty acids and sugar.

- During acidogenesis, the products from stage 1 are fermented to form volatile fatty acids, principally lactic, propionic, butyric, and valeric acid.
- In acetogenesis, bacteria consume the fermentation products from stage 2 and generate acetic acid, carbon dioxide, and hydrogen.
- Methane is produced when methanogenic organisms consume the acetate, hydrogen, and some of the carbon dioxide.

Biogas, liquid petroleum gas and natural gas have similar properties when heated and burnt. Only biogas is a renewable energy sources as its produced from organic waste where the other two components are from fossil fuel components. Biogas and biomass have little carbon footprint as emission generated is already part of the carbon cycle to the atmosphere.

6.5. Wind energy:

6.5.1 To produce wind energy, it is important to understand the wind system. The system is known as the wind turbine which consists two or more blades attached to a rotor. The turbine converts the kinetic energy of wind into electrical power. The wind turns the blades which captures the kinetic energy by the rotor which turns the generator through a rotary motion. The amount of energy produced is primarily dependent on the rotor diameter. The design of wind turbines depend at the location where it will be placed which consists of:

- Blade shape
- Number of blades

- Height of tower (the higher the tower the more power can be produced)
- Monitored control system
- Types of turbines: Vertical or horizontal

Wind power technology is an intensive and effective technology. Wind energy is widely available for most of its time which poses no fuel price risk or constraints, energy security and no direct greenhouse emission. Wind power technology causes social impact due to visual impact, use of land, increase of bird deaths and noise from rotor.

Another downfall of using wind technology is the energy produced from wind cannot be stored.

7. Large scale grid:

What are the main sustainable technology focuses which can be taken in consideration in Cuba?

The major energy characteristic is the high electrification rate with a low consumption rate. The consumption rate is relatively low due to electricity cost affordability. Unfortunate the cost of electricity is high for a poor household therefore not everyone has the facility of electricity. Based on this problem, renewable energy system needs to be introduced to lower electricity prices.

Other companies looked into modelling renewable energy system mix

Irena is an international renewable energy agency which work on and off-grid renewable energy systems. They have looked into Asian countries that have limited energy access for their basic needs and used homer as an example modelling tool.

(reference:http://www.irena.org/DocumentDownloads/Publications/IRENA_Off-grid_Renewable_Systems_WP_2015.pdf)

Equally Hong Kong University of Science and Technology have looked into renewable mix using the modelling tool to determine the demand projection for 2030. This strategy can be applied to my study of renewable energy in Cuba by 2030. Homer is a useful tool to determine energy capacity generation for different term. The new software of homer can also determine the impact determine the impact on environmental and the analysis of carbon footprint.

3.1What is a centralised microgrid?

Centralised grids are known as a large scale central system which receives and distributes energy to any building and transportation in the form of electricity.

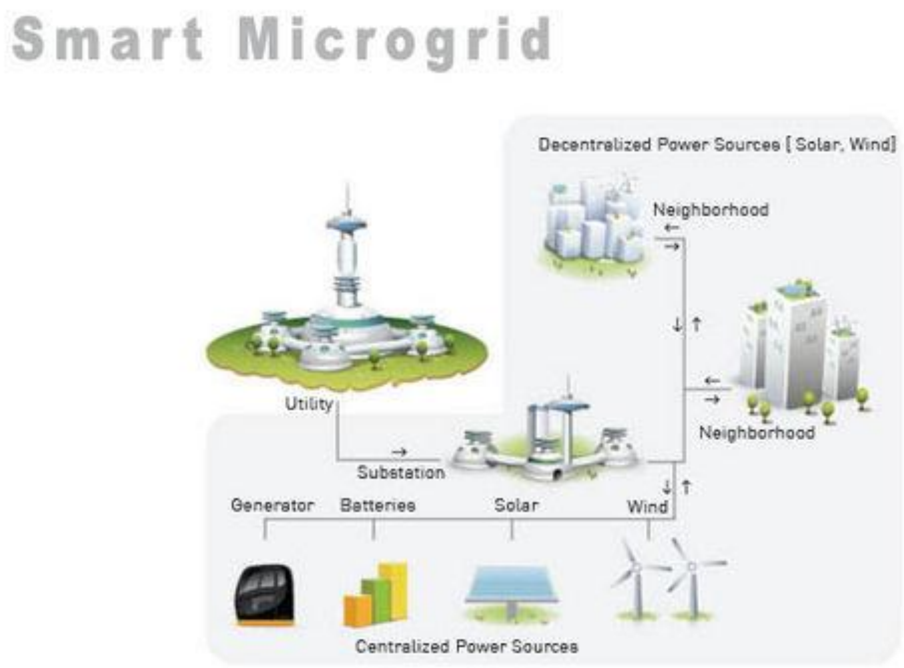


Figure 6 smart grid by computes Scotland

(references:

http://www.computescotland.com/images/rIhhwJj1iWDhkhyUQvTx0ff0a9.jpg)

The features of the micro grid which are essential to work efficiently:

- dispatch able base load (natural or coal power station)
- mixed renewable energy resources
- fossil fuel or coal to run the base load when required
- storage capacity
- control systems to monitor demand, supply, import and exports for data collections which will be useful for future references

to build a better infrastructure for electricity supply, detailed research are required. For investor to provide finance risk assessments are required based on installation, extreme weather conditions in Cuba and health and safety within the construction site.

A grid at the moment cannot be 100% renewable as the grid need to have a base load which at the moment can only be a natural gas power station or a large diesel generator. It will only be used when not enough renewable energy is produced through solar wind and other renewable energy sources to run the grid. It will take a long way for the grid to be 100% renewable. Further research is required to determine how the based load can run only on renewable energy systems. To have a mix of low fossil fuel and high renewable energy resource for the production of electricity will have a reliable and secure distribution to the community in Cuba. This needs to the future solution and can strengthen the grid connection on the island which is not only necessary for the community, also for tourist and increase the economic development. The grids need to have a smart monitor to follow and collect data for analyse of how to improve the distributed grid and how it might develop interconnections to the surrounding island.

Cuba`s current energy profile

Domestic electricity generation:

96.5% fossil fuel

3% biofuels

1% hydro

0.1% solar PV

> 0.1% wind

(IEA resource)

Nuclear power station would be an alternative base load for running the centralised grid. For a renewable distribution it is essential to have a dispatch able base load, which can be turned on and off when required, whereas nuclear needs to run on a constant process as it requires time to turn on and off. Therefore potentially gas power station would be ideal but has its downside of producing carbon dioxide and monoxide which will raise concerns based on pollutions.

3.2 What is the difference between off grid and centralised system? What would be the best option for Cuba?

Off grid systems are small scale energy systems used in smaller areas which are not connected to the main grid. This provides enough energy capacity to operate basic needs to run their daily lives. The advantage is the low cost of appliance.

Centralised systems are installed in many countries like America, China, Germany and many other countries. Centralised systems provide transition of energy to building, industry and transportation. They take large space of land as they are large in size. The installed capacity is in megawatts and gigawatts depending on system size and required capacity. It will be ideal to develop centralised systems in Cuba to provide electricity to long distances.

Imports:

A trend of imports from 1990 to 2016 has been show in the graph below. The data was taken from the international energy agency:

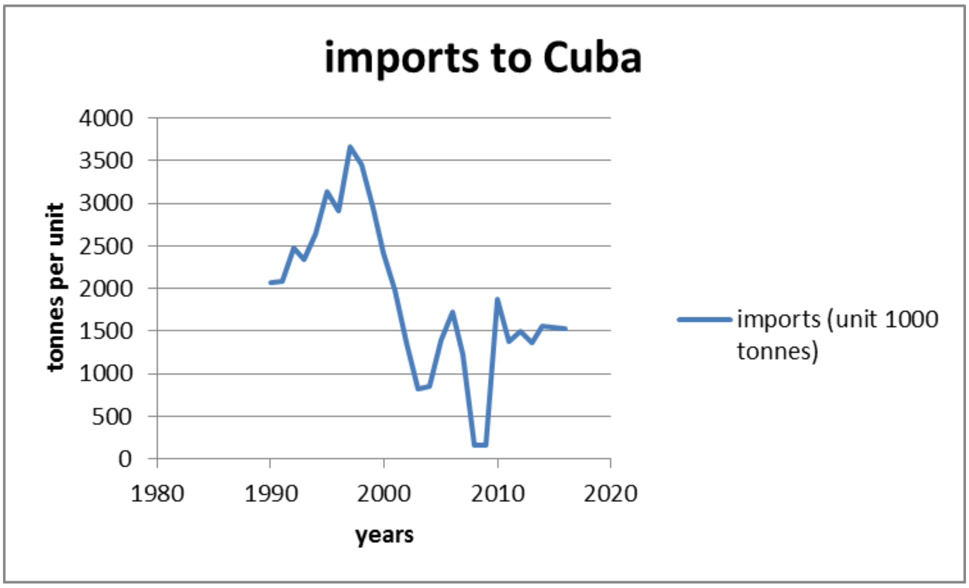


Figure 7- import trend chart in Cuba by IEA, 2016

It shows a from 1990 to 1997 a steady increase of import of fossil fuel when Soviet union was in partnership. The deal of importing fossil fuel was to provide the Soviet Union large quanities of sugar cane which equally caused an increasing trend to improve it economy and was provided fossil fuel at a low cost. After the downfall of Soviet Union, cuba struggled with its energy supply to meet communities demand for their basic needs. Everyone struggled for oil, gas and food.

Energy technology storage for Cuba:

A list of available storage will be provided which could be potentially be useful in Cuba to store extra energies:

- **Pumped Hydro** is a type of hydroelectric energy storage used by electric power systems for load balancing. This method stores energy in the form of gravitational potential energy of water pumped from a lower elevation reservoir to a higher elevation. During the period of high electricity demand, power is generated by releasing the

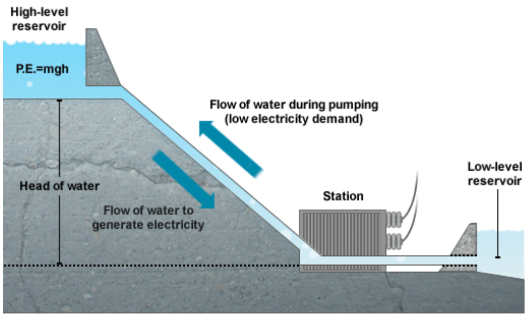


Figure 8- pumped hydro system

stored water through turbines in the same manner as a conventional hydropower station. During the periods of low demand, the upper reservoir is recharged by using lower cost electricity from the grid to pump the water back to the upper reservoir. By using the surplus electricity to pump water from the lower reservoir to the upper reservoir, energy can be stored in the form of gravitational potential energy, which ccan then be converted back into electrical energy at a later time by allowing the water to flow back down from the upper to the lower reservoir through a turbine and generator, similar to a conventional hydroelectric technology. In this way, energy is converted from electrical to kinetic to gravitational potential and then back to kinetic and back to electrical.

(reference: http://energystoragesense.com/pumped-hydroelectric-storage-phs/)

- **Flow Batteries** are a form of a battery in which the electrolyte contains one or more dissolved electro-active species which flow through a power cell reactor where the chemical energy is converted to electricity. They are based on the reaction-oxidation reaction between two electrolytes. The reaction is reversible allowing the battery to be charged, discharged. The electrolytes are stored in external tanks and pumped through separate circuits for positive and negative species, while on ion exchange membrane separates them within the reaction chambers.

- **Fly wheel** is a rotating mechanical device that is used to store rotational energy that can be called up instantaneously. A basic flywheel contains a spinning mass in its centre that is divided by a motor and when energy is needed, the spinning force drives a device similar to a turbine to produce electricity, showing the rate of rotation. A flywheel is recharged by using the motor to increase its initial rotational speed. Flywheel technology has many beneficial properties that enable us to improve our current electric grid. It is able to capture energy from intermittent energy source over time and deliver on interrupted power to the grid. Flywheels are also able to respond to grid signals instantly, delivering frequency regulation and electricity quality improvement.
- **Supercapacitor** is a double layer capacitor which has a relative high capacitance but low voltage limits. Super capacitors store more energy than electric capacitors and have a unit in farads (f). The capacitor store electrical energy at an electrode – electrolyte interface. They consist of two metal plates, which only are coated with a porous material know as activated carbon. The plates are immersed in an electrolyte made of positive and negative ions dissolved in a solvent when a voltage is applied; two separate charged layers are produced on the surface with small separation distance. This is the reason why super capacitors are often referred to electric double layer capacitor.
- **Solar batteries** provide energy storage for solar, wind and other renewable energy systems. A solar battery is capable of surviving prolonged, repeated and deep discharged which are typical in renewable energy system that are off grid. Solar batteries are a key component in a stand-alone renewable energy system. In renewable energy systems, solar batteries provide the energy storage for individual systems. They are meant to be discharged and recharged separately.
- **Wind-diesel system** combines two or more generating technologies such as wind and diesel which creates a hybrid power system. Wind-diesel hybrid system combine wind turbines with diesel generating sets for electricity generation. This can either be a new Wind-diesel hybrid plant or wind turbines can be integrated with an existing diesel power plant having one or more diesel generating sets supplying power into de-centralised grid. The main

purpose of adding wind turbines is to reduce diesel fuel consumption leading to the environmental and cost effective association by reducing fossil fuel dependency in Cuba.

8. : Electricity generation in 2016:

8.1. Electricity production

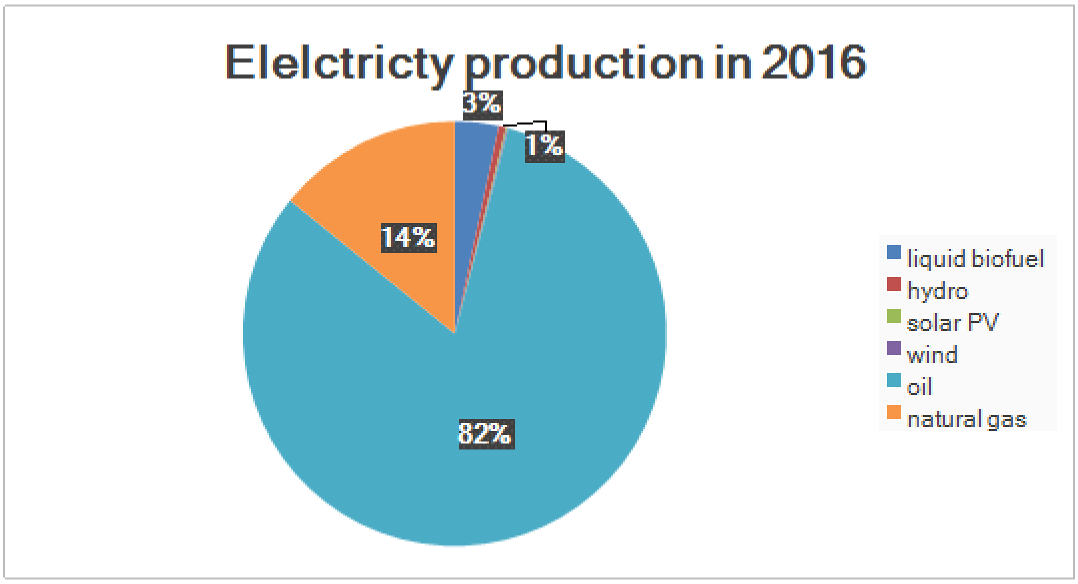


Figure 9 – Electricity production in Cuba by IEA,2016

The piechart in Figure shows, Cuba`s energy mix is heavily dependent on fossil fuel and most of it generate to produce electricity. A very small proportion is made from renewable energies. As the percentage of hydro, solar PV and wind is very small this is not clearly presented in the diagram. Nealy 53% of fossil fuel is imported by Venezuela, which brings high cost of oil price with the addition of transport cost and is currently under 40% dept based on the Cuban GDP. Cuba is depepending on Venezuela fo imported fuel which is currently at a risly stage as they are looking to close the partnership of transporting fossil fuel to the island. Therefore cuba needs to introduce higher renewable energy resource to the energy mix to keep up inhibitans electricity needs. This will increase energy self-sufficiency in cuba and reduce greenhouse gases.

8.2. Energy consumed:

The graph shows a representation of a simplified bar chart which the data from production and consumption in Cuba by 2016. It a clear indication, the production rate is higher than the consumption. In 2016 the percentage of energy lost after consumption is nearly 20%. This is electricity lost during distribution. Storage technology can be introduce to avoid energy being lost and improve distribution cable for a more efficient electricity transfer.

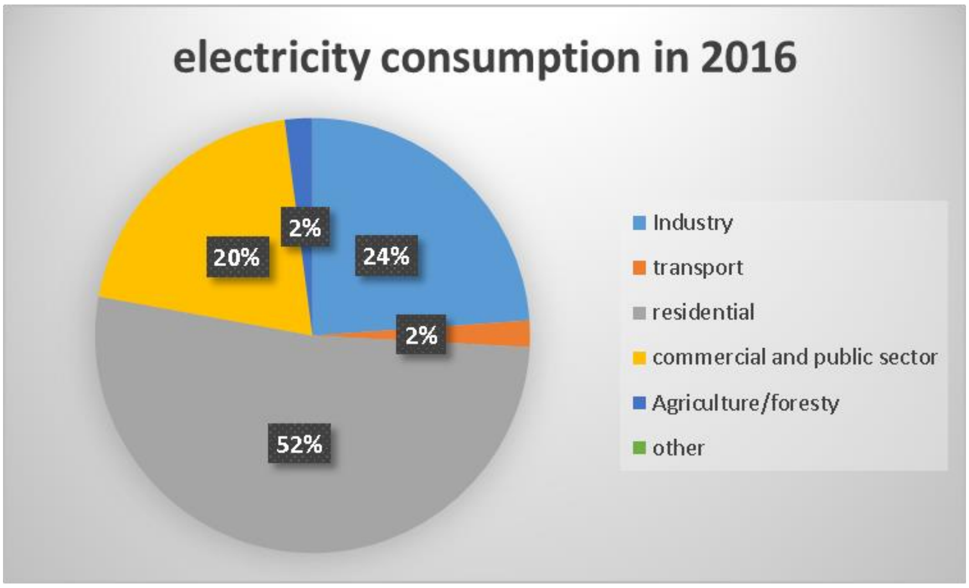


Figure 10 – electricty consumption data in Cuba by IEA, 2016

Suarez stated in his study, nearly 140,000 households have access to electricity
The electricity distribution pie chart shows, residents are the largest electricity consumers of approximately 4,000 GWh in 2016. The high number of electricity is used for cooking, lightening and heating. The industry is the second largest consumer followed by a small margin which is commercial and public sector. Unfortunately rural and isolated areas still have limited or no access to electricity and transportation. Currently transports run by diesel and petrol and therefore the electricity demand is very little. Many major countries for example the Unites states, the UK, China and Germany are looking to develop vehicles which will run by electricity which can increase electricity demand.

8.3. Total Electricity generation:

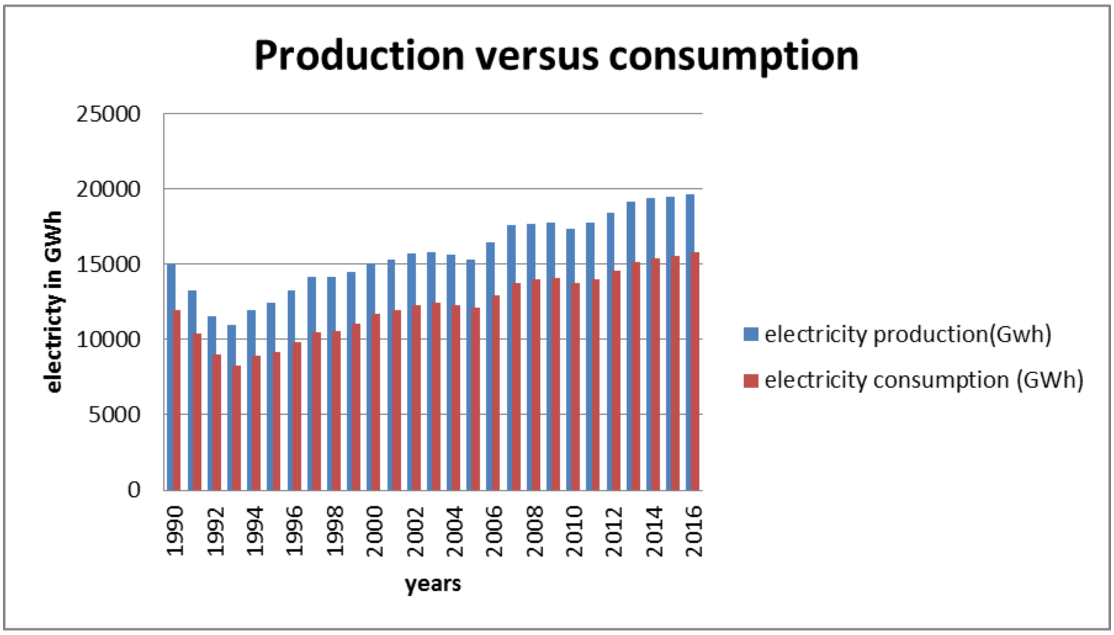


Figure 11- Production versus consumption data in Cuba by IEA, 2016

(reference: https://www.iea.org/statistics/statisticssearch/report/?country=Cuba&product=ElectricityandHeat&year=1990)

The greatest contribution of nearly 20,000 GWh is from fossil fuel and very small contribution of renewable energy (mainly solar PV, biofuels and wind energy). Other technologies have not been introduced yet due to low financial condition.

The figure above illustrates, energy is lost after electricity has been consumed. Nearly 22% of energy is lost from an electricity production of 20,000 GWh. This is a lot of energy lost which can be used for other purposes. The introduction of storage can hinder for energy being lost.

9. Software validation- Homer

The aim of using the optimized software tool- Homer- is to determine best scenarios for Cuba by increasing the use of renewable energy resource and generating enough cost effective electricity which can be provided to the whole population. This is determined by running several scenarios by installing wind turbines, PV, hydropower and batteries in a large scale.

9.1. Analysis data from homer

	Installed capacity [MW]
Solar	7.1
Wind	11.7
Hydropower	58
Bioenergy	332
Diesel generators	1200
Oil fired power plants	3105
Gas fired power plant	400

Table 3- current installed capacities

9.2. Energy validation for 2016 in Cuba

Demand Profile

1. Residential electrical load

A load profile was created in homer, shown in figure . The graph indicated the demand per hour for electricity requirement for the inhabitant in Cube. A peak of nearly 600 kW shows at 6 am. The high peak at 6 am indicated people in the residence use electrical power to use the appliance for heating, lightening, cooling in summer days and use electrical equipment's for making breakfast or use communication to get in touch or complete work on their laptops. Another peak shows at 7 pm when people return home and use electrical power for shower, making dinner or complete work on electronic devices. The total electricity consumed for cuba is 8,815 kWh/day (World data et al, 2016). Below is an illustration of a load profile diagram made by HOMER,

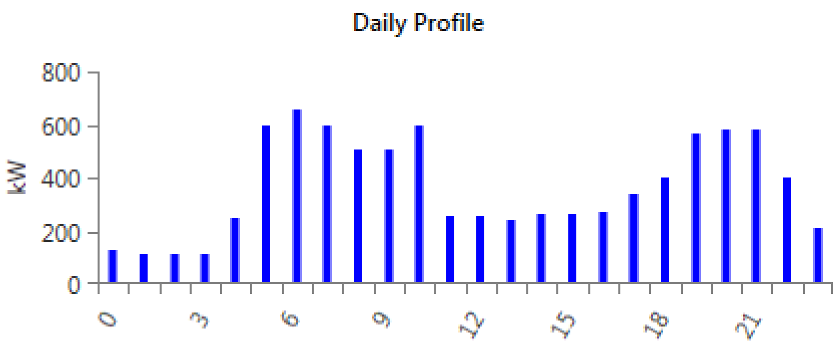


Figure – 12 residential demand profile. HOMER

Based on the daily profile to meet demand a table was generated for different factors taking in consideration:

Metric	Scaled values
Scaled annual average in kWh/d	8,815
Scaled average peak load in kW	367.31
Peak in kW	1,118.1
Load factor	0.33

Table – 4 load profile data generated by Homer

To validate the model before developing scenarios for a better sustainable island for the reassurance of determining ideal and realistic results. The graph below is an illustration for the highest peak month which is August. Cuba is a favourite tourist country and it can be very hot during summer season, therefore electricity demands is at its highest for air conditioning, proving warm water to the tourist and have lights and increase in tourist population more electricity is used.

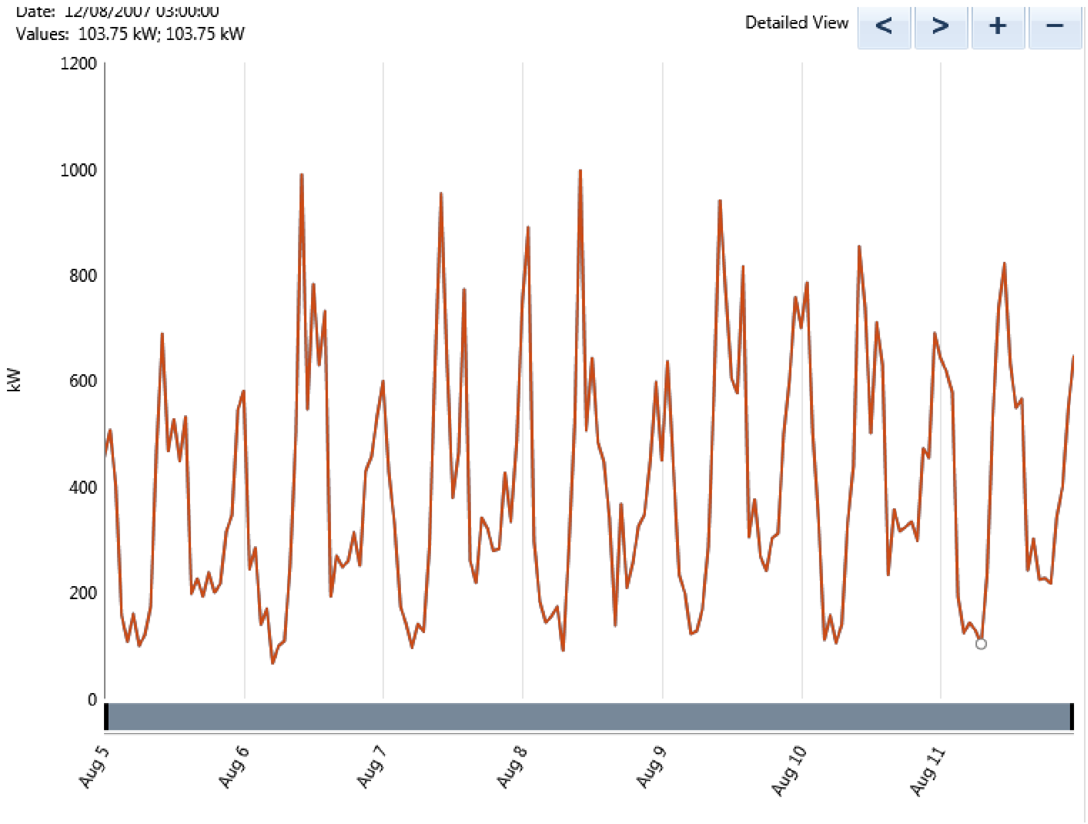


Figure 13 – weekly demand profile in Cuba, Homer

Validation:

In order to validate the performance for a realistic result from the model realistic data, a generator was added. Generator is an important equipment for Cuba to avaoid previous black out incident mentioned in the Introduction chapter. The figure illustrated below the generator will just meet the demand of an average load of 8,815 kWh/day.

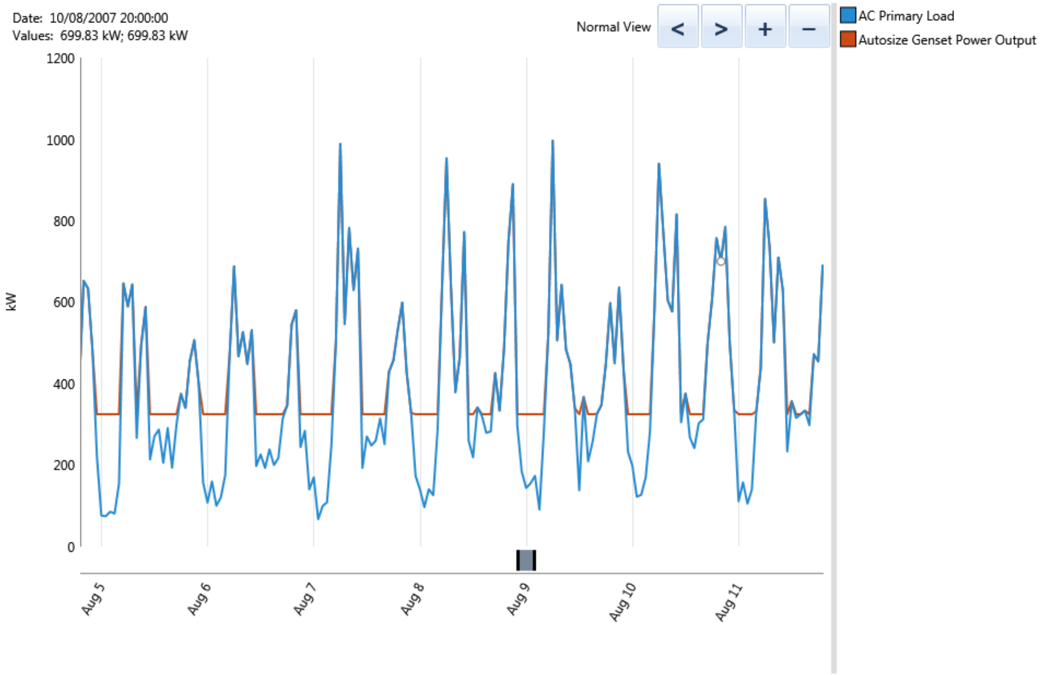


Figure 14: demand profile with generator

For a more realistic result further renewable energy sourced used in Cuba was added to the simulation. Homer contains PV array data information from NASA Surface Meteorology and Solar Energy Database (NASA, 2017). The installed capacity of Solar systems is 7.1 MW (710 kW) and therefore the size of PV array was added with the size of its initial capacity of 710 kW.

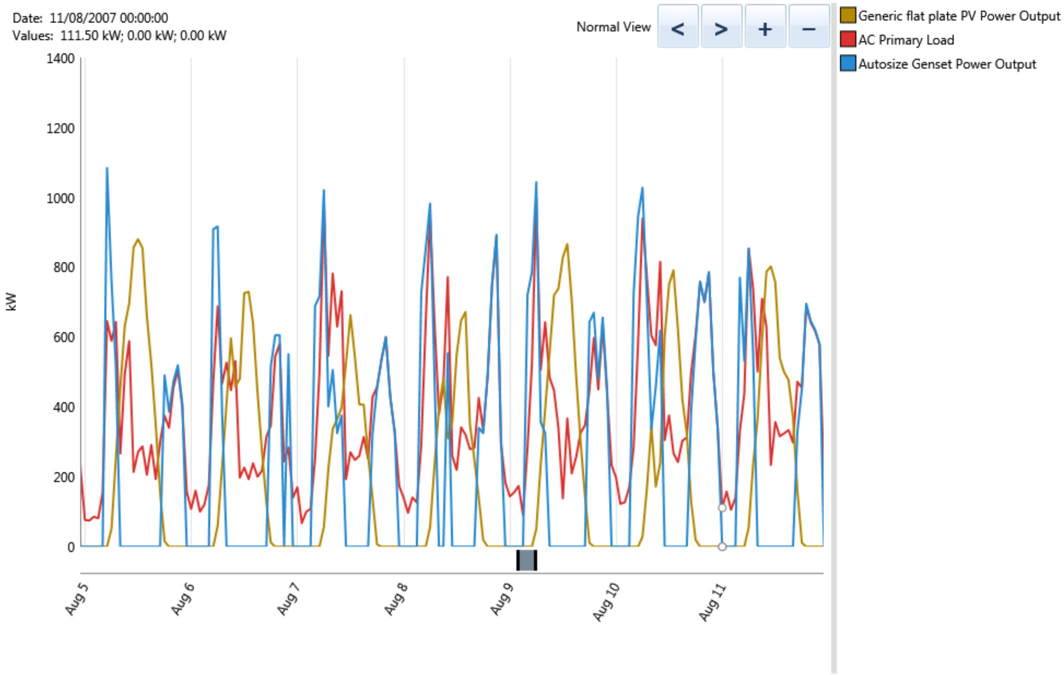


Figure 15- weekly demand with PV and generator

August week demand with the addition of generator and a PV with an average capacity of 1100 kW. A generator is added to the homer modelling for a real case scenarios when PV does not generate enough energy to meet demand. To validate the graph and data from Homer it is important to match the result with a solar PV plant in Cuba. The annual PV array generated by Homer is 7,386,427 kWh per year and with a peak value of 1100 kW which gives a ratio of approximately of 6715 (see appendix for calculation).

To prove the result validation of the PV plant in Cuba (Javier Cubas et al 2014) are compared to the homer calculated values:

6,545,000/1150 = 5691

When calculating the difference a low percentage of approximately < 20% will validate the model

= (5691/6715) * 100%

= 85%

Difference = 100 % - 85% = 15%

The difference of radiation could be due to a different timescale.one needs to take in consideration the value from solar plants in Cuba is the correct value where Homer only uses average data for modelling. As the difference is very low the model has been validate.

When solar system is used in a system, the surplus energy from solar and generators can be stored in a battery which can be released in the time during low production or low demand.

Demand with bio generators:

Bio-waste is high available source in Cuba and can be used as a renewable energy source for electricity production. Based on world waste management, Cuba produced nearly 360 tonnes per day (120,000 tonnes per year, WMW et al, 2017)

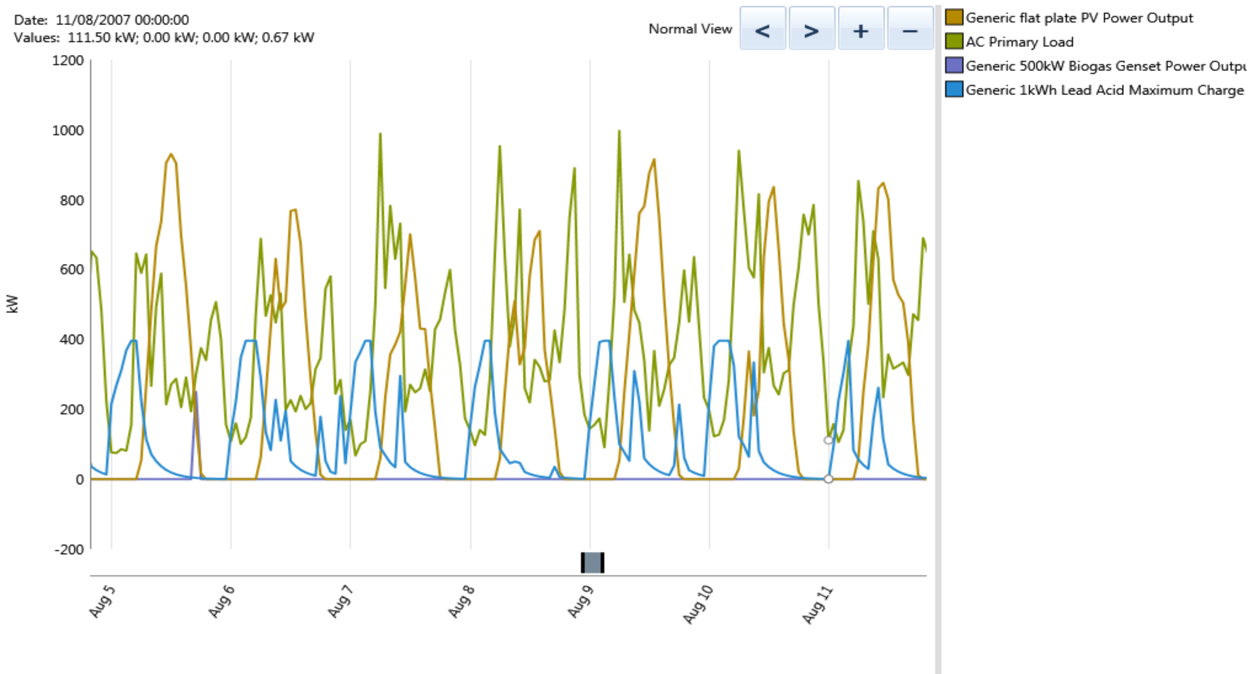


Figure -16 weekly demands with bio generators

As Cuba is known as the largest sugarcane exported, a large increase of bio-waste is produce. Not only sugarcane but also through other agricultural waste. Analysis was used with the bio generator capacity of 500kW. When increasing the bio generator this help to reduce or replace diesel generator for a more sustainable development by decreasing carbon footprint. At this stage bio generator cannot replace diesel generator to meet demand as the electricity production output is very little. Nearly 200kW is produced which can only operate small devices for a short period. As stated in figure … the PV output is under 1000kW. When PV output is at its highest, storage of Lead acid battery is introduced to short excess supply for later demand needs. In a system when PV system, bio generator and storage are connected the system will operate as an cycle to store surplus energy. This will hinder for loss of energy or alternatively the generator will produce enough electricity supply to meet daily demand without producing excess energy.

5.3 Demand projection for 2030

Energy is the main domain which helps to develop a country and to be sustainable, it is important to install further renewable energy generating equipment to increase energy supply, use energy efficient materials and introduce foreign investments. The potential of using clean renewable energy will have no negative consequences to air pollution or global warming as the dependency of fossil fuel will be very small.

Transportation, use of modern appliances and further living standards has been eased by fossil fuel. The main focus of this projection to apply renewable energy sources to the island and reduce the dependency of fossil fuel. Equally this will strengthen the economic development, increase environmental protection and increase social energy security. Orlando Nicoloa Hernandez quoted:

"Our expectations for the year 2030 is that we will reach 24 percent of our energy production coming from renewable energy sources, thus replacing 1.75 million tons of fuel, which would mean we would stop emitting 6 million tons of carbon dioxide every year,"

http://bi.galegroup.com/global/article/GALE%7CA499300141/6ffc313610247d942fbe94088d5cd8d7?u=ustrath

The analysis of adding addition renewable capacity by 2030 will determine the effect on overall capital and electricity cost.

Solar

According to official figures, clean energy sources presently contribute just 4.65% to the national generation of energy, but experts consider that massive potential exists for the exploitation of biomass, wind and solar energy.

Expert calculations indicate that Cuba receives an annual average solar radiation exposure in excess of 1,800kw per square meter, ensuring the potential for advantageous economic investments.

https://search.proquest.com/docview/1868280593?rfr_id=info%3Axri%2Fsid%3Aprimo

The solar radiation in Homer is generated from the NASA Surface Meteorology and Solar Energy website. The radiation is made of average daily insulation incident radiation on a horizontal surface (kWh/m^2/day) for the last 22 years.

The location data is necessary which determines the solar radiation data of:

- Latitude: 21.5218°N
- Longitude: 77.7812°W
- Time zone : UTC – 05:00 Eastern Time (US & Canada)

Cuba`s energy profile 2030 according to Rosell Guerra, director of renewables at the Cuban: Ministry of energy

Planning to install additional 2 GW of renewable energy capacity

13 wind farms = 633 MW

700 MW solar photovoltaics

19 biomass power stations = fuelld by sugar cane residue 755 MW

74 small hydroelectric plants = 56 Mw

(http://bi.galegroup.com/global/article/GALE%7CA433798309/8391a0b1784de44ca346f36120cabab0?u=ustrath)

capital investments totaling approximately U.S.$3.5 billion

A table of an average radiation is illustrated from NASA:

Month	Clearness Index	Daily Radiation ($kWh/m^2/day$)
January	0.548	3.980
February	0.577	4.780
March	0.567	5.400
April	0.568	5.968
May	0.530	5.810
June	0.530	5.860
July	0.544	5.970
August	0.534	5.670
September	0.529	5.190
October	0.535	4.610
November	0.534	3.990
December	0.537	3.710

Table 5– Solar radiation data per month in Cuba

Solar PV cost

For the selection of a generic flat plate of 1PV panels for the electricity generation it is important to calculate the total system cost which is shown in table .for further system addition in the future will decrease in the next coming years up to 2030 and beyond.

Characteristics	Current cost	Future cost
Capacity (kW)	1	1
Capital ($)	3,000.00	1,250.00
Replacement ($)	3,000.00	1,250.00
O&M ($)	10.00	4.17
Average Panel Efficiency (%)	80	80

Table 6 – The total instillation characteristic cost of Solar systems, Homer

Wind

The wind data is provided by Homer which is presented below from NASA and Solar Energy Database:

Month	Average wind speed in m/s
January	5.790
February	5.740
March	5.580
April	4.830
May	4.790
June	4.650
July	5.240
August	4.780
September	4.600
October	4.910
November	5.960
December	5.260

Table 7– Wind speed in m/s per month in Cuba

Information given above is only an average wind data. A graph created based on information above:

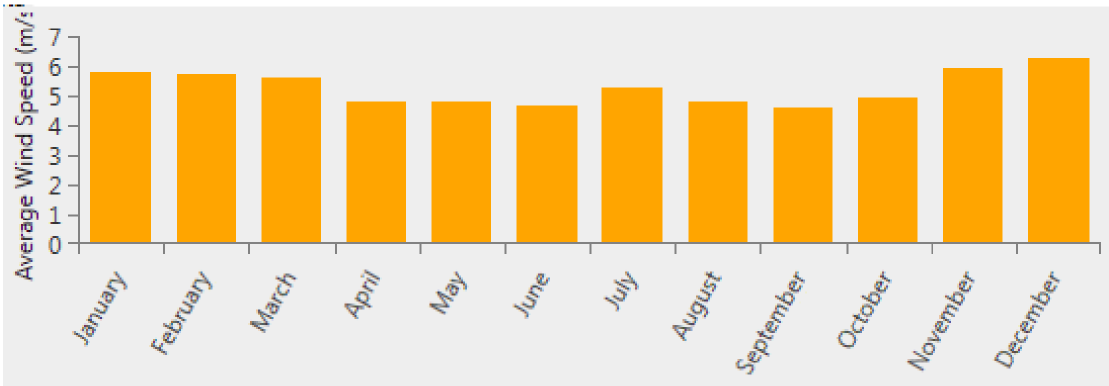


Figure 17- Average wind speed in m/s

Wind speed in Cuba is fairly constant and is at its lowest in September. The average For determine wind speed data, algorithm equation was used to determine the hourly time series data with the wind speed at the hub height of the turbine by:

(equation)

The simulation used for validation was 1.5 MW turbine which seems sufficient enough based on current installed capacity in Cuba. The power graph of EWT`s DW 52 and electricity is generated at 4 m/s and produced a steady electricity output at 12.5 m/s which is illustrated below:

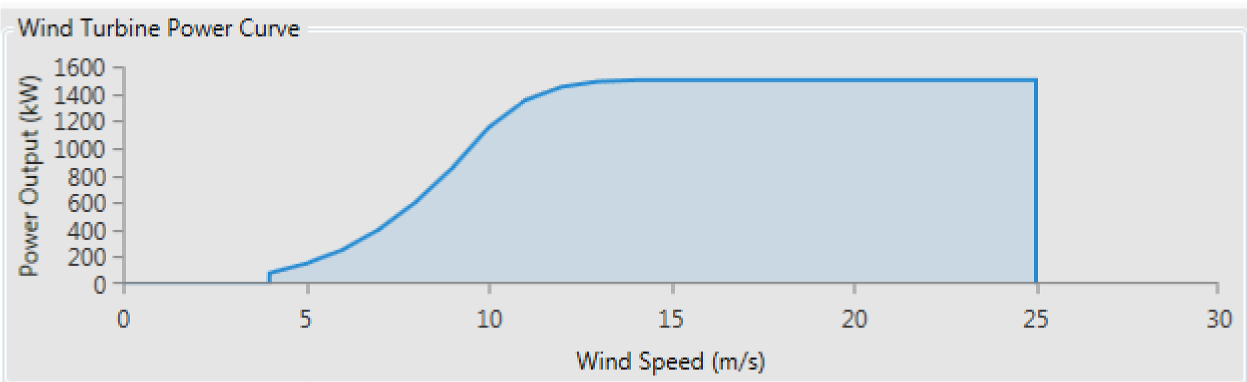


Figure 18 - wind turbine power curve

Cuba has 4 windfarms installed with a total capacity of 11700 kW. For a high capacity, ideal turbines are required to provide enough energy output. It is essential to choose systems which are capable to handle extreme weather conditions in Cuba. Based on capacity, a turbie of 250kW with a height of 52 m. Homer does not hold specified wind turbins, therefore standardised wind turbines needs to be used for the evaluation of a model. For a better wind turbine selection in a real case scenario a specified table is shown by EWT`s Direct:

Specifications	value
Type	DW52/DW 54
Rotor diameter	54 m
Variable rotor speed	12 – 22 rpm
Nominal power output	250 kW
Cut-in wind speed	2.5 m/s
Rated wind speed	7.5 – 8 m/s
Survival wind speed	52.5 m/s

Table – DW52 Specification table by EWT`s Direct

(http://www.ewtdirectwind.com/wind-turbines/dw5254-250kw.html)

Capital cost:

Characteristics	Current cost
Capacity (kW)	1500
Capital ($)	3,000,000
Replacement ($)	3,000,000
O&M ($)	30,000.00
Hub height (m)	80

Table 9 – cost analysis for wind turbines

Bio generators

Bioenergy is an important energy resource in Cuba. This will provide electricity and reduce landfill burden. The reduction of carbon dioxide and toxic gases will reduce further. Cuba has 18 large biodigestors, 300 biodigestors and 600 private digesters units installed. These need to be considered in Homer as the total capacity generation is 350,000 kW. Biogas generators have different sizes from 1 to 10 kW with gas consumption of 0.65m^3/kWh.

Capital cost:

Characteristics	Current cost
Capacity (kW)	500.00
Capital ($)	3,000.00
Replacement ($)	1,250.00
O&M ($)	300.00

Table 10 – cost analysis for biogenerators

For generators, fuel curve is an important part to determine the fuel consumed per unit power output.

5.3.4 Hydropower

Hydropower in a small scale is the oldest renewable energy technology. Currently the total capacity in Cuba is installed by 58,000 kW and will continue to increase by 2030. 173 hydroelectric plants are present and which 31 are connected to the grid. For the Homer to model the component of hydropower only 1 system can be added. To determine the average number of hydropower capacity at each plant:

Average capacity at each plant = total hydropower capacity/ number of hydropower plants

Average capacity = 58,000 kW/173 plants = 335 kW at each plant. Based on the UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANISATION, there are 8 small hydropower systems, 35 hydro systems and 137 micro hydro system in isolated and rural areas. These are located near water availability and can 120 litres per seconds residual flow was measured.

(referencehttp://www.smallhydroworld.org/fileadmin/user_upload/pdf/2016/Americas_Caribbean/WSHPDR_2016_Cuba.pdf)

The parameter was virtually added to Homer to provide the following criteria:

Parameters	Values
Available head	250 m
Flow rate	350L/s
Minimum flow ratio	10%
Maximum flow ratio	100%
Hydropower efficiency	80%

Table 11– hydropower parameters for a total installed capacity of 58,000 kW in Cuba

For the determination of average monthly hydro output, averages where taken based on total capacity installed.

Based on these parameters the power output from hydropower can be calculated by where the flow rate follows the pattern on average hydro resources.

Equation;

5.3.5 Diesel Generator

Cuba has 57 turbo generators installed to provide electricity demand. This was introduced after Cuba suffered blackouts for 300 days. More information on Cuban energy revolution is given in the introduction. These generators can be reduced by increasing renewable energy sources off and on grid which could reduce maintenance cost in the future and will reduce carbon footprint and its taxes. In the initial validation model a generator was added which determines a huge involvement in electricity production. Currently the total capacity of the diesel generator is 120,000 kW. Currently the diesel price cost is $ 1.07 and will increase in the future due to reduction of finite resources. The table below show the characteristic cost of installed generators in Cuba which was carried out similarly to the other resources:

Characteristics	Current cost
Capacity (kW)	1
Capital ($)	500
Replacement ($)	500
O&M ($)	0.03
Fuel cost ($/L)	1.07

Table 12– Cost analysis for diesel generators

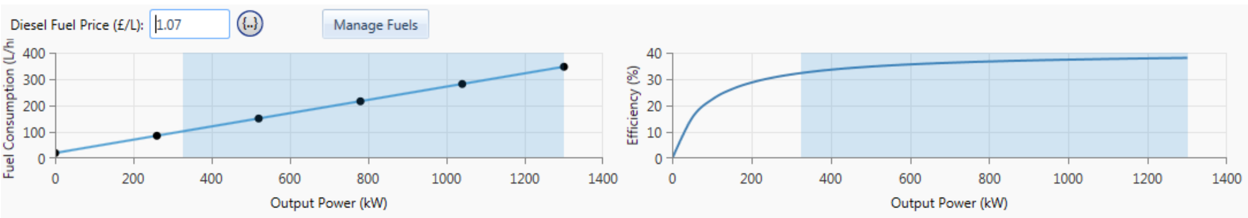


Figure 19 – diesel fuel price graph from Homer

5.3.6 Storage – Batteries

Storage is an essential system which will be used in the future to store excess energy. Battery storages can be installed to control peak demand and lower electricity bills by reducing demand charges. When adding battery to the modelling scenario it is essential to add a suitable battery and their size. For this model the battery chosen was a Generic 1 kWh Lead Acid Battery. The battery characteristic and values were obtained from Homer which is shown below:

Characteristic	Values
Quantity	1
Capital ($)	300
Replacement cost ($)	300
O&M ($)	10
Nominal Capacity (kWh)	1670
Round trip efficiency (%)	80
For a float life (years)	13
Nominal Voltage (V)	12
Maximum capacity (Ah)	83.4

Table 13– Lead Acid battery characteristic

Convertors

As this system can operate in AC and DC mode a convertor is required to change the mode according the system power requirements. The cost of system is provided below:

Characteristic	Values
Quantity	1
Capital ($)	300
Replacement cost ($)	240
O&M ($)	0
Efficiency (%)	95

Table – 14 Convertor parameters

5.4 Analysis and results

This chapter will have different types of scenarios based on Homer simulation and optimisation results. The optimisation result will define the best combination of system connection and capital cost based on the scenarios and environmental aspect for a feasible development. The aim is to increase renewable generation and reduce fossil fuel consumption.

Scenario 1:

This scenario will look into the planned system by increasing the total renewable energy capapcity to 24% . The list below indicates the planned capapcity installment by 2030:

Systems	Current installed capacity (MW)	Future capacity (MW)
Solar	7.1	1200
Wind	11.7	633
Hydropower	58	117
Bioenergy	332	755
Oil fired plants	3105	1700
Gas fired plants	400	2605
Diesel generators	1200	1000

The scenario above will determine the feasibility of the planned capacity.

The average daily profile was created in homer based on residential, industrial and commercial. The load profile below is a representation on Cuba's energy demand. In the early hours the demand seems very low and increases around 5 am where systems are operating, people waking up to go to work, etc. Based on the demand its necessary to have enough energy supplied in a sustainable manner.

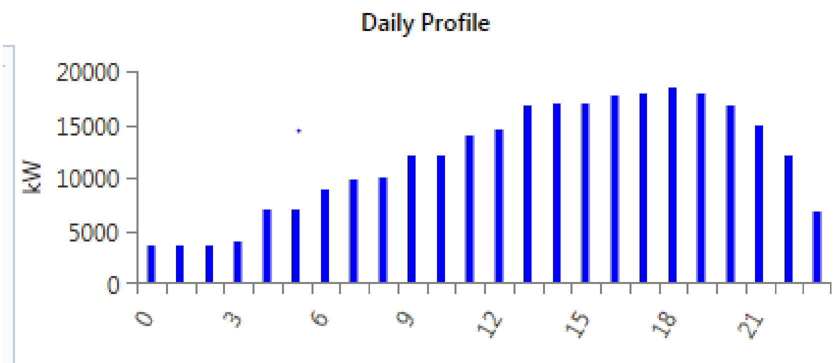


Figure 20: demand profile 2030

To validate Cuba's target of 24% increase in renewable energy the system was modelled in homer as :

To determine different scenarios for ideal system structure, solar PV and wind energy was used to connect with the generator. A schematic design is shown below:

1. Generator:

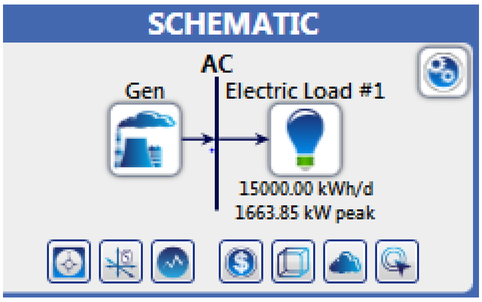


Figure 21 – schematic flow diagram of model

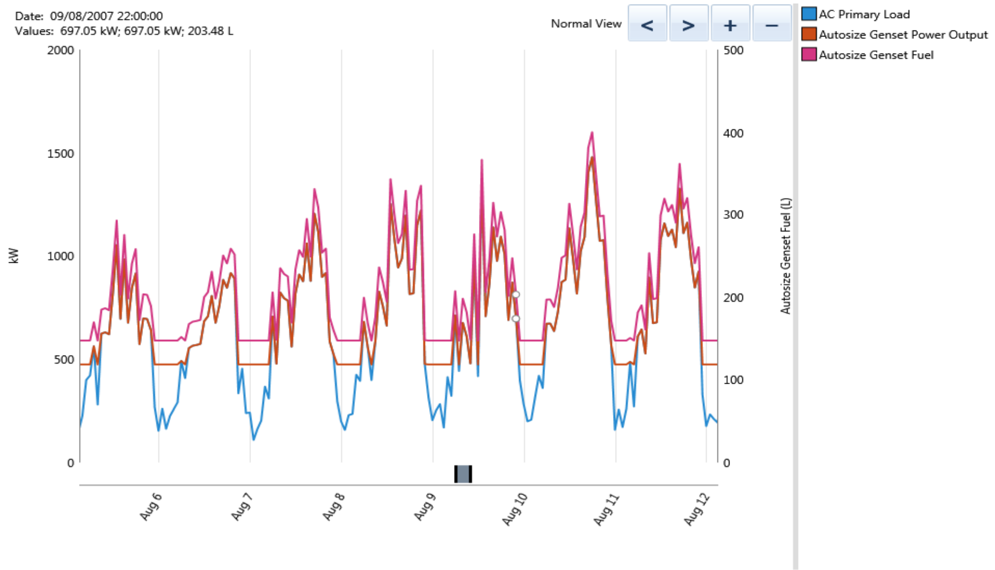


Figure 22- projection of 2030 using generators

It is estimate the daily demand of electricity will increase to 12 MW per day.

A generic generator was used with a capacity of 1 MW. 1 MW can produce nearly 1100 kW per day. Therefore 12 large size generators would be required to meet minimum demand.

Component	Value
1 MW Generic Generator	$950,000 capital cost
12 MW Generic generators	$1,140,000 capital cost
Fuel cost	12 * $ 24,487.000

Table 15 – generic generator cost analysis

Additionally carbon emission will be huge where Cuba would have to pay carbon taxes. Nearly 5 million kg per year of carbon dioxide is produced. This not a feasible scenario for Cuba based on demand, capital cost and fuel cist to run the generator for the production of electricity

2. The second scenario will have a higher capacity or renewable energy which is given in the Appendix II:

The renewable energy system is modelled below:

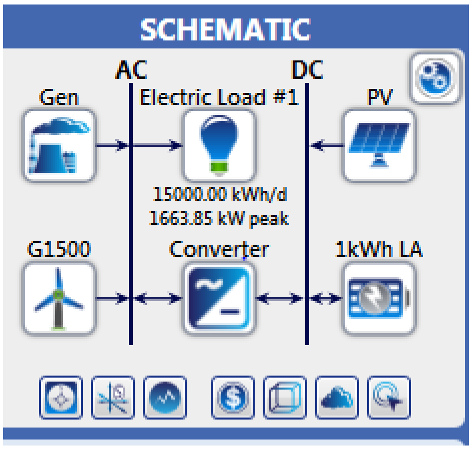


Figure 21 – renewable technology model for 2030

For an optimum result to determine the target of 24% increase the storage battery property has changed to a Li-ion for better storage capacity as more energy is produced from solar systems. Solar system is expected to have a capacity by 2030 of 1200MW.

The 2nd scenario was broken down in 2 section:

a. when generator as used with the connection to PV systems, storage and convertor. The total of instillation will be :

- Capital cost of $3,244,509
- plus fuel cost of $16,914,414

1. when generators are removed and only operated through PV systems the capital cost is huge of $ 1,594,978,688 and a capacity of electricity output of 53 MW which was determined through the optimisation simulation.

If scenarios are decided by capital cost, section a. of scenario 2 will be viable based on financial but not feasible based on emission output as it will produce 41,400,000 kg per year.

For the 3rd scenario is when Wind turbines , hydro and bioenergy is taken in consideration (see Appendix) the total renewable energy mix will be 25.1 % which is similar to the target Cuba has set for 2030.

https://www.researchgate.net/figure/281624611_fig9_Figure-11-Cuba-Additional-electricity-production-optimal-projection-2015-2035

6.Conclusion

The analysis is indicating that electricity demand has grown dramatically over the past decades which reflect the continued importance of electricity for economic development. This analysis will help to determine the importance of renewable energy and will lead to planning and methods of meeting future energy requirements. The analysis indicate Cuba has the potential to make use of sustainable renewable energy sources and reduce dependency of fossil fuel and not worry of fuel to be transported to the country. Cuba has already worked slowly by adding renewable energy to the country. This electricity was only used in a small scale system to provide energy to rural areas.

This report has shown many scenarios of how Cuba can move towards a sustainable electricity supply. This can motivate government and investors and show the potential of Cuba becomes a sustainable electricity producer. It will reduce the stress of economic crisis by developing jobs, energy affordability to all community, shortage of fuel to operate daily needs, inefficient power plants, carbon foot print and weather-proof materials used for the new technologies.

The advantage is, Cuba has 2 main resources which are human and natural resource which will help to become a sustainable country with running natural resources which are renewable. Cuba is a highly qualified country with lots of researchers, engineers, scientist and many energy organisations. Cuba can become a leading country for a sustainable and renewable energy distributor. The major down fall for Cuba is the lack of financial support to develop. Cuba has managed to build small scale renewable energy even though to limited access to funding and has received limited foreign materials and technologies. These small scale renewable energy technologies are bagasse, solar energy and hydropower.

By developing the shift from small scale to large scale energy will provided electricity to the whole area in Cuba. Cuba has already become the second country after

Denmark to be a distributed energy country by replacing appliances to more efficient material to reduce electrification demand. Cuba has become the first country to replace incandescent bulbs to compact fluorescent lamps to become more efficient.
Many social workers and volunteers helped in the energy revolution program to have efficient lightening at every household, government and private buildings. Not only light were changed, also fans were replaced at no cost. This only happened successfully due to government will and cleaver strategies but making people involved.
When developing large scale renewable energy system, an affordable electricity tariff needs to be set up, for an incentive electricity payment plan. This will help the poorest household to have electricity at a low energy price.
We all need the requirement of change of energy production by changing energy policy and making this a priority of making a successful energy planning and structure for the production of efficient energy. It has a many implication of using renewable energy system. It is therefore to support the system and develop machinery which are efficient and low in cost which is still a challenge. It will be in long term a reduction in financial risk and provide us energy which reduces carbon footprint. This is particularly promising, when considering the rapid advancement of renewable energies efficiency and the fall in electricity prices. This will increase the electricity provision from fossil fuel resources.
Renewable energy is still neglected due to lack of awareness and knowledge of existing renewable energy technologies and deficient financing frameworks and opportunities.
This will lead to a more sustainable approach to electricity planning.

Energy policies that aim to promote the introduction of Renewable energy technologies but result in higher costs for equal services would certainly.

It is important we see renewable energy as a necessary investment for social development and economic growth. Policy makers and government develop an energy policy that encourages the production of electricity that is non-disruptive in its socio-economic aspects, encourages environmentally benign systems, and is secure in its supply.

Introducing renewable energy will reduce devlopment problems. An additional factor that contributes to the high transportation costs is inevitable imbalance between inbound and outbound movements of goods. Cuba is a small island country which has a narrow production base imports than it is able to export. This is the reason why fossil fuel import costs for islands can be several times higher than world market rates.

Has cuba the potential to meet its target?

For Cuba to meet its target of 24% total renewable energy contribution to the grid

Cuba has a total of seven thermal oil-fired power stations, where two have be maintened and replaced. For a better efficiency power plant, it can be improved to a higher efficiency combined-cycle natural gas turbine system, CCGT. This can be connected to the grid to run the renewable energy systems and can be switched off when the renewable energy technology run in a stable manner. These power plant can be a back up for a during a blackout situation.

For a stable future power sector, financial access support from government, World bank and international investment or lending instituation is neccessary. These support can provide efficient resources to reduce energy loss. Finacial access will recover Cuba to avoid history. It will lead future expansion to better energy resource from renewable energy technology and will slowly reduce imported fuel and equally will reduce transport cost.

The initial capital cost of adding renewable energy will be a high investment cost which will benefit in the long run and cn provide enough electricty supply. Based on evaluted result from Homer, Cuba has the potential to meet its target and provide cheap energy in the future. Renewable energy has many advantages which could favour cuba. Equally The main concern is not the contant availability of this resource which could not be favourable.

Hybrid renewable energy systems can be combined with several renewable energy systems. The renewable energy systems are combined biomass and diesel generators for optimising a stable power supply.

Environmental Aspect:

Renewable energy sources are attractive for many applications due to their advantages of being continous, pollution free and some of their globally available resouces which are wind, solar, hydropower and biomass.

It is essential to develop a renewable energy systems to islands, similarly to Cuba. Global warming has been the main concern for several years and as Cuba is a costal country, the community is more likly to be affected with increasing sea level and other climate conditions.

From the first scenario nealr 5 million kilogram per year is produced when generators are used. This can be reduced by integrating renewble energy system.

6.1 Improvements:

To introduce wind farms it is essential to take in consideration weather conditions in Cuba. As cuba is part of SIDS area, hurrican is a common weather condition, therefore is is important for wind farm but also ther systems to be hurrican proof inorder to reduce maintenance or reinstallment cost.

The Energy revolution of renewable energy technologies in cuba will result in a successful and sustainable energy production. This energy production chnage will result in low carbon footprint, reduction in electrcity cost and affordable to the whole community.

New progressive electricity tariff has also encouraged electricity saving in households. The decentralisation of electricity production has increased the relia-bility of supply and improved the efficiency when new smaller scale power plants have replaced older tech-nology. In terms of distributed energy generation Cuba holds currently the second place in the world right after Denmark. This may better enable the future development of renewable energy. [2]The energy revolution has, so far, not had much impact on energy use in industry and transport which are the areas where the future policies should be directed. Also the country's energy mix still remains to be domi-nated by fossils

By improving appliances to be more efficient and increase renewable energy will leaad to low imported fossil fuel for energy supply. This will reduce carbon emmission dramatically.

Another reference: https://www.utu.fi/fi/yksikot/ffrc/julkaisut/e-tutu/Documents/eBook_4-2014.pdf

The systems could also be partially produced in Cuba. This would be especially possible if providers of wind turbines choose Cuba as a starting point towards entering the markets in Central America

6.2 Future Work:

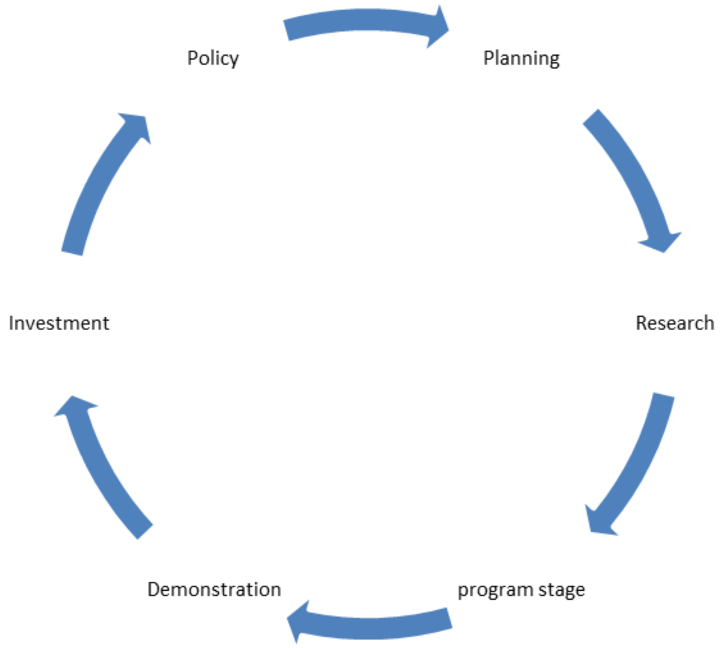
Public sector to Privation:

Many islands around south america are supported by public sectors which will become difficult after Presendient Donal Trump being in leadership for america not being supportive to cuba, will force them to lead to Privation by accepting foreign investors for system planning, designing, construction and operating cost. This will tie cuba being controlled by foreig investors as they will have a ownership of the island. If cuba receives pulic sector support and by the world bank this will make cuba not being controlled by another country and can become reponsible for country improvment and growth.

[2] https://www.utu.fi/fi/yksikot/ffrc/julkaisut/e-tutu/Documents/eBook_4-2014.pdf

Policy:

Electricty is dominated by the policy makers, therefore its their responsible to focus on predominantly on renewable power generation technologies. Cuba has high potential in solar PV, Biomass and wind power energy.



For the step of a better stable and sustainable energy mix it is important to develop a better a planning process executed by the policy maker and government. Currently Cuban policy is highly endorsed with fossil fuel energy generation.

It is essential; the policy maker takes full responsibility to develop a strong policy for increasing the use of energy from renewable energy technologies. Every year an energy review chart is checked to determine how much renewable energy is produced and used. These will determine better structure and action for future renewable energy mix. Not only renewable energy production is important, it is important to review potential environmental concerns it is beneficial and helps to reduce carbon footprint which we are leading into for a better planet. The new **policy** should include important clauses for increasing renewable energy technologies for meeting demand and supply. This will be the guideline for introducing renewable energy for generation of new energy development through resources from sun, wind and water. This will help meet demand when fossil fuel is low and not available in the future.

Structure of a policy:

1. Determine high potential renewable energy sources in the area.
2. Analyse if the renewable energy has no or very little impact on environment, by carrying out environmental impact assessment, carbon footprint measurement.
3. Report submission for approval of assessment based on potential renewable energy and their environmental impact assessment.
4. Design and construction plan

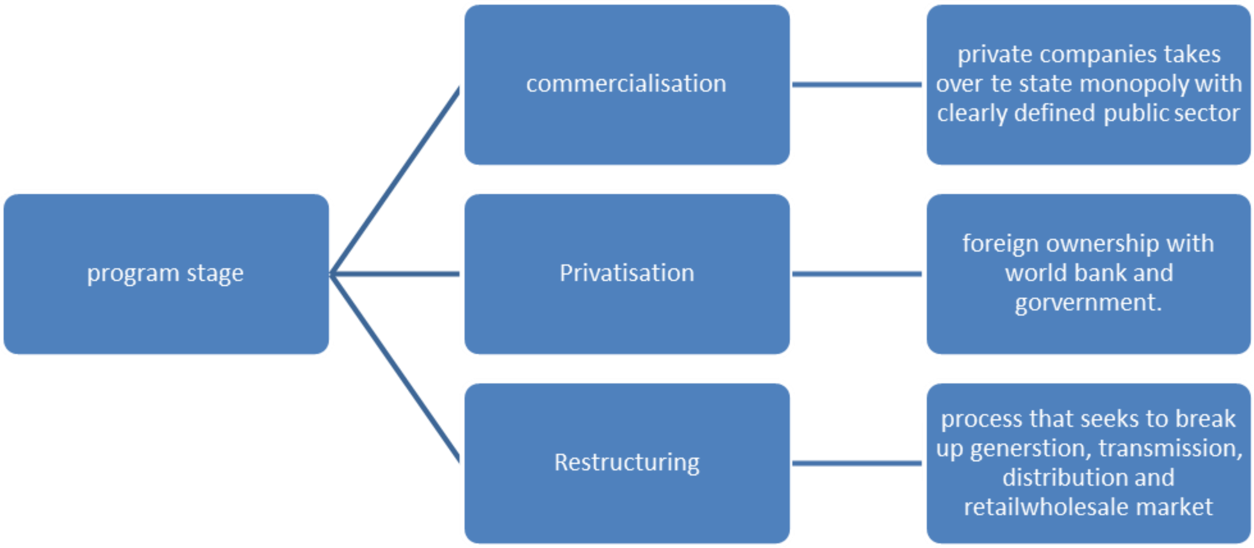
Singh[4] has emphasized policy is the main stepping stone for a successful renewable energy technology. He has stated:

"..electric power reform may be a once-in-generation opportunity to…stimulate renewable energy use in developing countries…"

He makes it clear what the advantage and disadvantage are and the effect on economy and finance for power generation.

Not only policy is important, a detailed planning assessment is essential for a successful construction. Additionally health and hazards assessment is required to operate machines and develop procedure during risk time.
After planning stage, research is in parallel to determine potential resources and what impact it has on social, economic and environmental. Research requires

Program stages:
The program stage will be stepping stones after research which will help to reform Cuba's energy sector which is illustrated below:



http://tlent.home.igc.org/renewable%20energy%20in%20cuba.html

Cuba becoming an independent powerhouse for energy, many measurements and aspects needs to be taken inconsideration which are:

- Renewable energy technology used in similar islands can be introduced to Cuba to run a constant energy supply through renewable energy at a low cost.
- Looking for strategies of how to import energy efficiency appliances at low cost.
- Training people to be available for maintenance

The illustration above highlights, privatization and commercialization pathways will attract foreign investors to finance renewable energy technology projects. This will cause credibility in social, economic and security to stay in Cuba. To understand current problem it is necessary to realize knowledge of new energy development and how to improve energy supply and storage. For further improvements, financial strategies need to be planned by organizations. Investment in new renewable energy technology still causes insecurity to invest for private and government banks.

Wastage:

From 2004 many appliances have been shifted to a more efficient way in order to reduce demand and meet the need of electricity usage. Major concerns currently we are facing are the appliance that have been removed and caused an increase in waste percentage in landfills. It is important to develop system or program by reducing waste in a more environment

7.Reference:

[1] Where is Cuba? [Internet]. WorldAtlas. 2017 [cited 22 August 2017]. Available from: http://www.worldatlas.com/na/cu/where-is-cuba.html

[2]. Cuba electric rate [Internet]. Power2switch. 2017 [cited 23 August 2017]. Available from: https://power2switch.com/IL/Cuba/

[3]. U.S. residential electricity prices decline for the first time in many years [Internet]. Eia.gov. 2017 [cited 23 August 2017]. Available from: https://www.eia.gov/todayinenergy/detail.php?id=28252

Reference:

http://www.blog.thesietch.org/wp-content/uploads/2007/07/windmapcuba.jpg

[2] World atlas. Cuba [Internet]. 2017 [cited 8 July 2017]. Available from: http://www.worldatlas.com/webimage/countrys/namerica/caribb/cu.htm

[3]

[4] 8. The World Factbook — Central Intelligence Agency [Internet]. Cia.gov. 2017 [cited 7 August 2017]. Available from: https://www.cia.gov/library/publications/the-world-factbook/geos/cu.html

[5] Energy Revolution in Cuba: Pionerring for the future [Internet]. 4th ed. Finland: Mira Kakonen, Hanna Kaisti and Jyrki Luukkanen; 2017 [cited 16 July 2017]. Available from: https://www.researchgate.net/publication/276118367_Energy_Revolution_in_Cuba_Pioneering_for_the_Future

[6] Mourant A. Can Cuba find the way forward to a renewables-based future?. Renewable Energy Focus. 2017;19-20(1):129-131.

[9]

1. DW52/54 - 900kW - EWT - wind turbines, 500kw, 900kw, medium wind, direct drive, gearless, feed-in-tarif [Internet]. Ewtdirectwind.com. 2017 [cited 21 August

2017]. Available from: http://www.ewtdirectwind.com/wind-turbines/ewt-wind-turbines/dw5254-900kw.html

2. Bühler A, Krenzinger A. Method for photovoltaic parameter extraction according to a modified double-diode model. Progress in Photovoltaics: Research and Applications. 2012;1(1):n/a-n/a.

3. Boudhiaf R. Numerical temperature and concentration distributions in an insulated salinity gradient solar pond. Renewables: Wind, Water, and Solar. 2015;2(1):na.

4. Mourant A. Can Cuba find the way forward to a renewables-based future?. Renewable Energy Focus. 2017;19-20(1):129-131.

5. Morales T, Oliva V, Velázquez L. Hydrogen from Renewable Energy in Cuba. Energy Procedia. 2014;57(1):867-876.

6. How much hydro energy could I generate? - Renewables First [Internet]. Renewables First - The Hydro and Wind Company. 2017 [cited 15 August 2017]. Available from: https://www.renewablesfirst.co.uk/hydropower/hydropower-learning-centre/how-much-energy-could-i-generate-from-a-hydro-turbine/

8. Appendix:

years	oil production	imports (unit 1000 tonnes)	electricity production(Gwh)	electricity consumption (GWh)	electricity from biofuel	electricity from oil	electricity from gas	electricity from hydro
1990	3602	2068	15024	11949	1449	13460	24	0
1991	2433	2092	13247	10384	1264	11864	14	0
1992	706	2477	11538	8995	1337	10115	5	81
1993	874	2348	11002	8307	887	10019	14	82
1994	736	2638	11965	8918	897	10978	41	49
1995	664	3143	12459	9133	690	11687	8	74
1996	862	2912	13236	9794	922	12209	10	95
1997	537	3666	14146	10482	870	13133	13	130
1998	416	3449	14146	10583	779	13180	92	97
1999	341	2946	14492	11049	881	12575	933	103
2000	800	2416	15032	11735	944	12692	1307	89
2001	903	1982	15299	11980	930	13036	1258	75
2002	774	1363	15699	12287	939	13431	1223	106
2003	1024	816	15810	12432	720	13351	1611	128
2004	1014	858	15634	12267	789	12886	1871	88
2005	859	1391	15342	12085	420	12917	1937	68
2006	892	1727	16469	12935	406	13736	2233	94
2007	940	1227	17624	13725	413	14594	2493	121
2008	2668	166	17679	13975	554	14440	2537	138
2009	2629	166	17734	14093	535	14657	2381	151

2010	2436	1869	17397	13726	455	14564	2269	97
2011	2322	1378	17760	14026	454	15135	2054	99
2012	2520	1497	18428	14545	551	15652	2092	111
2013	2352	1363	19140	15156	680	16320	1987	127
2014	2428	1553	19366	15392	637	15794	2794	104
2015	2580	1549	19467	15546	635	15675	2754	98
2016	2654	1530	19654	15768	657	15567	2699	101

Current energy mix versus energy mix in 2030:

Technologies	Current installed capacity in MW	GWh produced per year	Installation capacity for 2030 in planning stage in MW	GWh produced per year (values taken from Homer simulation results)	GWh produced in percentage for renewables
Solar	7.1	20.7	1200	3756	9.3%
Wind	11.7	16.5	633	1220	3.0%
Hydropower	58	104.1	117	456	1.1%
Biomass	332	837.5	755	4712	11.7%
Oil fired plants	3105	11738.8	1700	8769	
Gas fired plant	400	2794	2605	21435	
Diesel generators	1300	3855	1000	0	
Total production		18,529.10		40,348	25.1%

Unit Conversion from GWh/ year to kWh/day calculation 1

kWh_{annual}/kW_{peak} = 7,386,427/1100 = 6715   calculation 2