CLIMATE CHANGE ADAPTATION AND MITIGATION IN GALAPAGOS PROGRAMME

Annex: Feasibility Study Report – Component 1

September, 2021

Contents

1 Introduction

The purpose of this document is to support the Funding Proposal with details and more information. This feasibility assessment focuses on the technical aspects of Component 1: Energy matrix change at the Galapagos archipelago. This component seeks to finance the execution of renewable energy generation projects and energy efficiency initiatives and strengthen the capacities of the different stakeholders for the development and implementation of the corresponding activities. The program will create the enabling conditions to accelerate the adoption of a distributed generation scheme among the touristic and commercial sectors.

The role of the feasibility study is to present an assessment of the proposed interventions in terms of the soundness of their technical design, costs and benefits, legal and regulatory environments in which the proposed interventions are expected to be implemented, and other relevant analysis to assess the feasibility of the investment. The feasibility study provides a clear conclusion, with recommendations that explain the underlying logic of the project structure and activities.

This feasibility study relies mostly on primary data sources complemented by secondary sources gathered through meetings with relevant stakeholders and public policy about energy transitions at Ecuador, especially Galapagos Islands. It makes use of existing evaluation reports for previously implemented and ongoing projects, uses proven technologies and solutions with a track record to demonstrate the feasibility of proposed technological solutions and assesses feasible options using existing/available data.

The next chapters describe the technical aspects of the Galapagos power systems, analyze the potential of renewable sources, prioritize the most promising interventions and justify the feasibility of GCF investments in the context of the Generation Expansion Plan for the Galapagos.

2 Reference and Context of Galapagos Power Systems (Base line)

The Galapagos power system consists of four isolated systems, one for each of the inhabited islands of the archipelago. Arranged from large to small size of energy demand these systems are Santa Cruz – Baltra, San Cristobal, Isabela and Floreana. Diesel power plants are the main source of electricity generation; however, the share of renewables in the energy mix has increased during the last years. Table 1 shows current installed power capacities and diesel consumption (2019), at the four Islands.

Table 1. Characteristics of electrical systems

System[1]	Customers 2019 [#]	Peak Load [MW]	Diesel Power installed [MW]	Wind power installed [MW]	Solar Power installed [MW]	Energy Storage [MWh]	Diesel Consumption 2019 [Gal.]
Santa Cruz-Baltra	7770	6.65	13.9 (11 units)	2.25 (3 units)	1.567	4 LA[2] 0.268 LI	2.31 million
San Cristobal	3792	3.39	8.4 (8 units)	2.5 (3 units)	-	-	1.11 million
Isabela	1417	1.37	1.62 (5 units)	-	0.922	0.258 LI	0.383 million
Floreana	94	0.078	0.283 (4 units)	-	0.021	0.19 LA	0.023 million

Source: Authors, based on data from (ELECGALAPAGOS , 2019)

Because each of the islands has its own power system, they are described and analyzed independently.

2.1 Public Energy Policy

The legal framework of the electric sector of Ecuador is given through the Law of Public Service of Electric Power (Registro Oficial Nro 418 , 2015), which establishes the conditions to regulate, plan, control, and manager the public service of electric power to national level, including Galapagos Islands.

[1] Energy Balance 2019, ELECGALAPAGOS

[2] LA: Lead acid battery; LI: Lithium-ion battery

The law establishes in article 26. that the Government, through its sectoral ministry, will promote the use of clean technologies and alternative energies, in accordance with what is stated in the Constitution that proposes to develop a sustainable electricity system, based on the use of the renewable energy resources. The electricity produced with this type of energy will have preferential conditions established by regulation issued by the regulatory and control agency.

The Electricity Master Plan, PME will be mandatory, it is the responsibility of the Rector Ministry in energy policy to develop and execute the plan in accordance with the studied demand needs.

In compliance with what the Law establishes, the Electricity Master Plan is updated and published every two years, in the latest version are the projects that are analyzed in a period of 10 years between 2018 and 2027, same as according to what it establishes the law are mandatory.

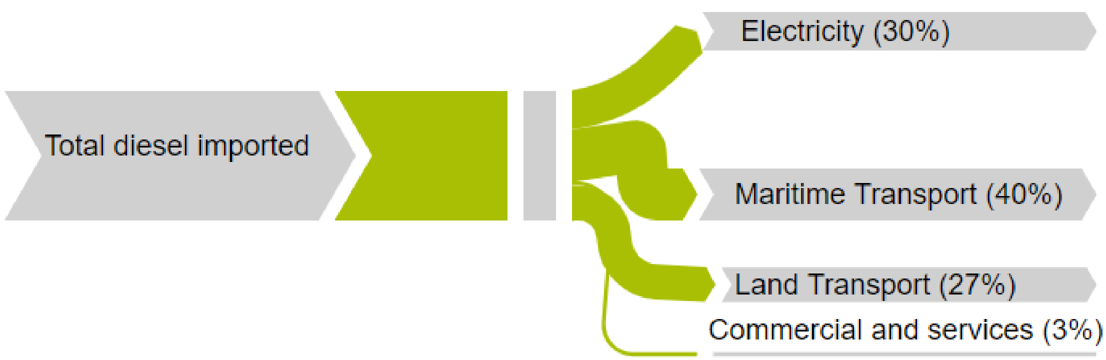
Article 74 establishes that energy efficiency will be promoted in the economy and in society in general, and in the electrical system, with plans and projects. These projects will seek greater efficiency in the use of energy sources and in the use of electrical energy by consumers or end users.

Additionally, regulations and secondary regulations have been developed that establish the preferential conditions for incorporating projects that take advantage of renewable sources, such as regulation 03/18 (ARCONEL , 2018), for distributed generation.

2.2 Historical Diesel Consumption.

Annually, about 11.6 million gallons of diesel are imported to the islands (IIGE, 2019), of which consumption for electricity generation corresponds to 30% of the total consumed, the remainder being distributed to land and maritime transport, in addition to other uses in the commercial sector and tourist.

Figure 1. Sankey Diagram of total diesel consumption by sector.

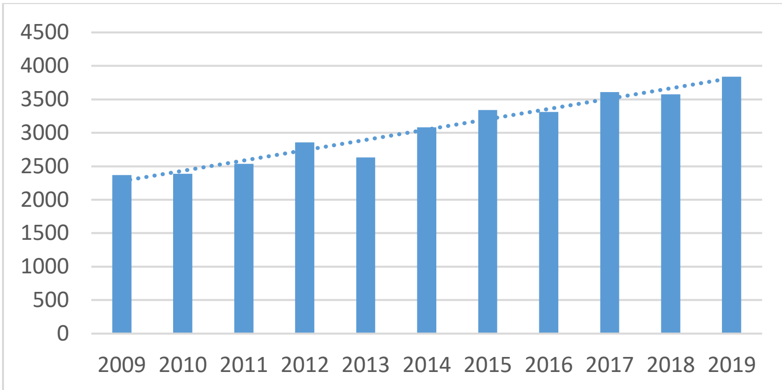


Source: Authors, based on data from (IIGE, 2019)

As shown in the previous Figure, electricity generation is the second highest diesel consumption in the Islands, and the one with the greatest reduction opportunities due to the incorporation of renewable generation.

Real diesel consumption for electricity generation has shown an average annual increase rate of 5%, the next figure shows the behaviour of consumption in generation plants in the last 10 years.

Figure 2. Historical diesel consumption in electricity generation (Thousand Gallons)



Source: Authors, based on data from (IIGE, 2019)

2.2.1. GHG emissions due to diesel consumption (historical).

La emisión de GEI, en el sector eléctrico se da principalmente por el consumo de combustible fósil (Diesel) en la combustión estacionaria de la industria de la energía.

A constant growth of greenhouse gases emitted by this stationary combustion of diesel for energy industries is observed (Figure 2). The emission baseline corresponds to the annual diesel consumption and is calculated by applying Tier 1 IPCC 2006 emission factors[3] and global warming potentials for CH_4 and N_2O obtained from the fifth IPCC report.

Table 2. GHG electrical system emissions by historical Diesel consumption.

GEI	Value
CO_2 Diesel EF	74,100 [KgCO_2/TJ]
CH_4 Diesel EF	3 [KgCH_4/TJ]
N_2O Diesel EF	0.6 [KgN_2O/TJ]

Source: (IPCC, 2006)

[3] Default emission factor (Chapter 2. IPCC Stationary combustion)

Table 3. Global warming potentials (100 years)

GEI	Value
CO_2	1
CH_4	24
N_2O	265

Source: (IPCC, 2014)

Applying these emission factors, with the annual diesel consumption, emissions are calculated from the carbon footprint that the energy transformation emits. The following table shows the annual GHG values resulting from diesel consumption.

Table 4. GHG electrical system emissions by historical Diesel consumption.

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Historical Diesel Consumption [Million Gallons]	2.07	2.21	2.37	2.39	2.54	2.85	2.63	3.08	3.34	3.31	3.61	3.57	3.83
Emissions by Diesel consumption [ktonCO2 eq.]	31,79	33,89	36,40	36,63	38,94	43,84	40,40	47,32	51,32	50,83	55,43	54,90	58,84

Source: Authors, based on data from (ELECGALAPAGOS , 2020)

The trend scenario for GHG emissions shows the behaviour of the system about diesel consumption for generation, in 2019 this value reached 58,84 kTons of CO_2 equivalent.

Emissions reduction has been achieved from 2007, due to the renewable power plants in operation, in addition to the optimization of diesel gensets (replacement by new thermal generators). These variables (renewable energy and replacement of thermal generators) have caused fuel consumption to be reduced from the expected value. The participation of each of these variables in reducing fuel consumption is shown below.

Historical Renewable energy generation

The incorporation of renewable energy projects has caused a displacement of fuels since 2007. The following Table shows the renewable generation per year and the displacement of diesel use.

Table 5. Renewable energy production and diesel mitigation

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Renewable Energy Production [MWh]	2.07	2.21	2.37	2.39	2.54	2.85	2.63	3.08	3.34	3.31	3.61	3.57	3.83
Reduced fuel [Million Gallons]	0.08	0.22	0.27	0,28	0.27	0.19	0.26	0.40	0.63	0.71	0.67	0.68	0.85

Source: Authors, based on data from (ELECGALAPAGOS , 2020)

Energy efficiency thermal generation

Since 2011, with the replacement of Diesel thermal groups, the energy efficiency per gallon of fuel has represented an optimization of the use of this fuel, the following table shows the best percentage in relation to the base year (2007), and it indicates the amount of fuel left to use due to this improvement in electricity generation.

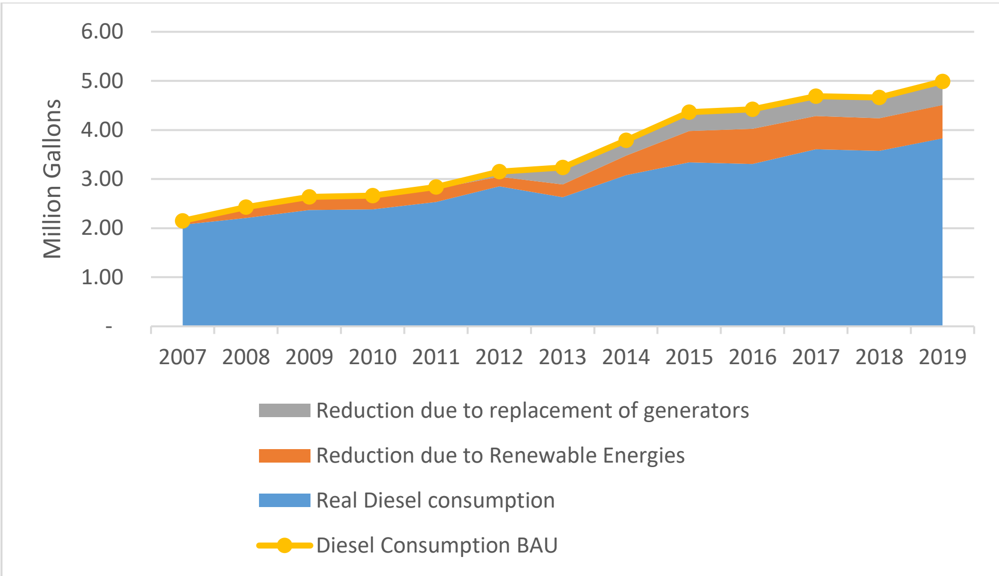
Table 6. Performance improvement of Thermal generation

	2011	2012	2013	2014	2015	2016	2017	2018	2019
Performance improvement (Thermal generation) [%]	1%	3%	12%	9%	10%	10%	10%	10%	10%
Yield per unit of fuel [kWh/gallon]	12.57	12.83	13.87	13.50	13.61	13.62	13.63	13.66	13.70
Reduced fuel [Million Gallons]	0.04	0.10	0.34	0.31	0.38	0.40	0.41	0.42	0.48

Source: Authors, based on data from (ELECGALAPAGOS , 2020)

From these information, next Figure shows the scenarios, Mitigation due to improve energy efficiency thermal generations and mitigation due to renewable energy incorporation plants.

Figure 3. Historical Diesel consumption and reduction scenarios

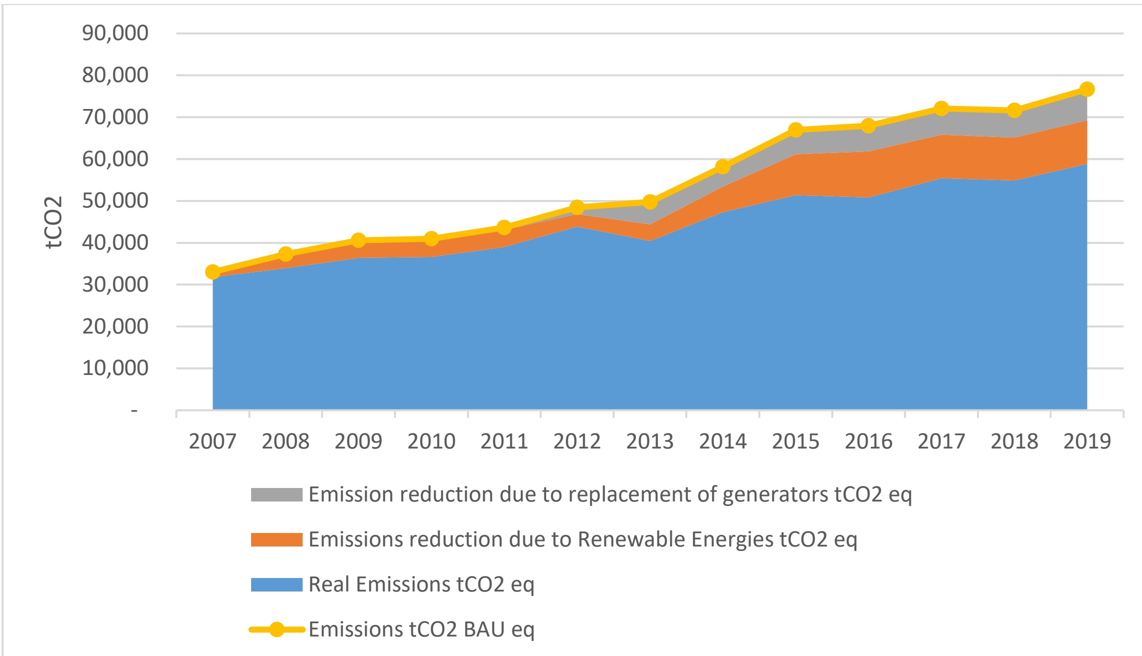


Source: Authors, based on data from (ELECGALAPAGOS , 2020)

Between 2007 and 2019, the generation of renewable energy and increased efficiency in the Diesel gensets, has mitigated 78,452 Tons of CO_2 equivalent[4].

[4] Sum of the reduction due to improved efficiency in thermal generators and renewable generation.

Figure 4. Historical Emissions scenarios



Source: Authors, based on data from (ELECGALAPAGOS , 2020)

2.3 Emissions due to transport from mainland

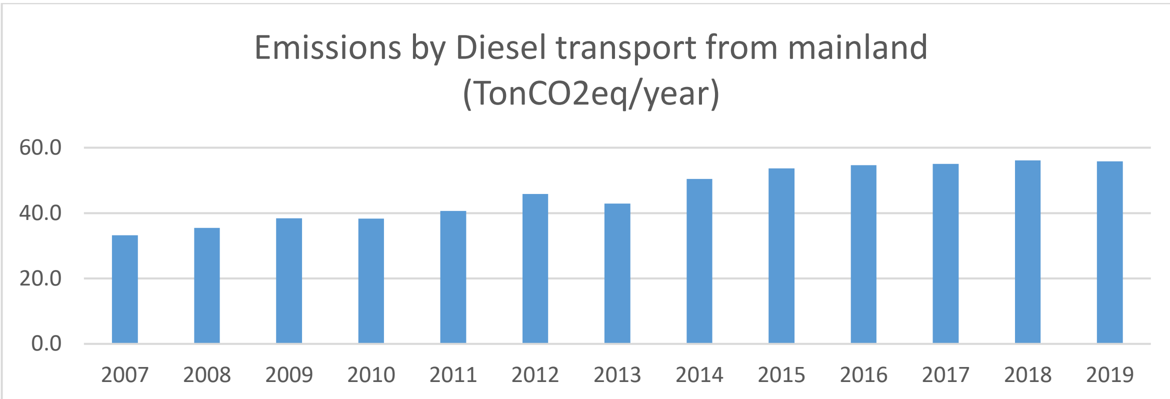
The emissions due to the transportation of fuel from the mainland, it constitutes a GHG emission from the use of Diesel. Additional risk of spillage that constitutes the transportation of fuel, emits greenhouse gases in an increasing proportion according to the need for fuel in the Islands.

In accordance with the Guidelines for Measuring and Managing CO2 Emission from Freight Transport Operations (ECTA CEFIC , 2011), the emissions have been calculated from maritime transport fuel to the islands. PUNA ship transports fuel to the islands, which transports 2,400 tons of Diesel [5].

[5] Deep-sea tanker EF: 5 gCO_2/tonne*km (Table 10. Recommended Average Emission Factors)

The following figure shows the trend of annual emissions from this transport.

Figure 5. Emissions by Diesel transport from mainland

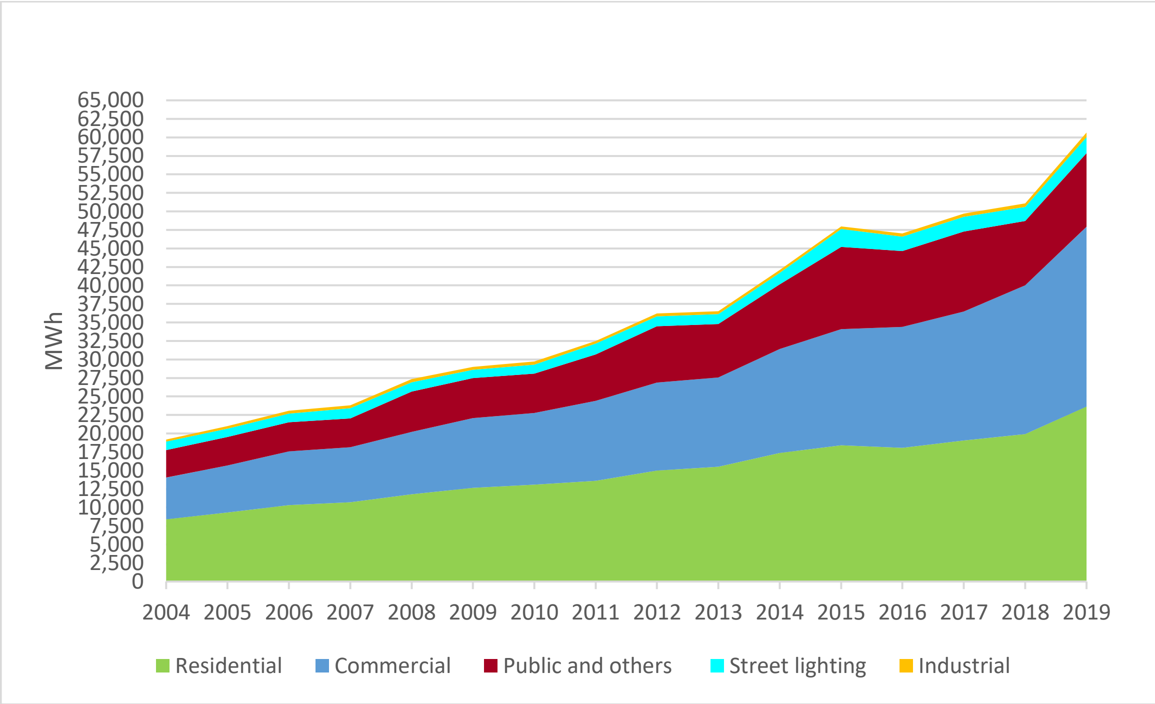


Source: Authors, based on data from (ELECGALAPAGOS , 2020)

2.4 Electricity Demand[6]

As the variable responsible for the constant increase in diesel consumption, electricity demand has been growing over the years, mainly driven by the entry of tourists who consume a larger amount of electricity, the historical evolution of the demand can be visualized in the following graph.

Figure 6. Historical Demand by sectors (MWh/year)



Source: ELECGALAPAGOS, 2019

Historical demand by sector shows how the commercial sector's demand has increased in the last years, being the main source for the growing total demand; table below shows electricity demand share by sector (2019).

[6] (ELECGALAPAGOS , 2019)

Table 7. Demand by sector

Residential	Commercial	Industrial	Street lighting	Public and others
39%	41%	2%	3%	15%

Source: ELECGALAPAGOS, 2019

Commercial sector (including all of the tourist facilities) is the main component of the electricity demand on all the islands and responsible for 41% of total electricity consumed, followed by the residential sector that consumes 39%.

The electricity demand evolution during the 2007-2019 period shows an annual cumulative growth rate of 7.4%, that is linked to the commercial and tourism growth of the islands at this period. The effect of COVID 19 has caused a decrease in demand due to the reduction in tourists from March 2020. The forecast of demand has a particular behavior for the year 2021, where mobility restrictions continue due to the pandemic. For later from 2023 and according to the control projections of COVID 19, the normal rate of tourist entry would resume, so the electricity demand would continue in the growing trend. These considerations are applied in the demand modeling indicated in the next section.

2.5 Forecast of the Energy Demand[7]

The forecast of the electricity demand considers a multivariable analysis, considering the variables that have correlation with respect to the historical values of the energy demand. The forecast of the demand uses historical data of variables that are more correlated, this mathematical model is defined by:

$$Y_{t+1} = a_1 X_1 + a_2 X_2 + \cdots + a_n X_n + k$$

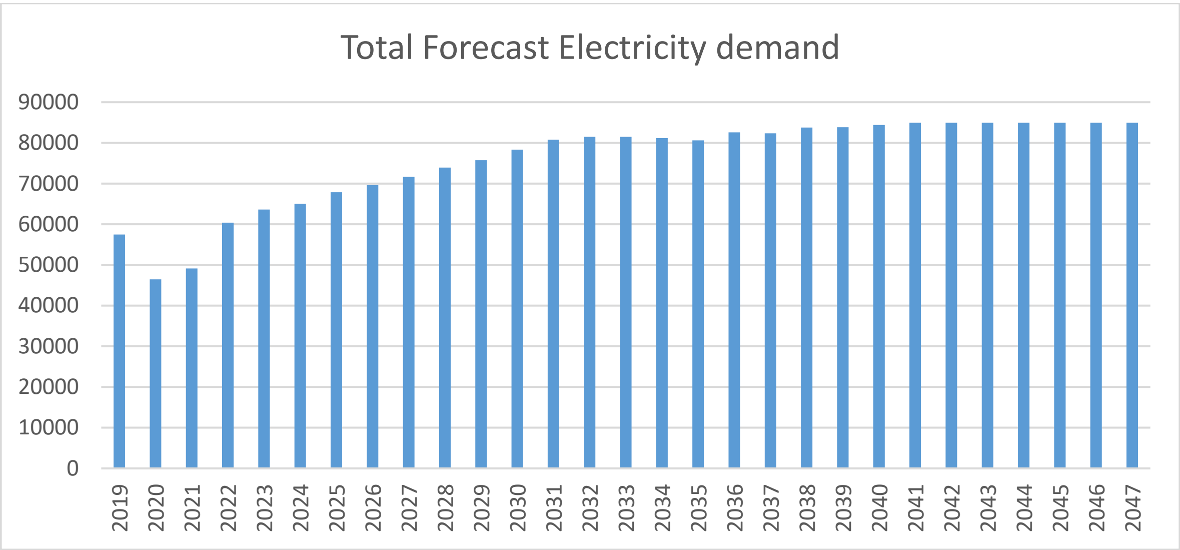
Where:

X_n =Independent variables: Number of customers per island, Population by Island, temperature, total tourist income, tourist income on land.

[7] Forecast of the Demand 2018 – 2027

Y= demand curve forecast

Figure 7. Forecast Electricity Demand (MWh/year)



The above figure shows a 20% reduction in demand for 2020, recovering by an additional 6% by 2021, and finally resumes the trend in 2023.

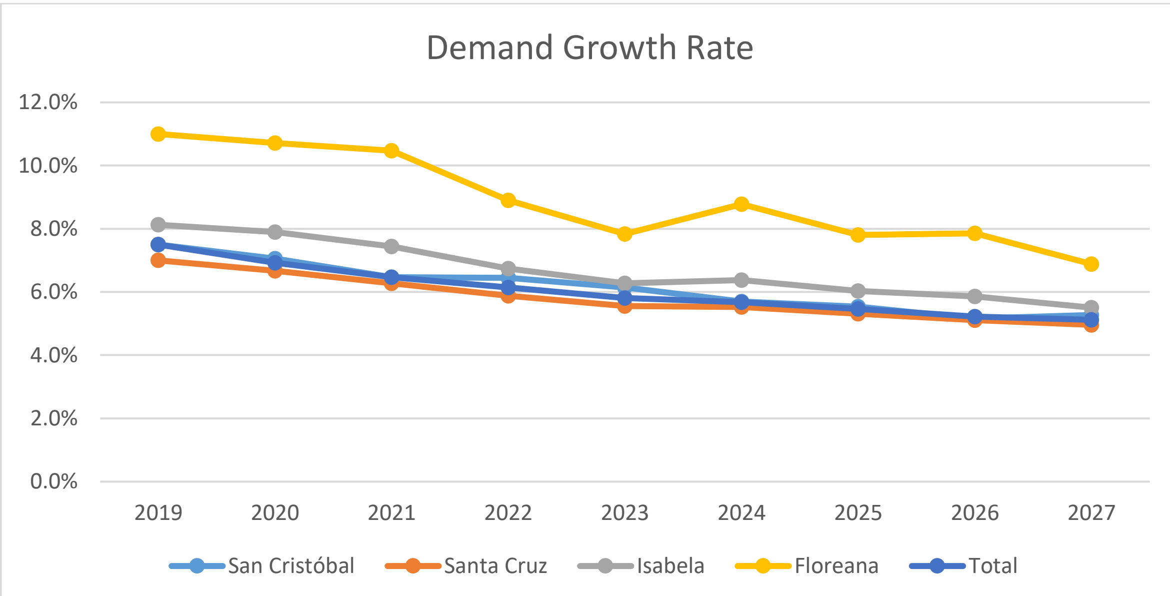
At normal conditions, each island has a specific growth rate, Floreana has the highest rate with 10.33%, because it considers recycling and desalination plants, followed by Isabela because it is planning to install a new slaughterhouse and waste treatment plants. Table 4 shows the average growth rate 2018-2027 for each of the islands and a total value.

Table 8. Growth rate 2018-2027

	San Cristóbal	Santa Cruz	Isabela	Floreana	Total
Growth rate 2018-2027	6.58%	5.87%	7.09%	10.33%	6.76%

As a result of energy forecast, the values of accumulated annual growth rates of each island were obtained considering the growth formula and the correlation of the variables that influence its growth.

Figure 8. Growth Rate Forecast

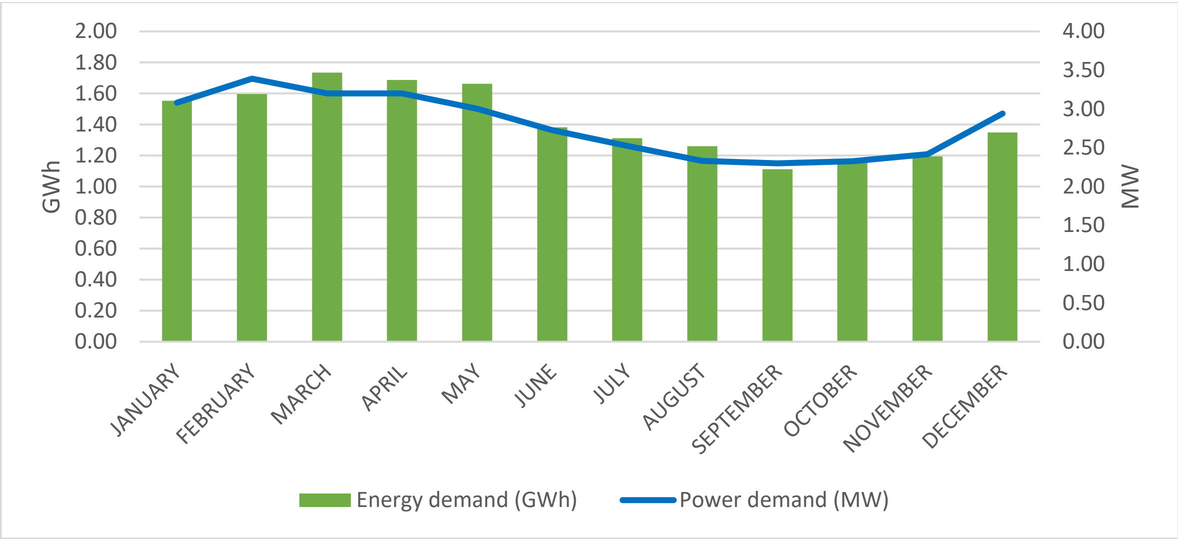


Source: ELECGALAPAGOS, 2018

2.6 Monthly demand variation

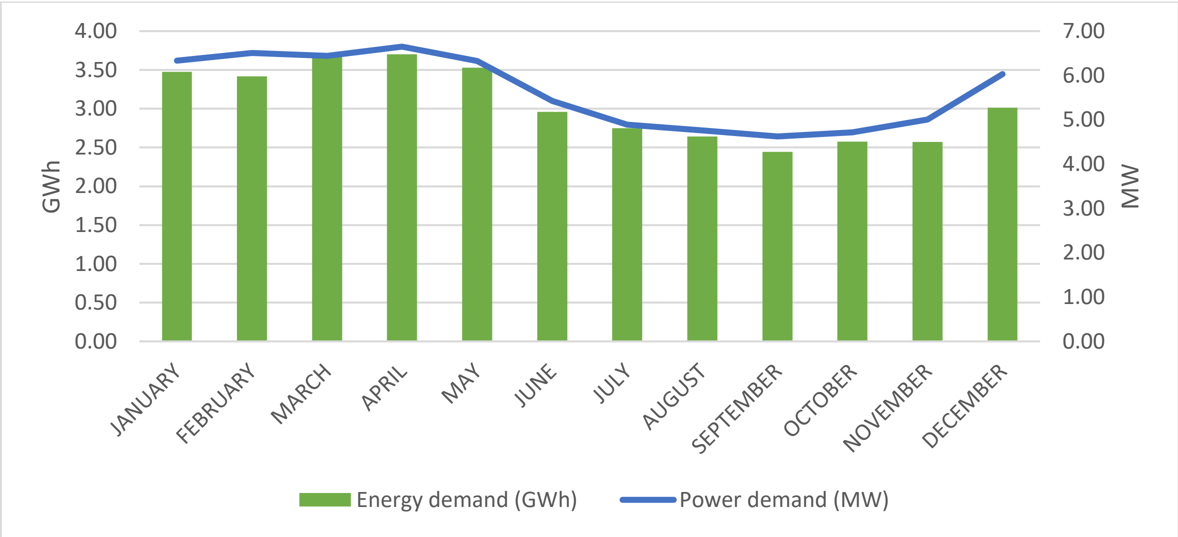
This behavior of the demand comes along with the climate conditions that mark two different seasons at the islands, a warm one between December and May, and a cold one between June and November. According to the generation-collected data, during the warm months (peak demand) the wind resources are minimum, and maximum in cold months. The contrary occurs with the solar resource although the variations are not as drastic as the wind speed.

Figure 9. Energy and Power Demand San Cristobal (2019)



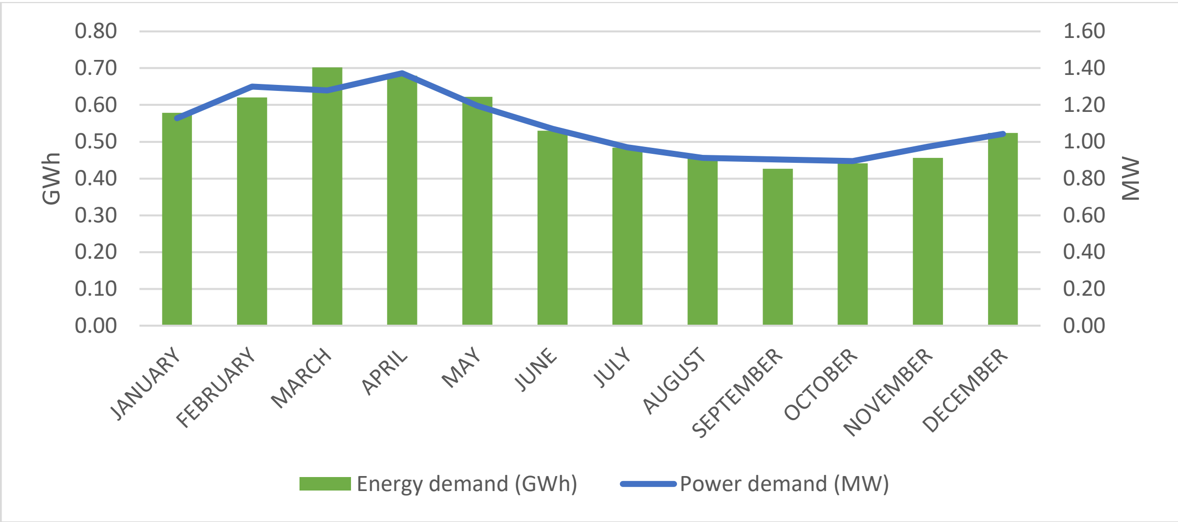
Source: ELECGALAPAGOS, 2019

Figure 10. Energy and Power Demand Santa Cruz Baltra (2019)



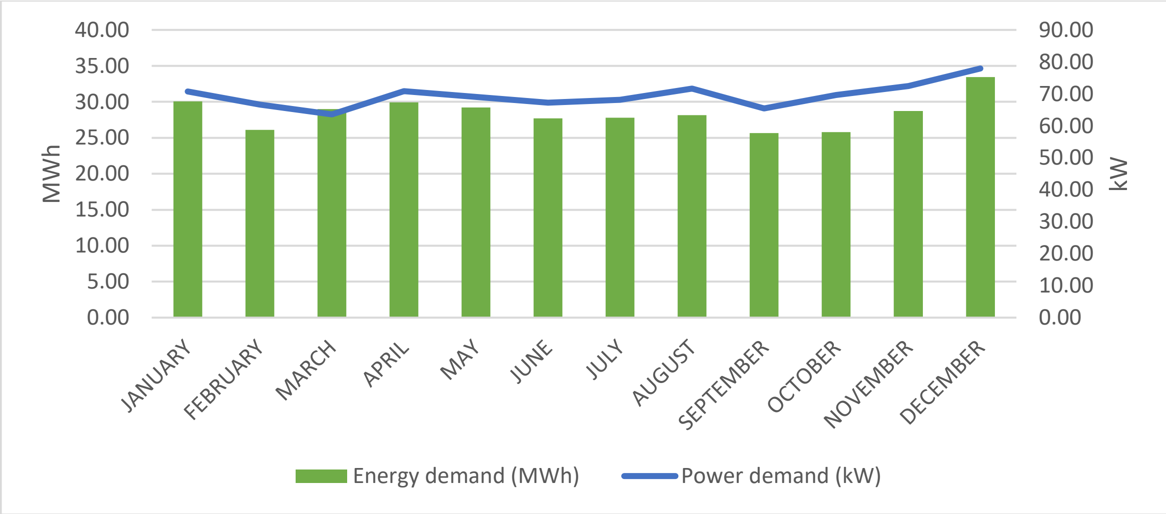
Source: ELECGALAPAGOS, 2019

Figure 11. Energy and Power Demand Isabela (2019)



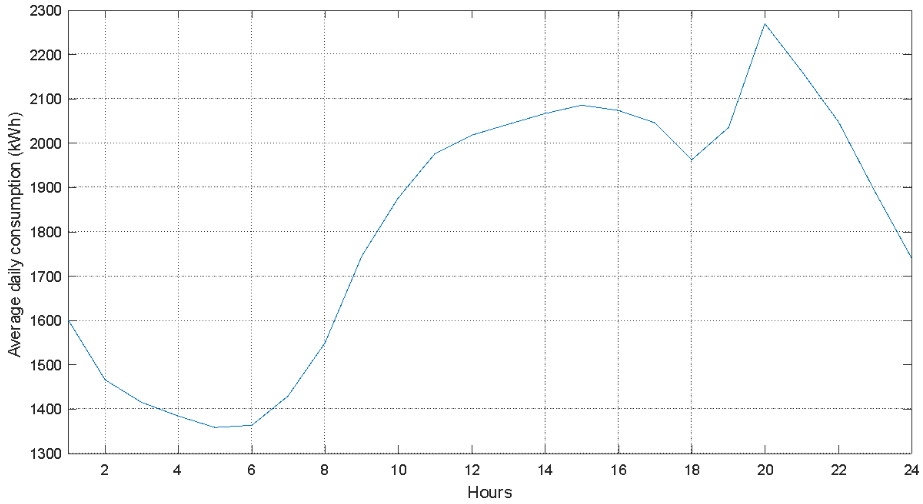
Source: ELECGALAPAGOS, 2019

Figure 12. Energy and Power Demand Floreana (2019)



Following figures show average hourly demand for each island. A similar trend can be seen, where demand valleys begin around 1:00 AM and two peaks, first one at 2:00 PM and highest at 20:00 PM, with a sharp rise of the energy consumption around 18h.

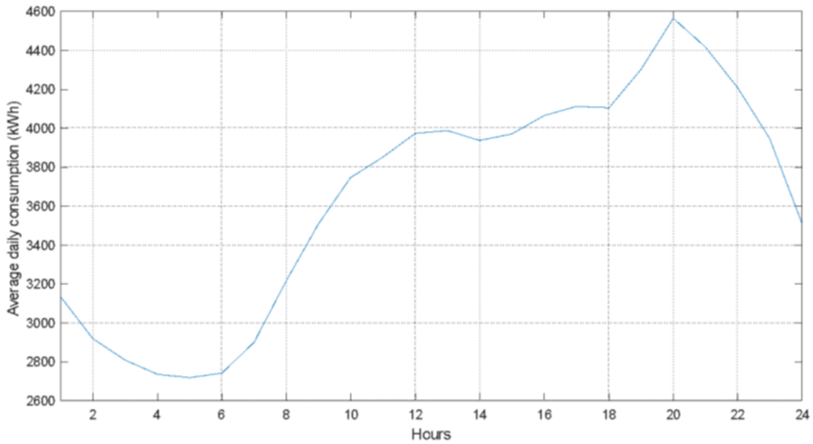
Figure 13. Average Hourly Power Demand - San Cristobal



Source: ELECGALAPAGOS, 2018

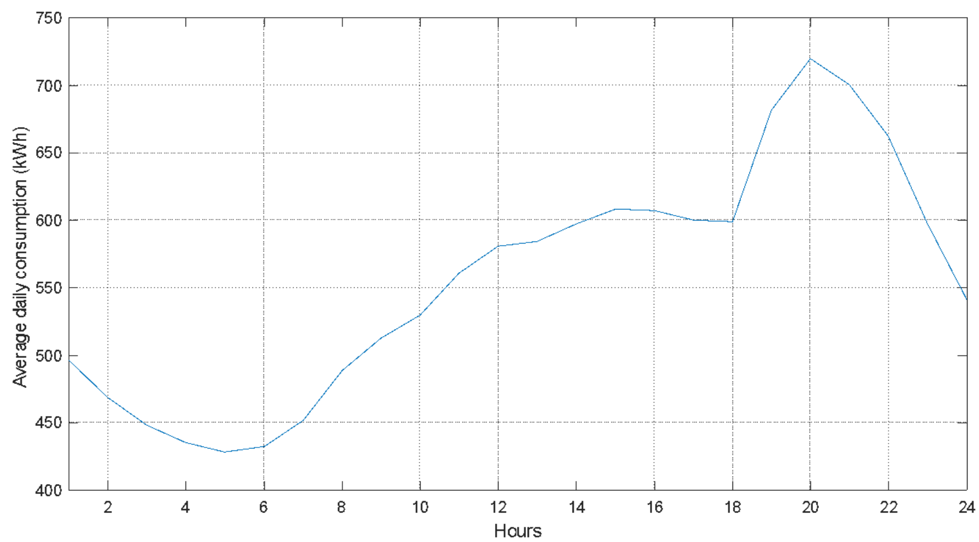
Figure 12.

Figure 14. Average Hourly Power Demand - Santa Cruz



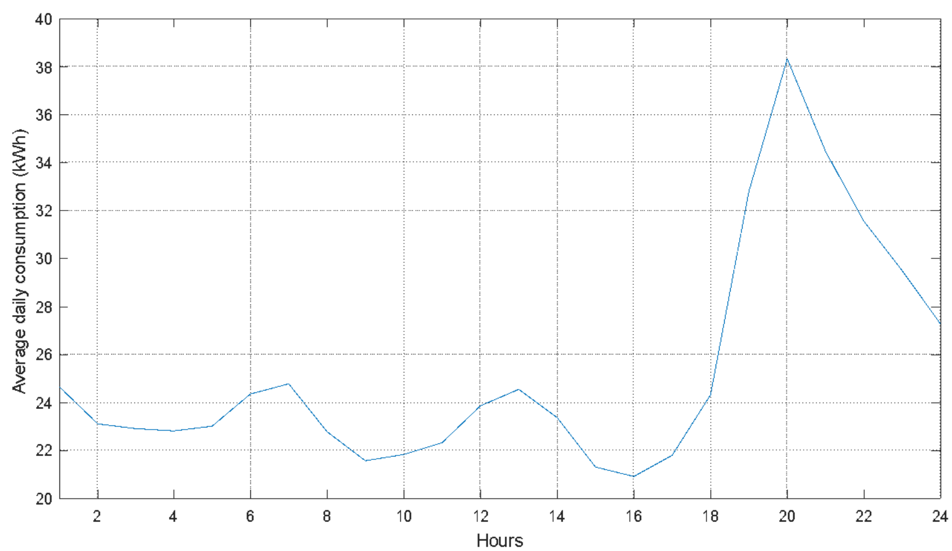
Source: ELECGALAPAGOS, 2018

Figure 15. Average Hourly Power Demand - Isabela



Source: ELECGALAPAGOS, 2018

Figure 16. Average Hourly Power Demand - Floreana



Source: ELECGALAPAGOS, 2018

The peak demand at noon shows the possibility of the demand curve being flattened by distributed photovoltaic generation without storage connected directly to grid.

3 Detailed Galapagos Islands Electrical System

3.1 San Cristobal Electrical System (2019)

San Cristobal power generation system consists of one diesel power plant, one wind farm and one solar photovoltaic with energy storage system.

The diesel power plant comprises six diesel generators with an installed capacity of 6.2 MW. The specifications of these units are shown in the next table.

For the fuel storage, the diesel power plant has six 10000-gallon tanks and two 3000-gallon tanks.

Table 9. Diesel Generators

Unit No.	Manufacture Year	Engine Manufacturer	Generator Manufacturer	Power Rating (kW)	Effective Output (kW)	Generators efficiency (kWh/Gal)
1	1991	CATERPILLAR	CATERPILLAR	650	560	12.88
3	1993	CATERPILLAR	CATERPILLAR	650	560	
4	1993	CATERPILLAR	CATERPILLAR	650	560	
6	2014	MTU	MagnaMax	900	760	
7	2015	SKL (MTU)	AEM	1670	1500	
8	2015	SKL (MTU)	AEM	1670	1500	
TOTAL						

Source: (ELECGALAPAGOS , 2019)

The wind farm, located in El Tropezon hill in El Progreso area, is comprised of three 800 kW wind turbines with the following characteristics:

Table 10. Characteristics of wind turbines

Generator	Output Voltage	Rated Power	Rotor Diameter	Tower Height	Cut-in Speed	Cut-out Speed
Synchronous	500 – 1000 Vac	800 kW	59 m	51 m	3.5 m/s	25 m/s

Source: ELECGALAPAGOS, 2019

In 2019, this wind farm supplied 2.3 GWh that accounts for a renewable energy penetration of 13.5%.

There is also a small 12.5 kWp solar plant, with a marginal participation that reaches around the 0.10% of the energy mix.

Currently, a new photovoltaic plant will come into operation with the following detail:

Table 11. Characteristics of New PV and ESS plant

PV capacity (MW)	Energy Storage System Capacity (MWh)
1,00	2,2

Source: ELECGALAPAGOS, 2019

3.2 Santa Cruz – Baltra Electrical System (2019)

Santa Cruz – Baltra power system includes electrical facilities located in Puerto Ayora city and Baltra island, connected by a sub-transmission line at 34.5 kV and with 10 MVA capacity. A diesel power plant located in Puerto Ayora consists of eleven generators with an installed capacity of 13.9 MW. Next table shows the specifications of these units. For fuel storage, the diesel power plant contains four 10000 gallons tanks, two 5000 gallons tanks and two 3000 gallons tanks.

Table 12. Diesel generators

Unit No.	Manufacture Year	Engine Manufacturer	Generator Manufacturer	Power Rating (kW)	Effective Output (kW)	Generators efficiency (kWh/Gal)
1	1990	CATERPILLAR	CATERPILLAR	650	550	14.10
3	1990	CATERPILLAR	CATERPILLAR	650	540	
4	1990	CATERPILLAR	CATERPILLAR	650	540	
5	1990	CATERPILLAR	CATERPILLAR	1100	880	
6	1990	CATERPILLAR	CATERPILLAR	650	540	
8	2011	HYUNDAI	HYUNDAI	1700	1400	
9	2011	HYUNDAI	HYUNDAI	1700	1400	
10	2011	HYUNDAI	HYUNDAI	1700	1400	
11	2011	HYUNDAI	HYUNDAI	1700	1400	
12	2011	HYUNDAI	HYUNDAI	1700	1400	
13	2011	HYUNDAI	HYUNDAI	1700	1400	
TOTAL				**13,900.0**	**11,450.0**	

Source: ELECGALAPAGOS, 2019

A 1.5 MWp solar PV power plant also operates in Puerto Ayora; it is located at the southwestern part of the urban area. In 2019, this power plant contributed with 5.75 % of the total power generation in Santa Cruz – Baltra.

Table 13. Characteristics of the solar PV power plan

Panels	Area	Efficiency @STC
6006 ea.	1.46 m^2	15%

Source: ELECGALAPAGOS, 2019

A 2.25 MW wind farm operates in the north area of the Baltra Island, closed to the airport; it delivers its power to Balta substation, which connects to the Santa Cruz island by the sub-transmission line. This farm consists of three wind turbines and its share in the energy mix in 2019 was of 8.64%

Table 14. Characteristics of wind turbines

Generator	Inverter type	Output Voltage	Rated Power	Rotor Diameter	Tower Height
PM Synchronous	Full Converter	690 Vac	750 kW	57 m	50 m

Source: ELECGALAPAGOS, 2019

Finally, a Battery Energy Storage System made of 500kW/268 kWh lithium-ion batteries and 500kW/4000 kWh lead-acid batteries operates together with a PV plant of 67 kWp in Baltra. This system smooths wind-power fluctuations and performs peak shaving.

This two-islands interconnected electrical system supplied in 2019 energy to a demand of 36.77 GWh, from which 14.4% was provided by renewable sources.

3.3 Isabela Electrical System (2019)

In September 2018, a hybrid power plant replaced the old diesel power plant in Isabela island. This hybrid system consists of a solar PV plant, a dual fuel power plant (jatropha oil - diesel) and a 833kW/333kWh lithium-ion energy storage system. Next table lists the main characteristics of this power plants.

Table 15. Characteristics of Isabela Hybrid System

System	Units		Transformers	Busbar
Solar PV Plant	2 units 458 kWp	2 Inverters 500 kVA	1 Transformer 3 winding 1000/500/500 kVA 13.8kV/270/270V	13.8 kV

Dual Fuel Power Plant Diesel – Jatropha Oil	5 generators 325kW – 480V	Busbar 480V	2 transformers 1000 kVA 13.8kV/480V	

Source: ELECGALAPAGOS, 2018

This power system provided electricity to an annual demand of 6.7 GWh in 2019, where the share of the PV plant was of 22.9%. This hybrid system came with a totally automated control and dispatch system, therefore with limited intervention of a human operator and with the capacity of diesel off operation.

3.4 Floreana Electrical System (2019)

The generation system consists of a dual fuel power plant, a photovoltaic solar plant and some isolated PV systems that generate a 1.5% of the total generation.

The dual fuel power plant contains two diesel generators with an installed power of 145 kW, and two dual fuel generators (diesel – Jatropha oil) with an installed capacity of 138 kW. For fuel storage, the dual fuel power plant has three 3000-gallon tanks and one 100-gallon tank.

Table 16. Diesel and dual generators

Unit No.	Year of Manufacture	Engine Manufacturer	Generator Manufacturer	Power Rating (kW)	Generators efficiency (kWh/Gal)
1	2010	DEUTZ	LEROY SOMER	69	9.9
2	2010	DEUTZ	LEROY SOMER	69	
3	2011	HYUNDAI	BOKUK	45	
4	2010	DOSSAN	BOKUK	100	
TOTAL				283	

Source: ELECGALAPAGOS, 2019

The Solar PV plant has an installed capacity of 21 kWp and is integrated to a 36 kW/192 kWh energy storage system.

Table 17. Characteristic of solar PV plant

Panels	Power @STC	Area
210 ea.	100 W ± 10%	0.857 m^2

Source: ELECGALAPAGOS, 2019

This power system supplied electricity to an annual demand of 0.34 GWh, with a renewable energy penetration of 7.4%.

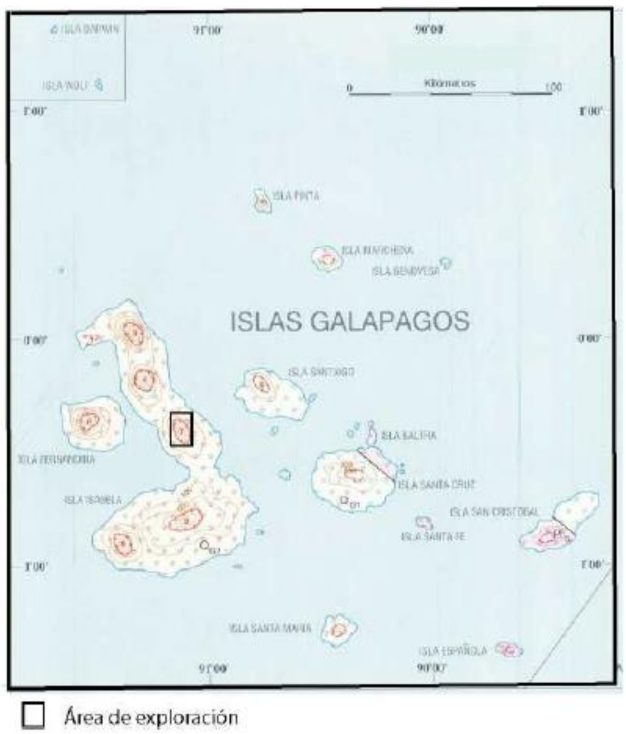
4 Potential of renewable resources

The estimate of available renewable resources on the Galapagos Islands was completed using a baseline of data measured during recent years at power stations using renewable energy sources. In addition, the potential of renewable resources available for the generation of electricity is analyzed. In each of the electrical systems of the four Islands, both wind and solar resources have been studied based on measurements from the meteorological stations installed in each power generation plant, and data from satellite images and correlation of data in stations located on the islands

The analysis of the potential of available renewable resources is essential for correct local energy planning. In order to carry out the analysis of wind potential for electricity generation purposes, the various factors that influence its determination have been taken into account, which are influenced by the environmental and atmospheric conditions present at the analysis site. (IIGE, 2018)

Although other sources of renewable energy have been analyzed, such as geothermal, there are no explorations of feasibility. Studies show that the availability of resources per island may not coincide with the demand for each of them. For geothermal energy, there would be a high potential on Isabela Island (MEER, 2010). Geothermal potential does not respond to the greater demand present on Santa Cruz Island. The interconnection between islands would consider an affectation to the seabed. The currently available resources must be analyzed for each island, except for the Baltra Santa Cruz system, which due to its proximity are interconnected.

Figure 17. Geothermal explorations



Source: (MEER, 2010)

In the case of the analysis of the photovoltaic potential, the radiation levels and average temperatures are taken into consideration. The performance that the PV systems would have under operating conditions is analyzed with the identification of the environmental conditions of the areas of interest.

In accordance with international norms, the measurement of wind speed should be taken at a minimum of 10 meters. The measurement of wind speed in the Baltra and Santa Cruz wind farms is recorded at over 30 meters, and the results in this study come from 50 meters. Data was collected by ELECGALAPGOS since wind farm and PV plant start operations.

The variations in wind speed are more unpredictable and variable than the variations in solar radiation. The curves and tendencies of solar radiation do not vary at the site of measurement, while wind speed and direction vary at every site, depending on the geography. therefore, the results of the wind analysis present in the atlas and multi-criteria evaluation are contrasted with the data taken from the project sites.

As mentioned in climatic rationality, on the Galapagos Islands, there are two primary seasons. December to May is dry with little cloud cover, thereby with high solar energy but a reduction in wind resources. The other season runs June to November and is rainy with an increase in wind velocity in mountain zones. Due to the rain and cloud cover, there is less solar energy available in this time.

4.1 Wind resources

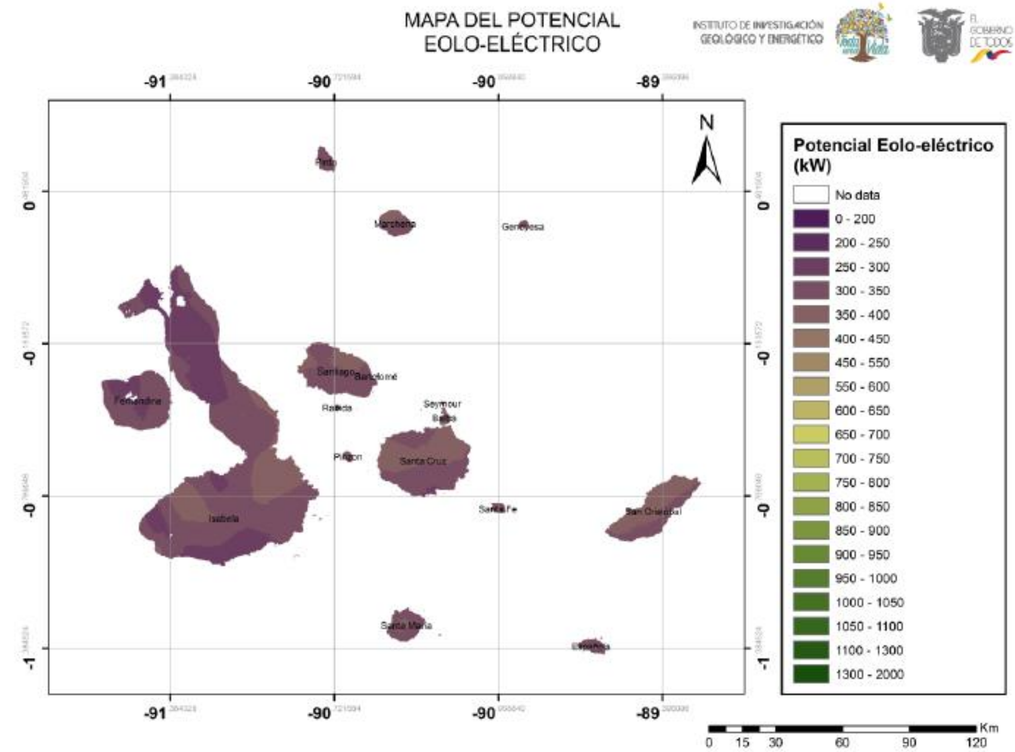
Each island having its own microclimate, wind velocity and solar radiation are primarily governed by the two overarching seasons on the islands. In the dry season, the San Cristobal wind farm experiences a decrease in average wind speed, and starting in May, sees an increase in the wind speed. The monthly averages fluctuated between 4.5 and 9 m/s, which decreased to 8 m/s. The average hourly wind speed of each month also exhibits a pattern.

For the study of the wind electric potential, the following variables were used, with a spatial resolution of 200*200 m^2:

- Average annual temperature map (WorldClim)
- Maps of wind speed correlated direct measurements (National Wind Atlas)
- Power curves of wind turbines installed in Baltra
- Factors of operations present in current wind farms
- Atmospheric pressure and estimated air density.

The electricity generation potential is determined through the availability of wind resources, the wind energy potential in each of the islands is indicated below:

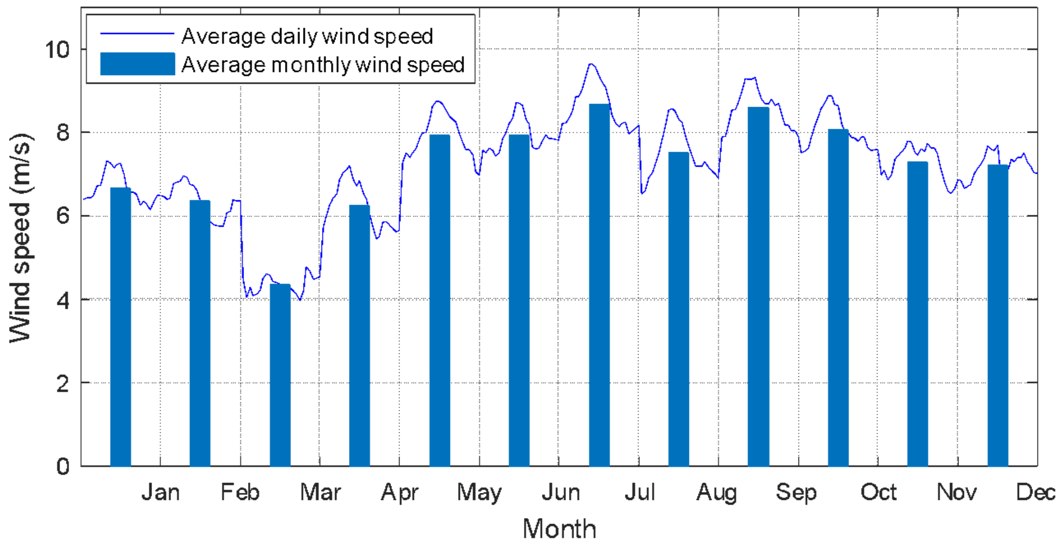
Figure 18. Wind electric potential



Source: (IIGE, 2018)

For the islands where there are installed wind generation projects, the present speed averages are shown; these data have served to develop the correlation of information to determine the global generation potential.

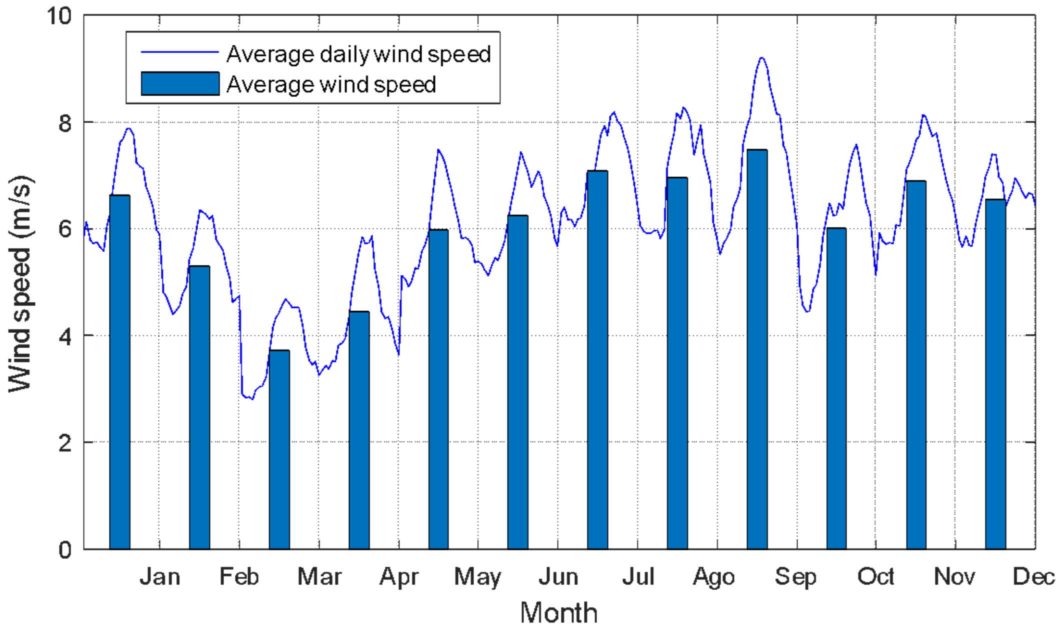
Figure 19. Average wind speed of each month – San Cristóbal



Source: (ELECGALAPAGOS , 2018)

In the case of the Baltra wind farm, the monthly averages closely follow the previously indicated trends, with minimum wind speeds around February and maximum wind speeds in August.

Figure 20. Average wind speed of each month - Baltra



Source: (ELECGALAPAGOS , 2018)

By examining the average values, the highest wind speeds occur on the island of San Cristobal. This is primarily due to the island's position as the easternmost island of the Galapagos and as the recipient of winds coming from the Southern Cone. Another factor that results in San Cristobal having the highest wind speeds is the elevated position of the island's wind farm.

4.2 Solar Energy

The intensity of solar radiation follows the same pattern; independent of the place where the irradiance is measured, maximum solar energy occurs around noon. Concerning solar energy and temperatures, one can refer to what was previously explained about dry and rainy seasons on the Galapagos.

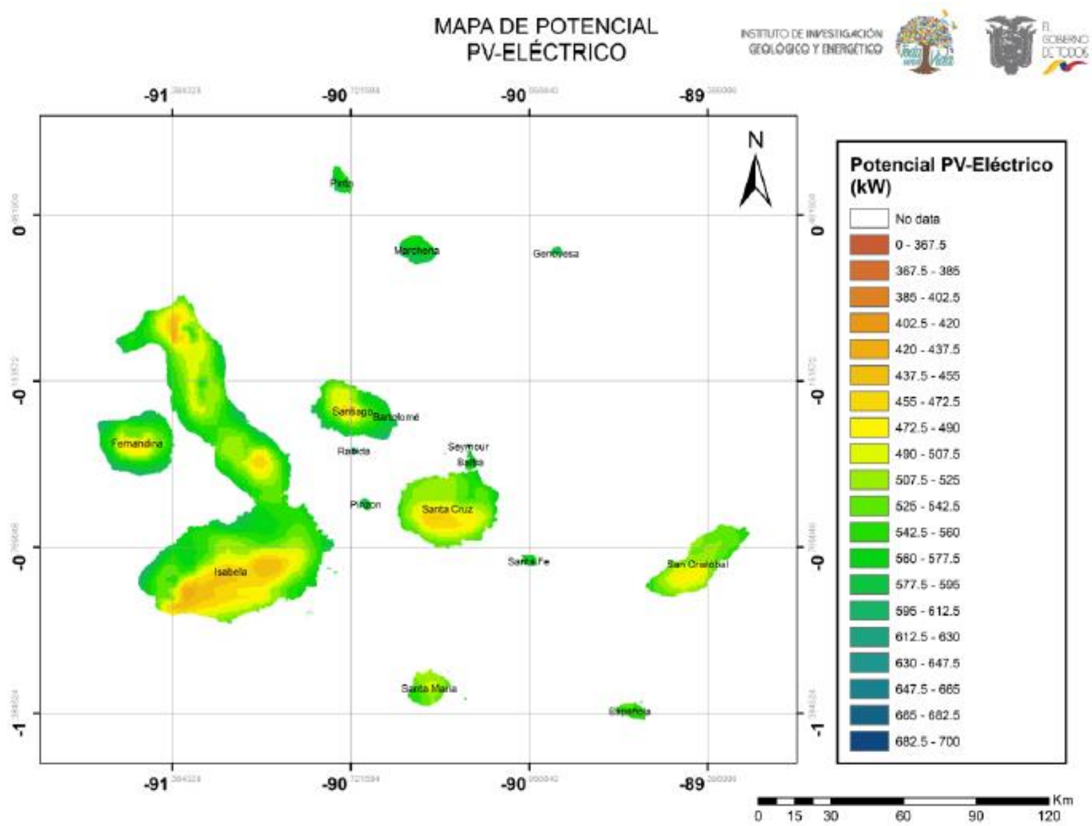
For the analysis of the electrical PV potential, the following variables are considered:

- Annual horizontal global settlement and

- Climatic conditions (temperature)

With this, the operating power of a typical 2.1 MW park is determined for one year, after which the electricity generation of the park is determined under the present temperature conditions, and the performance of the panels exposed to the determined conditions, the electrical PV potential per island is indicated in the following Figure:

Figure 21. Electric PV potential

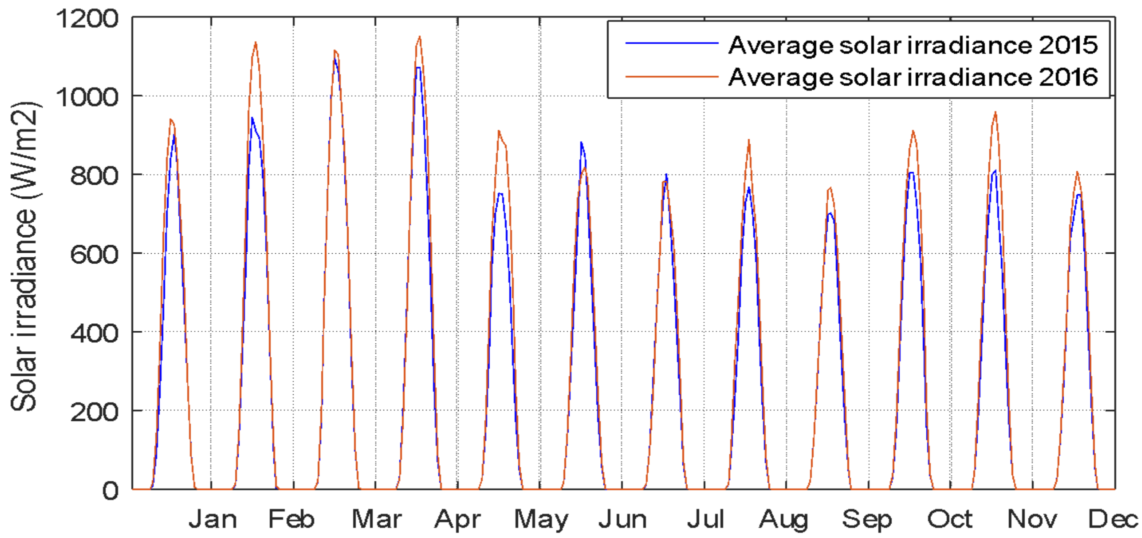


Source: (IIGE, 2018)

So, solar energy will be more efficient in coastal zones, meaning in the Galapagos, urban areas. Marine breezes help to remove clouds along the coastlines, allowing these to be the areas with the highest clarity index.

This observation is based upon the values of solar irradiance taken at the Puerto Ayora solar plant.

Figure 22. Values of solar irradiance - Puerto Ayora solar plant



Source: (ELECGALAPAGOS , 2017)

The highest temperatures, around 26°C, occurred in the months of February and March, while the lowest temperatures, around 22°C, occurred in the months of August to October. Similarly, the days with the highest average hours of sunshine (approximately 8 hours / day) occurred during the dry season, while the days with the lowest daily average hours of sunshine (approximately 3 hours / day) occurred during the rainy season.

The electrical PV potential contemplates the performance under the analyzed temperature conditions.

5. Generation Expansion Plan of the Galapagos Isolated System (PEGSAG)

With available studies of demand, studies of renewable resources and conditions of the systems of the four islands, the Ecuadorian Government developed the Generation Expansion Plan of the Galapagos Isolated System (updated 2018), it considers a planning period of 10 years, which contains a portfolio of energy generation projects that, by 2027, aims to supply more than 56% of electricity demand with renewable energy sources. The prioritization of these projects will also encourage new studies and research on how to efficiently integrate renewable energy into the power grid.

Any project concerning the expansion of the generation system must also consider economic competitiveness, environmental responsibility, energy security, and electrical system stability and reliability. These aspects are the guiding principles that will determine the necessary changes in the infrastructure and the general performance and operation of the system.

The Galapagos electrical grid must provide a reliable, high-quality, and efficient service that uses non-conventional renewable energy technologies to minimize the environmental impact, it must employ infrastructure that presents minimal interruption to the electrical supply and reestablishes itself rapidly in the case that an interruption does occur. In addition, renewable generation must be considered at maximum priority for the generation dispatch.

The continuing development of the Galapagos' electrical system will expand the labor force and increase the income level for the residents of the islands, which is quantified in the later section on strengthening capacities.

The 2018-2027 PEGSAG was developed through analysis using energy software and applying demand growth, renewable resources availability and land use restrictions. With its proposed projects distinguished by short-term (0 to 4 years) and medium-term (4 to 7 years) implementation periods. Next Table shows the proposed Projects for each one of the four electrical systems.

Table 18. Projects by electrical system

Electrical System	Project	Power	Year
San Cristóbal	New PV + Energy Storage System	1.00 [MWp] 2 [MWh]	2021
	Wind	5.6 [MW]	2022
	Energy Storage System	2.2 [MWh]	2022
	PV	2.5 [MW]	2024
Santa Cruz – Baltra	Conolophus Project (PV)[8]	14 [MW] 40 [MWh] ESS	2024
Isabela	PV	0.8 [MWp]	2021
	Energy Storage System	1 [MWh]	2021
	PV	0.5[MWp]	2023
	Energy Storage System	7.1 [MWh]	2023
	PV	0.5 [MWp]	2025
	Energy Storage System	4.3 [MWh]	2025
Floreana	PV	0.09 [MWp]	2020
	Energy Storage System	0.384 [MWh]	2020
	PV	0.08 [MWp]	2023

Source: (MERNNR, 2020)

The completion and successful operation of Isabela´s Hybrid Power Plant[9] showed that a renewable generation technology together with a battery energy storage system (BESS) integrated with a fully automated central control allows a suitable operation for the diesel-off[10] concept while keeping the grid code requirements. This type of integration has been

[8] Private project proposal.

[9] Isabela Hybrid power plant technologies: PV 0,9 MW, Thermal 3,3 MW, ESS 0,66 MW (0,333 MWh)

[10] The concept of diesel off refers to periods of the day without use of the thermal power plant, only the system is provided with renewable generation.

adopted by ELECGALAPAGOS and the Ministry of Energy and Non-Renewable Natural Resources (MERNNR) as the model to follow for the other islands. In the same way, for the Baltra Santa Cruz system, an optimized hybrid controller has been designed that would be put into operation with the Conolophus project.

KEITI Consortium (as part of a technical cooperation by Korean Government) performed a study to analyze the PEGSAG's implementation impact on energy share, using the electricity demand scenario forecasted by ELECGALAPAGOS and its own developed forecast. (KEITI , 2020)

With ELECGALAPGOS' forecast, KEITI found that the whole Galapagos' renewable generation penetration will achieve 53% by 2022 and 52% in 2027, with a low in 2024 with 48% and a high of 56% in 2025.

On the other hand, KEITI's forecast used maximum, average, and minimum demand scenarios for each island, obtained by linear analysis of the historical demand, in order to determine the renewable generation penetration. As a result of this analysis, San Cristobal island would have by 2027 a 66%, 66% and 67% renewable penetration for the corresponding scenarios; meanwhile, Santa Cruz island renewable share by 2027 would reach to 50%, 51%, 52% for each scenario, but by taking into account the private initiative projects the average renewable share would rise to 82% in that island. In the case of Isabela island, the analysis found a renewable energy penetration of 47% by 2027 for all three scenarios.

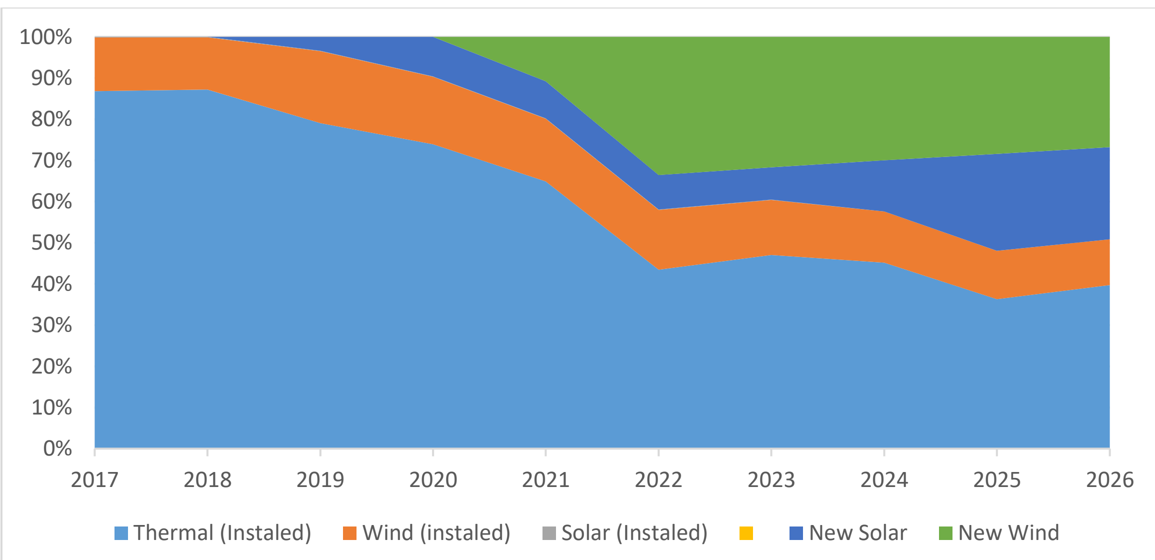
KEITI also analyzed how much renewable power and storage energy capacity would be needed to accomplish the Galapagos carbon free island initiative by 2025. Thus, for San Cristobal 12 MW in PV and 42 MWh of BESS would be necessary, for Santa Cruz 18.6 MW in PV and 79 MWh of BESS would make it, and for Isabela Island 5.6 MW in PV and 19.6 MWh of BESS.

5.1. San Cristobal Projects (PEGSAG).

Two solar PV, one wind, and two Energy Storage System projects got building priority in San Cristobal Island under the PEGSAG. By the end of 2020, the underway construction of 1 MWp PV plant and 2 MWh BESS will finish and within 2021 first quarter operation would start.

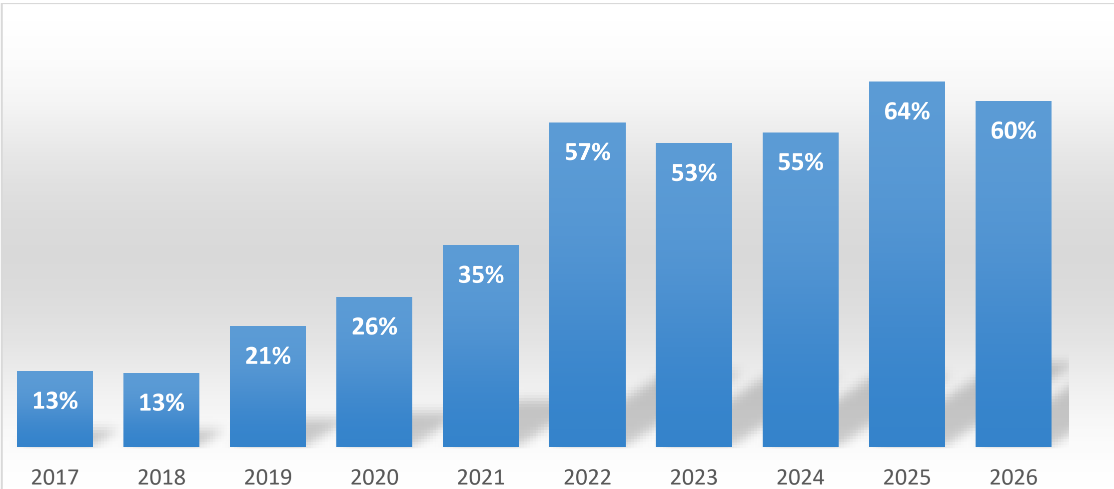
The new renewable energy projects in the San Cristobal System will achieve a 60% participation in 2025, next figures show energy share in next 5 years.

Figure 23. San Cristóbal Energy Share



Source: (MERNNR, 2020)

Figure 24. San Cristóbal Renewable Energy Penetration



Source: (MERNNR, 2020)

5.1.1. Second Phase of San Cristobal Wind Farm Project

This project will add 5.6 MW to the current Wind Farm and would supply roughly 7.25 GWh/year, displacing consumption of 600 thousand gal/year of diesel and achieving a reduction of 6000 Ton CO_2/year.

In 2018, the IIGE (Instituto de Investigación Geológico y Energético del Ecuador) made an assessment for suitable locations of wind farms in San Cristobal and Baltra island, based on available local wind data, it found average wind speed of 7.1 m/s for the San Cristobal sites. The assessment also included evaluation of 5 wind turbines brands with different power rates, resulting that 1 MW turbines have the best performance. A further analysis of the assessment carried out by KEITI using criteria for suitability of the infrastructure concluded that new wind turbines should be installed in the same place of the current wind farm in El Tropezon area.

The PEGSAG gives a raw estimate of US$ 12.3 million for the cost of this project.

5.1.2. Energy Storage System San Cristobal Project

The Energy Storage System (ESS) in batteries will allow the proper and reliable integration of the wind farms with the electric grid. It should include a centralized automatic control for the generation plants and storage.

The PEGSAG indicates a ESS capacity of 2.2 MWh and it must be carried out together with the second phase of the wind farm. The BESS and the centralized control system have a roughly budget of US$ 1.8 million.

5.1.3. Second PV Plant San Cristobal Project

This is a medium-term project with a proposed capacity of 2.5 MWp and approximated cost of US$ 5.71 million. Further analysis is needed to determine a suitable location and grid interconnection.

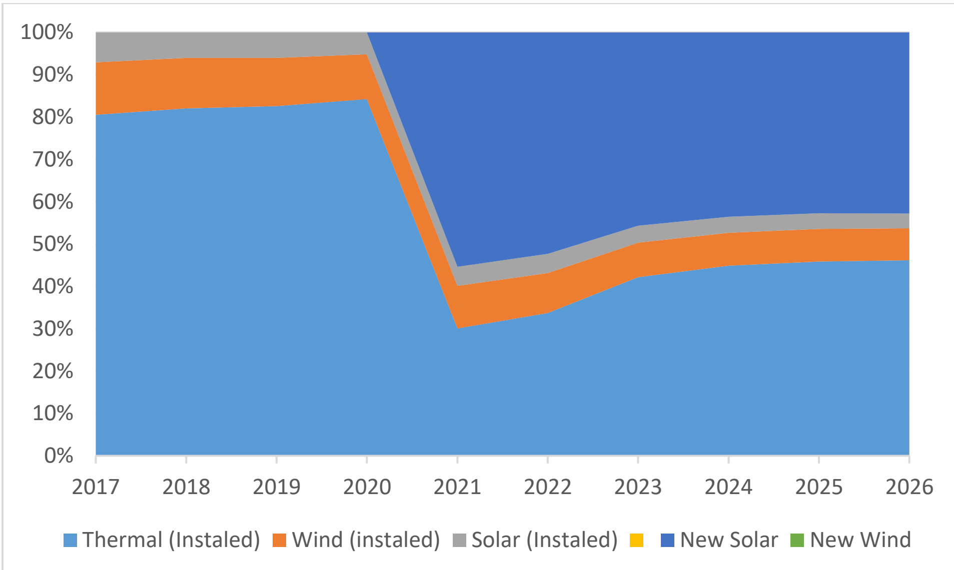
5.2. Santa Cruz Baltra Projects (PEGSAG)

The 2018 PEGSAG proposed a set of wind farm, PV plant and ESS projects for the short-term and a similar set for the medium-term. However, government endorsement of the private initiative PV project for this island, called PV Conolophus[11] project and currently in a tender process, would shift these sets of projects to medium-term and long-term executions.

The new renewable energy projects in Santa Cruz Baltra System are expected to achieve a 54% participation in 2026, next figures show energy share for next 10 years.

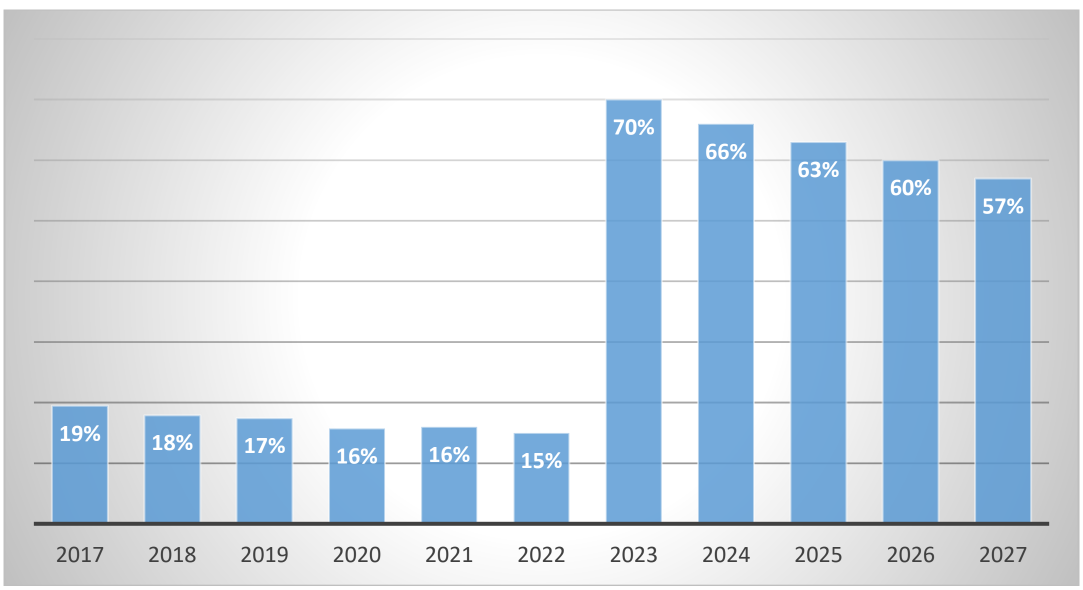
[11] Section 7. shows more details about Conolophus project.

Figure 25. Santa Cruz baltra Energy Share



Source: (MERNNR, 2020)

Figure 26. Renewable penetration Santa Cruz-Baltra



Source: (MERNNR, 2020)

Renewable penetration in Santa Cruz Baltra System considers the incorporation of a new private initiative photovoltaic project and energy storage system. A decreasing trend is observed from 2024, this due to the growing demand and degradation of equipment currently installed in current projects.

5.2.1. Second Phase Baltra Wind Farm Project

This project will expand the current wind farm by installing 6.75 MW in wind turbines that would generate nearly 13.4 GWh/year, preventing consumption of 1.11 million gal/year of diesel and avoiding 11.5 thousand tons of CO_2/year.

This project was initially proposed in the feasibility review report of the original Baltra Wind Park Project by Factor 4 GmbH and conceived as a natural expansion of the first 2.25 MW; by which Elecgalapagos has a 30 hectares land concession in Baltra where only a fraction of it was used by the first phase of the wind farm.

The assessment made by IIGE established an average wind speed of 6.54 m/s for Baltra site and the 1 MW turbines showed the best performance.

The PEGSAG proposed an early estimated budget of US$ 14.8 million for this project.

5.2.2. Second PV Plant Santa Cruz Project

The diversification of the renewable energy sources includes a second photovoltaic plant to be installed in Santa Cruz island, it will have 4.0 MWp and would produce 6.9 GWh/year, avoiding use of 0.57 million gal/year of diesel and preventing emission for 5.8 thousand tons of CO_2/year. It is expected to be built concurrently with the second phase of the wind farm and its cost is about US$ 9.14 million.

5.2.3. Energy Storage System Santa Cruz Project

The first set of projects will be completed by building its energy storage in batteries in Santa Cruz island. It would have a capacity of 30 MWh and an estimated budget of US$ 18 million. The power converters of this BESS must have characteristics that provide support to the electric grid, such as: establish voltage and frequency, virtual inertia, voltage and frequency regulation, and so on.

This project together with the second PV plant and second phase wind farm projects must be connected to the centralized automatic control implemented by the Conolophus project. This will ensure that grid stability, energy security, product quality and system reliability are achieved.

5.2.4. Third Phase of Baltra Wind Farm, PV Plant Santa Cruz Projects and Second Phase ESS Santa Cruz Project

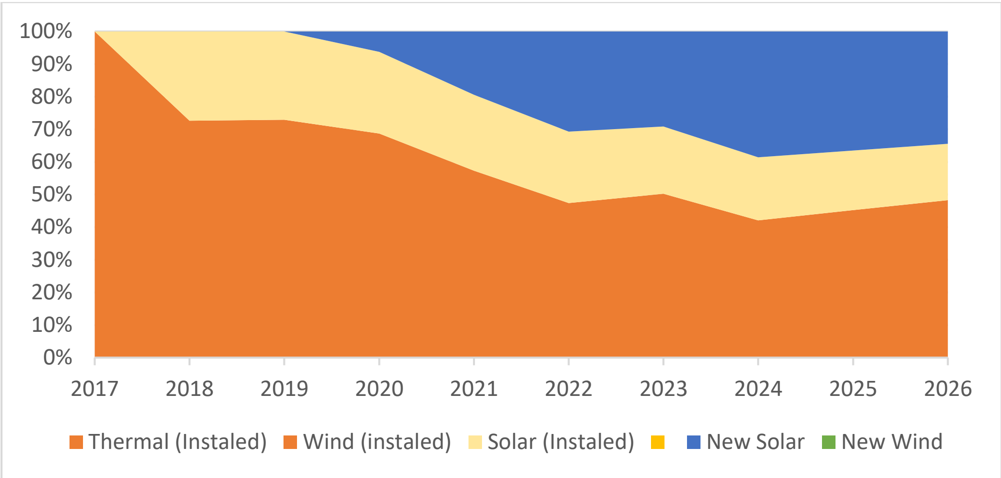
Initially conceived as a set of projects for medium-term, they include 2.75 MW in wind turbines, 1.5 MWp of photovoltaics modules and 10 MWh in battery energy storage. With a rough budget of US$ 15.46 million they might move to long-term planning.

5.3. Isabela Projects

The PEGSAG proposes three expansions for the PV plant and the BESS of the Isabela Hybrid Project, two in the short-term and one for medium-term.

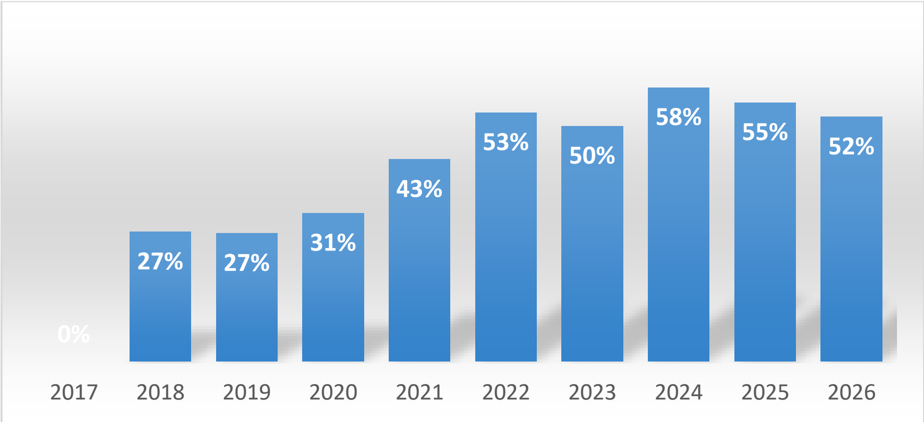
The new renewable energy projects in Isabela System will achieve a 52% participation in 2025, next figures show energy share in next 10 years.

Figure 27. Isabela energy Share



Source: (MERNNR, 2020)

Figure 28. Isabela renewable penetration



Source: (MERNNR, 2020)

5.3.1. PV Plant Expansion of Hybrid Isabela Project

A straightforward expansion of the Hybrid Project's PV plant will cope with the growing demand of electricity in this island. This expansion will use the remaining area of ELECGALAPAGOS' land concession.

This project will install 0.8 MWp of PV modules that would supply roughly 1.41 GWh/year and would cut emission for 1.2 thousand tons of CO_2/year. Its estimated budget is about US$ 1.82 million.

5.3.2. BESS Expansion of Hybrid Isabela Project

This project complements the PV plant expansion, by adding a 1 MWh battery energy storage facility next to the PV plant. It has a cost of nearly US$ 1.5 million. These BESS and PV expansion must be connected and integrated with the centralized automatic control software of the Hybrid Plant.

5.3.3. Second Phase of PV Plant Expansion of Hybrid Isabela Project

The whole area around Isabela Hybrid Plant is flat, there is enough space available for growing and the main load remains nearby. Thus, keeping expansions of the PV plant on that land makes pretty sense.

This expansion adds a 0.5 MWp PV field that would generate 1GWh/year and would drop emissions by 850 tons of CO_2/year. This project has an estimated budget of US$ 1.14 million.

5.3.4. Second Phase of BESS Expansion of Hybrid Isabela Project

This facility will expand the energy storage capacity by 7.1 MWh, making possible services like peak shaving during the night. It is roughly valued in US$ 4.26 million. Of course, the plant and the BESS must be merged into the centralized control.

5.3.5. Third Phase of PV Plant and BESS Expansion of Hybrid Isabela Project

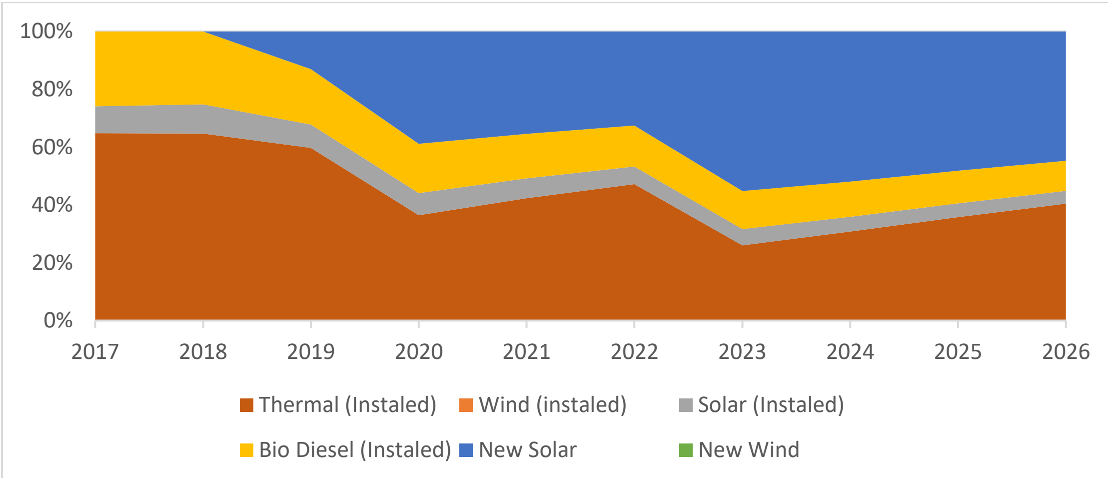
These medium-term projects follow the same setup of the previous expansions of the hybrid system. Adding 0.5 MWp of PV modules and 4.3 MWh of storage and with an approximate cost of US$ 4 million.

5.4. Floreana Projects

Floreana has a really marginal demand (about 1/100 of Santa Cruz by 2019) and for that reason several pilots' projects were first developed there, such as 100% deployment of induction cookers, first PV plant grid connected, first power generation with dual engines (diesel / jatropha) and so on. However, the PEGSAG proposes for this island quite standards projects: a set of PV plant + BESS in the short-term and a PV plant for the medium-term.

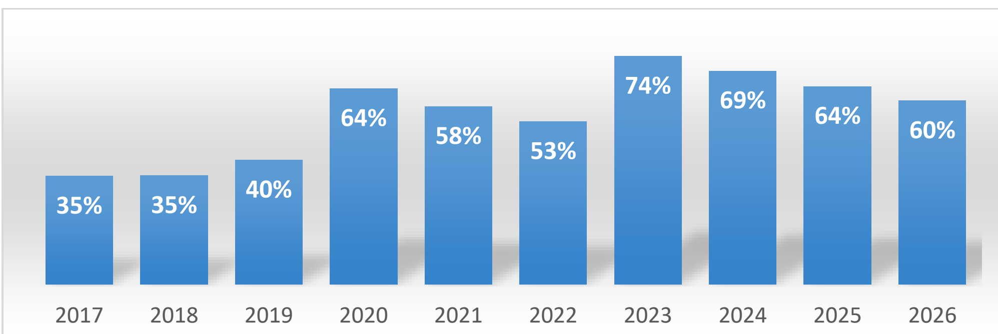
The new renewable energy projects in the Floreana System achieve a 52% participation in 2025, next figures show energy share in next 10 years.

Figure 29. Floreana Energy Share



Source: (MERNNR, 2020)

Figure 30. Floreana Renewable Penetration



Source: (MERNNR, 2020)

5.4.1. PV Plant Foreana Project

This project will increase the current PV capacity in 90 kWp and would provide 0.16 GWh/year, this plant will be located within the town, nearby to the dual power plant and substation. Its operation would decrease 13 thousand gallons of diesel consumption per year and reduction of 140 tons of CO_2/year. It has an estimated budget of US$ 0.31 million.

5.4.2. BESS Floreana Project

This energy storage facility will be built together with the PV plant and will add 384 kWh in batteries to the current capacity. Its budget is approximately US$ 0.33 million.

5.4.3. Second Phase PV Plant Foreana Project

This medium-term project will add 80 kW of PV modules to the plant.

6. Multi-criteria analysis of project prioritization

The evaluation of projects to be prioritized within the financing proposal is carried out using the methodology shown in the Multi-criteria evaluation methodological manual for programs and projects. [12]

After identifying the projects that contribute to the objective of the Program (Table 15), they are evaluated according to the following criteria:

Potential Impact: To first assess the potential impact of the identified projects, a quantitative evaluation according to the power to be installed.

Feasibility Level: The level of feasibility available studies for each project is considered. The technical, legal, and environmental feasibility available in public and private institutions that developed project studies are analyzed.

[12] Multi-criteria evaluation methodological manual for programs and projects. CEPAL (2008)

Potential paradigm shift: The transformative capacity in the energy performance of the islands is analyzed, taking as a key point the involvement of society as key actors in the transformation and contributes to the environmental sustainability of the islands.

The matrix of projects to be evaluated is the result of the analysis of the available studies and government plans regarding the change of the electrical energy matrix in the Galapagos Islands, shown above.

Table 19. Projects to be prioritized

Nro.	Projects	Detail/ Phases
1	**San Cristobal (PEGSAG)**	• *Second Phase San Cristobal Wind Farm* • *Energy Storage System* • *PV Plant San Cristobal Project*
2	**Santa Cruz Baltra (PEGSAG)**	• *Second Phase Baltra Wind Farm* • *PV Plant Santa Cruz* • *Energy Storage System Santa Cruz* • *Third Phase of Baltra Wind Farm, PV Plant Santa Cruz Projects, and Second Phase ESS Santa Cruz Project*
3	**Isabela (PEGSAG)**	• *PV Plant Expansion of Hybrid Isabela Project* • *BESS Expansion of Hybrid Isabela Project* • *Second Phase of PV Plant Expansion of Hybrid Isabela Project* • *Second Phase of BESS Expansion of Hybrid Isabela Project* • *Third Phase of PV Plant and BESS Expansion of Hybrid Isabela Project*
4	**Floreana (PEGSAG)**	• *PV Plant Foreana Project* • *BESS Floreana* • *Second Phase PV Plant Foreana*
5	***Centralized renewable energy generation (Conolophus)***	• *Baltra PV Project* • *BESS Baltra* • *Hybrid control* • *Transmission line*
6	***Smart Grid implementation in distribution system***	• *Santa Cruz Smart Grid project*

7	***Renewable distributed power generation projects in the tourism/commercial sector***	• *PV distributed micro power generation Santa Cruz.* • *PV distributed micro power generation San Cristóbal.* • *PV distributed micro power generation Isabela.* • *PV distributed micro power generation Floreana.*
8	***Energy Efficiency (replacement of equipment)***	• *Replacement of refrigerators and air conditioners*
9	***Sustainability standards applied to construction.***	• *Efficient construction standards*

Source: Authors

The objective to fulfil within the prioritization of projects will be: Maximize the contribution to the change of the energy matrix in the Galapagos Islands, by incorporating renewable sources and optimizing the use of energy.

The objective is to establish a maximization of emission reduction in the generation of electrical energy necessary to supply the demand. the reduction potential is evaluated by the power evaluated as feasible.

6.1. Prioritization results

After applying the criteria shown in this section, on each of the options considered, the following prioritization was obtained, which will be developed in the proposal below:

Table 20. Results

Nro.	Project	General Results
1	Centralized renewable energy generation (Conolophus)	High potential impact. Availability of feasibility studies. High potential paradigm shift.
2	Renewable distributed power generation projects in the tourism/commercial sector	Medium potential impact. Availability of technical pre-feasibility and legal feasibility studies. High potential paradigm shift.
3	Energy Efficiency (replacement of equipment)	Medium potential impact. Availability of government plans. High potential paradigm shift
4	Centralized renewable energy generation Santa Cruz Balta (PEGSAG)	High potential impact. No feasibility studies are available. High potential paradigm shift.
5	Centralized renewable energy generation San Cristobal (PEGSAG)	Medium potential impact. No feasibility studies are available. High potential paradigm shift.
6	Centralized renewable energy generation Isabela (PEGSAG)	Small potential impact. No feasibility studies are available. High potential paradigm shift.
7	Centralized renewable energy generation Floreana (PEGSAG)	Small potential impact. Low availability of feasibility studies High potential paradigm shift.
8	Smart Grid implementation in distribution system	Low potential impact No feasibility studies are available. Medium potential paradigm shift
9	Sustainability standards applied to construction.	Low potential impact No feasibility studies are available. Medium potential paradigm shift

Source: Authors

From the results obtained, the three best rated projects are prioritized for development, as they have the characteristics that guarantee the fulfilment of the objectives. The projects that are not prioritized have high potential to contribute to the energy transition of the islands, after the feasibility studies are available that will guarantee their execution.

The prioritized projects are developed in the section 7. Description of the Component", where the available information, the contribution in reducing emissions and technical characteristics is specified as part of the studies developed.

6.2. Eligibility of technologies

The next table shows the eligible criteria for the Renewable energy and energy efficiency projects that could be developed under the program. Section 7 provides further detail on each case.

Table 21. Eligibility of technologies

Renewable Energy	Energy Efficiency
Micro distributed PV generation must comply with the current regulation about Equipment specifications and protection requirements.	Equipment rated A in energy consumption
Centralized generation project must comply with grid connection regulations, environmental licenses and enabling conditions for land use	Split air conditioners Inverter technology

Source: Authors

For each of the facilities, minimum technical conditions must be guaranteed, in addition to the regulatory conditions that must be met, the following conditions must be taken into consideration for the evaluation of the facilities.

Table 22. Minimum objectives

Technology type	Minimum objectives	
	Reduced energy consumption (%) / selection criteria	**Reduced GHG emissions (%)/ selection criteria**
Micro distributed PV generation	The distributed systems should be sized to make sure that at least 80% of the electrical consumption of the user/owner	80% per user
Air conditioners	Split Inverter-Category A (energy consumption)	Equipment with Natural Refrigerant Gas is eligible. Equipment with gases (HFC / HCFC) will not be allowed
Refrigeration	Category A (energy consumption)	Equipment with Natural Refrigerant Gas is eligible. Equipment with gases (HFC / HCFC) will not be allowed
PV-ESS Centralized	The project must guarantee 70% Renewable energy at Santa Cruz Baltra system. The project must contain the battery and control system for the grid stability.	70% Santa Cruz Baltra emissions base line.

Source: Authors

6.3. Local capacity building

As part of the gathering of information on local technical capacities, developed by the National Government, it has been identified that: there are not enough technicians with specialized training. For this reason, it is necessary develops plans to strengthen technical skills, both for financial institutions as well as technicians who can develop facilities and maintenance plans in the projects mentioned above and that are later developed.

Within the National Energy Efficiency Plan (2016-2035), one of the lines of action is established, the implementation of energy management systems and with it the strengthening of local technical capacities that can guarantee the sustainability of the projects to be developed in the energy field.

7. Description of the component

Component 1: Energy matrix change in the Galapagos archipelago.

This component will increase centralized and distributed renewable energy generation and guarantee the stability of the electrical system, to increase the energy security of the islands, and reduce GHG emissions associated with the Galapagos livelihoods, and especially with the tourism value chain in the Galapagos Islands.

Outcome 1.1: Reduced energy dependency of the Galapagos livelihoods through increased low-emission energy access and power generation

Output 1.1.1: Increased renewable energy generation and storage to reduce GHG emissions, diversified energy matrix, and reduced dependency of imported fuels.

7.1.1. PV Conolophus Project

By the end of 2018, the Ministry of Energy and Non-Renewable Natural Resources issued a declaration of public interest for this private initiative project, thus, a series of feasibility studies and analysis were performed with the purpose to start an open selection process for a private concessionaire. The project model refers to a public-private partnership where the private organization builds, owns, operates and transfers the facilities after a 25-year concession period.

The project tendering includes a 14.8 MWp PV plant, a 40.9 MWh battery energy storage system, a switching station at 34.5kV, 49 km of sub-transmission line, and a centralized automatic control system for all the power plants in the island. The project itself would be responsible to reduce consumption of 1.4 million gallons of diesel per year and would avoid the emission of 12 thousand tons of CO_2 per year. The project has a budget of US$ 44 million dollar[13].

7.1.1.1. Concept and Location

The technical concept of this project tackles specific aspects such as the intermittent nature of the renewable energy sources, the stability and reliability of electric grid operation, and the optimization and renewable sources priority in the generation dispatch. All of them have been main constraints for the expansion of power plants based on renewable energy technologies in the small and isolated Santa Cruz – Baltra island electric grid.

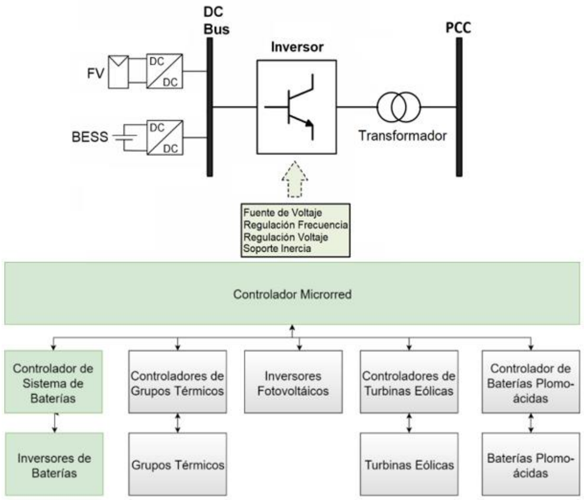
This project becomes the cornerstone for achieving high penetration of renewable energy in Santa Cruz – Baltra and provides the technical means for future generation projects' integration.

The heart of the project is the concept of a Dispatchable PV+BESS power plant, where the batteries banks and PV modules strings connect at direct current level, instead of traditional alternating current level connection after power electronics, and its power converter that features novel functions like virtual inertia, grid forming capacity, bidirectional and four quadrant control, and voltage and frequency regulation. Furthermore, optimal and secure operation and dispatch become possible by implementing a centralized automatic control

[13] More detail at Financial model

system for current and future power plants either conventional or renewables. The following figure shows the conceptual design of the two main project's components.

Figure 31. Dispatchable PV+BESS power plant and Automatic Control System.

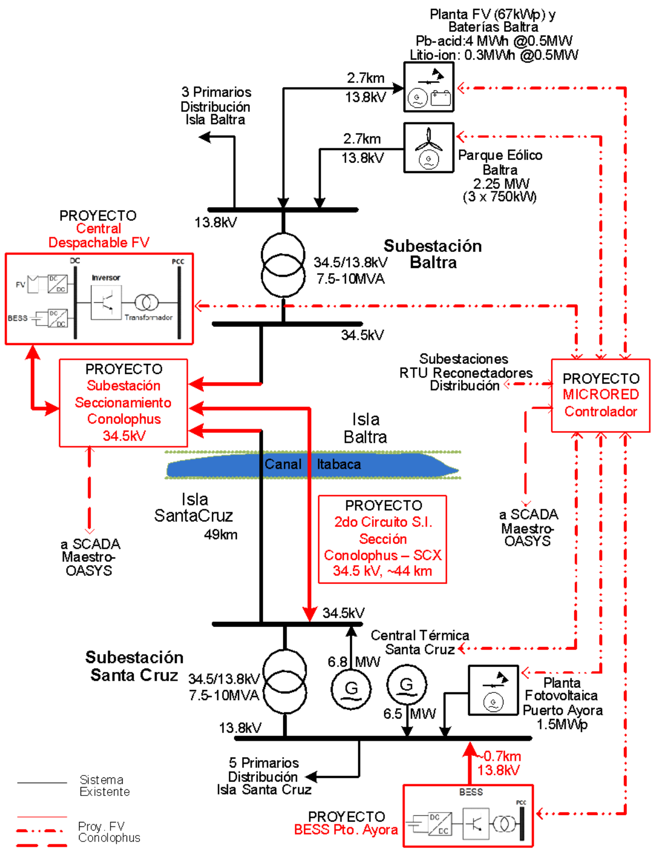


Source: (ELECGALAPAGOS, 2020)

The project's components will be located in both islands as depicted in red color in the next figure. The dispatchable PV+BESS power plant and substation will be located in a WWII decommissioned runway in Baltra island, following the recommendation of the territory development plan issued by Galapagos Government Council (CGREG). The centralized automatic control system will have its main equipment in Baltra while a backup will be placed in Santa Cruz diesel power plant.

The sub-transmission line corresponds to the second circuit of the current electrical interconnection system of both islands; therefore, it will use the existing infrastructure. Finally, a fraction of the dispatchable plant's BESS will be installed in the current Puerto Ayora PV plant at Santa Cruz island.

Figure 32. Project's Components and location



Source: (ELECGALAPAGOS, 2020)

7.1.1.2. Energy Supply Forecast and Share

The PV solar production study for the site using PVSYST software projected a yearly generation of 23.60 GWh at P90 and 25.47 GWh/year (P50) as average energy production for a 14.81 MWp plant.

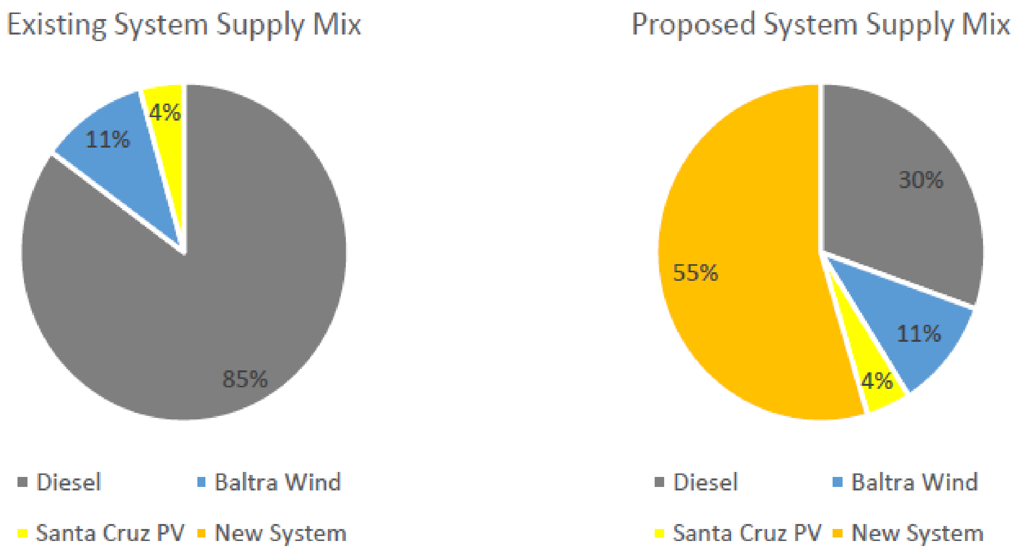
The studies included modeling of the demand and supply with the purpose of identifying the suitable while keeping electrical stability.

Therefore, under the current scenario the study recommends a 70% participation of renewables in the generation mix. With future reductions in renewable energy technologies costs and diesel subsidies phaseout, higher renewable energy penetration will turn feasible. By 2019, the renewable energy penetration accounted for 14.4% so the RV Conolophus Project should provide the remaining amount to reach a 70% participation at the first whole year of its operation.

The simulations on the model concluded that suitable components of the project would be a 14.8 MWp PV solar plant, 10.2 MW / 40.9 MWh battery energy storage system and an associated control system.

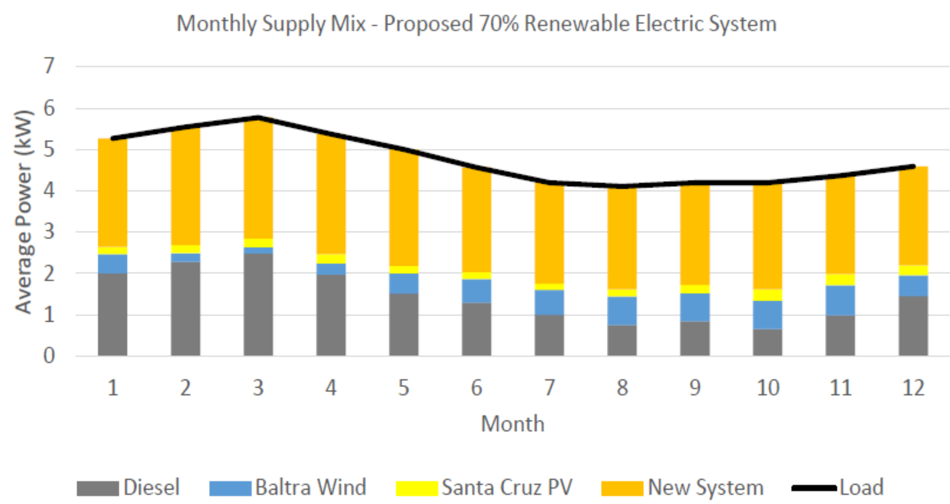
The expected increase in the renewable generation share for the first year of operation of the project and its forecasted monthly share are shown in the following figures should provide the remaining amount to reach a 70% participation at the first whole year of its operation.

Figure 34. Santa Cruz energy mix with PV Conolophus project



Source: (ELECGALAPAGOS, 2020)

Figure 35. Expected Monthly Share of energy mix with PV Conolophus project



Source: (ELECGALAPAGOS, 2020)

7.1.1.3. Dispatchable PV+BESS Power Plant

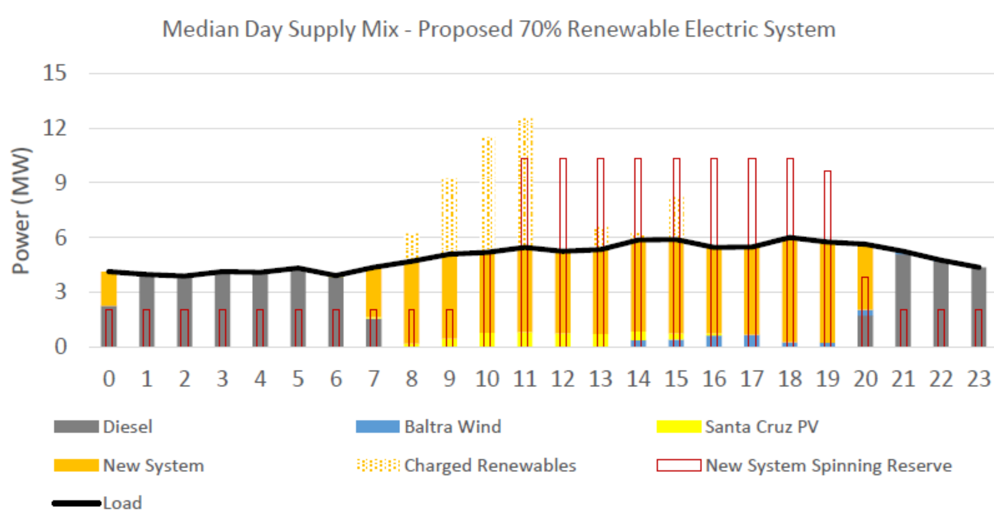
The technical feasibility study proposed the basic design for the PV plant and associated BESS.

The PV solar field includes 1701 strings, each one with 26 PV modules of 335 kWp, and connects with 14 power converters of 910 kVA and 7 step-up transformers of 2 MVA, 34.5 kV. The modules are supported in fixed galvanized steel structures with pillars stuck in the ground.

The BESS is formed by 14 power converters that in turn are made of 13 bidirectional inverters of 70 kVA each and 17 lithium-ion battery modules with nominal capacity of 174 kWh. The battery modules could operate between a 5% to 95% range. The BESS splits between Baltra's facility and Santa Cruz's facility, last one located in Puerto Ayora PV plant.

The dispatchable plant operates in such a way that during many day-hours the demand is totally supplied by the renewable sources without the need of diesel generators and when PV generation surplus occurs, the battery modules store it for later use. The power converters provide spin reserve to keep electric stability as well as supply the critical virtual or synthetic inertia, which is key for secure and reliable operation when having high penetration levels of intermittent renewable generation. The following figure displays an average day operation profile.

Figure 36. Expected Monthly Share of energy mix with PV Conolophus project



Source: (ELECGALAPAGOS, 2020)

Electrical studies for transient, dynamic, and steady state behavior were performed to understand and evaluate the impact of the project in the stability of the grid. As well as analysis of harmonics, spin reserve and electrical protections philosophy.

The studies showed that the new electrical system avoids low frequency scenarios under normal conditions even in the case of diesel-off operation.

7.1.1.4. Connection with the main load

The dispatchable plant will deliver its generated electricity to the Santa Cruz – Baltra grid through the Conolophus Substation. As a switching station at 34.5 kV, the basic design of this facility presents a single busbar arrangement with bus sectionalizing, two income positions for the generation plant, one position towards the Baltra Substation, two positions towards Santa Cruz Substation and one auxiliary services position. All these positions will have metal-enclosed gas insulated switchgears with its own control and protection intelligent electronics devices and measurement equipment.

To enhance the reliability of the electrical system, the analysis for the bidding process included in the project the construction of the second circuit of the Baltra – Santa Cruz sub-transmission line in the section between Conolophus Substation and Santa Cruz Substation. Thus, this three phase sub-transmission line requires building 22.60 km of overhead line, 0.85 km of submarine cable, 20.54 km of underground cable, and adding one switchgear to the 34.5 kV busbar at Santa Cruz Substation. Additionally, a 24-core fiber optic cable must be installed along the 44 km between these two substations. The following figure sketches the layout of the sub-transmission line that electrically interconnects Baltra and Santa Cruz islands.

Figure 37.Layout of 34.5 kV sub-transmission line

Source: (ELECGALAPAGOS, 2020)

7.1.1.5. Centralized Automatic Control System

The optimal, reliable, and stable operation of an isolated electric grid with high share of renewable generation requires full integration and control of all large power plants under a centralized automatic control system. As experienced with Isabela Hybrid system, such a kind of control system guarantees maximum dispatch of renewable sources, quick responses for grid stabilization after electrical disturbances, and efficient use of the generation system's components.

The centralized automatic control system consists of hardware and software and uses telecommunications networks, algorithms, actuators, and interfaces to interact and control each of the generations units. The control system will base its operation in pursuing the following objectives: minimize diesel consumption, minimize operative costs, and maximize renewable generation participation.

The centralized control has a hierarchical structure where its top level is a Process and Control Central Unit that interacts with several group controllers and single controllers of generations' elements such as power converters, PLCs, diesel engines, etc. A Human Machine Interface allows operators to monitor the performance of the system and in some cases override commands.

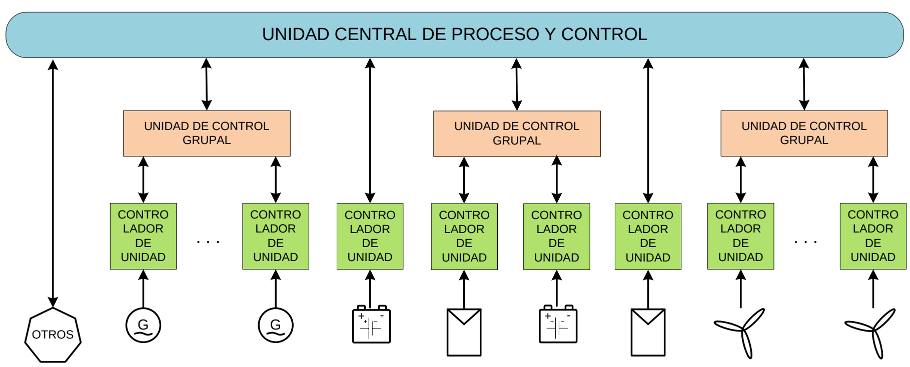
The main functions of the Automatic Control System include keeping spin reserve, secondary control for voltage and frequency, tertiary control (optimal economic dispatch, unit commitment, demand forecast, renewable generation forecast, etc.), energy storage management, diesel-off operation, black start, load transfer and load shedding. The control system is also responsible to apply in the optimal dispatch the pre-defined strategies and constraints established for each power plant.

The main hardware of the control system will have a principal set and backup set, the first installed in the dispatchable PV+BESS power plant and the second in Santa Cruz diesel power plant. The integration of the current power plants to the centralized control system will require several updates of hardware and telecommunication network upgrades.

7.1.1.6. Stability control and operating model.

The operation model of the generation of the Santa Cruz - Baltra electrical system is based on a Central Control System (CCS) programmed with an algorithm that maintains the stability of the electrical system while performing an optimal dispatch to minimize the consumption of diesel and operating costs and maximize renewable generation. For this, a central controller acts on the controllers of each of the components of the generation, following a hierarchical structure.

Figure 37. Hierarchical referential structure for the central control system of the Microgrid.



Source: (ELECGALAPAGOS, 2020)

The Central Processing and Control Unit is in charge of computing the optimal dispatch, carrying out high-level control actions of the entire system and coordinating all controllers to ensure that the generation components are used in the most efficient way. efficient to maintain the stability of the electrical system. For which, it has a central multiprocessor and interfaces for communication and data acquisition of Group Control Units, Unit Controllers and other components of the electrical system.

At this level of control, the current status and limitations of the electrical generating units and groups are evaluated, and control loops and expert control algorithms are executed to guarantee the electrical stability of the system.

The Group Control Unit is in charge of carrying out the data acquisition of the Unit Controllers, processes the commands and adjustment values sent by the Central Processing and Control Unit, evaluates the status and current limitations of the units. generation units in its group, assigns the setting values to the generation units, commands the individual switching on and off the generation units.

The Group Control Units could be embedded in the Central Process and Control Unit.

The Unit Controller is the element that is together or is part of the generation unit and is responsible for acquiring data and direct and individual control of the generation unit hardware, executing the primary control of frequency and voltage through Droop control curves. In addition, among others, it processes the commands and adjustment values received from its superior controller, executing the on and off of the generation unit, the change of the power point delivered by the generation unit, etc.

The Historical Data Server is the set of equipment and computer programs that stores in databases the records obtained from, at least, 10-minute samples of the maximum, minimum and average values of the electrical variables (f, V, I, P, Q, FP) of the entire electrical system, generation units and generation plants, as well as specific operating variables and meters for each generation unit or generation plant such as SoC, energy delivered and received (Wh, VArh), and other metrics such as performance, faults, alarms, etc.

A satellite-controlled GPS Clock will be the equipment that provides the time stamp to the records of the variables and metrics of the electrical system. The equipment of the Central Control System must be synchronized to this clock.

The Post-Operational Analysis and Development Console is the set of hardware and software that allows the Electric Company personnel to develop and test new integrations to the Micro-grid and perform analysis of the operation of the electric generation system.

The Central Control System must guarantee the integration of future generation units and plants; therefore, it must be open, scalable and allow the inclusion of new generation components, the modification of the control algorithm, the programming of new control logics, modification of its human-machine interface and must have open industrial communication protocols such as: Modbus, DNP3.0, among others.

The Central Control System must guarantee its reliability through a redundant design, for which the main elements of the Central Control System will have a main team and a backup team operating in standby, one located in Baltra Island and the other located in Puerto Ayora. If there is a failure in the main equipment, the backup equipment will automatically and immediately go into operation, replacing all the functions of the main equipment without affecting the stability of the electrical system.

7.1.1.7. Microgrid Central Control System Functions

The algorithm that the Microgrid Central Control System will have must at least simultaneously perform the following functions to maintain stability and comply with the optimal dispatch of the electrical system.

Operating Reserve. The electrical system must maintain minimum levels of operating reserve; both for ascending reserve (power capacity that the generating units in operation can supply, above their current power, until reaching their maximum power) and for descending reserve (power capacity that the generating units in operation can decrease, by below its current power, until it reaches its minimum power). The minimum levels of this reserve had been determined in the Electrical Studies carried out by the Concessionaire[14] in coordination with the Electric Company, considering that these must guarantee that the

[14] The electrical studies have been developed by the Concessionaire, as part of the tender process carried out. (The information will be accessible once the process is finished)

electrical system can achieve a balance between generation and demand, overcome failures in the primary distribution lines, overcome generation failures.

For this, the Central Control System must:

- Operate autonomously to maintain the operating reserve without operator intervention, under normal conditions.
- Be configurable for minimum reserve requirements at any time.
- Continuously calculate the additional reserve that the electrical system needs, when intermittent renewable generation is operating.
- Send set points and commands to the generation units to fulfill the reserve. Being able to turn on diesel generators and limit renewable generation.
- Being able to detect when a generation unit is no longer available for dispatch and continue to maintain the reserve using the other components of the electrical system.
- Provide the ability to manually dispatch diesel generating units when necessary.

Primary Control. This is a local control that acts directly on the hardware of the generation units, performing the primary regulation of frequency and voltage to limit their deviations in the short term (seconds) and restore the balance between generation and demand. The primary regulation of frequency and voltage will be carried out at the level of each Generation Unit Controller, that is to say outside the algorithm of the central control. This primary control for the generation units that work as voltage sources will be implemented individually through Droop curves of frequency-active power (fP) and voltage-reactive power (VQ).

Secondary Control. This control is implemented in the algorithm of the Central Control System and executes the secondary regulation of frequency and voltage to restore them to their reference values in the 13.8 kV bus of the Santa Cruz Substation and regulate voltage in the 13.8 kV bus. of the Baltra Substation in the medium term (minutes).

For this, the Central Control System must:

- Calculate the active and reactive power requirements to restore frequency and voltage.
- The Concessionaire must work in coordination with the Electric Company to identify the Droop settings that the current generation units allow, and which minimum and maximum powers allow before activating the reverse power, overload, over frequency or low frequency protections.
- The Electrical Studies will determine what additional infrastructure for voltage regulation of the Santa Cruz - Baltra electrical system should be implemented by the Concessionaire.

Tertiary Control. This control of the Central Control System acts seeking an optimized load distribution in the long term (hours).

For this, the Central Control System must:

- Calculate an economic dispatch of the electrical generation system with the objective of minimizing the cost of generating energy for the Electric Company, while maximizing renewable generation and minimizing diesel consumption and equivalent CO2 emissions.
- Optimize the operation of diesel generating units considering maintenance costs, on and off cycles, hours of operation, and maximum and minimum load limits.
- Minimize the number of diesel generation units that participate in operating reserve, considering the specific requirements of the electrical system for its stability.
- Limit renewable generation only when it is necessary to avoid a shortage of descending operating reserve and considering the specific requirements that the electrical system has for its operation.

Special Operating Conditions. The Central Control System must face non-standard operating conditions that the new Santa Cruz - Baltra generation electrical system may have, such as:

- Storage almost full. The Central Control System must ensure that energy storage never reaches its maximum load level, because its contribution to electrical stability would become unidirectional; For which, before this point is reached, diesel generation units should be progressively disconnected without causing a shortage of rising reserve, as the amount of renewable generation is closer to the maximum load point, the amount of renewable generation should be limited.

- Storage almost empty.Similarly, the Central Control System must ensure that energy storage never reaches its minimum load level; For which, before this point is reached, the greatest amount of renewable generation possible should be commended to produce without causing a shortage of descending reserve, when approaching the minimum load point, the diesel generation units should be switched on progressively.

- Diesel-off operation.The Central Control System must be capable of shutting down all diesel generation units in case the new Battery Energy Storage Systems (BESS) are capable of meeting the reserve and operational safety requirements of the electrical system by yes alone. In this mode of operation, the short-circuit current capacity of the electrical system will be significantly reduced, therefore, the Concessionaire in coordination with the Electric Company will carry out the Electrical Studies to determine protection schemes that guarantee the location, clearance, and isolation of faults. in the electrical system and that its implementation has a minimal impact on the current protection equipment installed in the system.

- Sectionalization of the electrical system.In the event of isolation of generation and demand sets in the electrical system due to the opening of a protection element in the event of a failure, the Central Control System must have procedures on how to act in this case. Thus, the Concessionaire must develop, in coordination with the Electric Company, the procedures to manage the sectionalization in such a way that each generation-demand set remains in operation.

- Black start of the electrical system. The Central Control System must have procedures to carry out a black start of the Santa Cruz - Baltra electrical system, being an option the black start commanded from the Central Control System using the generation units that work as voltage sources.

- Load transfer. The Central Control System must be capable of transferring all the load from the Photovoltaic Renewable Dispatch Power Plant to the Santa Cruz Thermal Power Plant by order of the operator. This is to ensure the continuity of the electrical service if the 34.5kV subtransmission line needs to be disconnected.

Human - Machine Interface (HMI). The Central Control System will have a man-machine interface (under standard ANSI / ISA-101.01-2015) that allows you to monitor, audit and control both locally and remotely the electrical generation system.

The Man-Machine Interface must:

- Have a graphical interface that allows the opening of hierarchical user sessions (engineering, supervision, operation) through remote terminals (PCs, laptops) via web / html interfaces.
- The graphical user interface will have representations of the generation units, sectioning equipment, electrical interconnection lines and the load; that is, an electrical scheme or a single line diagram of the Santa Cruz - Baltra electrical system.
- The graphical interface will show the instantaneous values of the main electrical variables (f, I, V, P, Q, FP) of the entire system, of the generation units or generation plants and of the load, as well as other metrics of the generation, charging and system plants such as: imported and exported energy, State of Charge (SoC), available energy, operating reserve, switch status, among others.
- Detect when a generation unit is not available for dispatch.
- Allow real-time adjustment of key parameters of the Central Control System such as: minimum reserves, maximum and minimum power capacities of the generation units, etc.
- Provide critical alarms of the Microgrid, detailed information on errors and actions to be taken by the operator or engineering team.

- Generate graphs based on the historical records of the variables and metrics.
- Allow to generate personalized reports with the historical data of the variables and metrics of the electrical system in samples of at least 10-minute and 1 hour and to be able to export them in cvs, xlxs formats.

7.1.1.8. Integration and Dispatch Strategies of Microgrid Components

The Concessionaire must integrate the generation components of the Santa Cruz - Baltra electrical system with the Microgrid Central Control System, ensuring that the control system operates the components based on the described functionalities and dispatch strategies. To achieve this, the Concessionaire must carry out the modernizations required by each of the generation units of the Santa Cruz - Baltra electrical system. Aspects of the integration and dispatch strategy for each generation component are described below.

Diesel Generation Units of the Santa Cruz Thermal Power Plant. For the integration of the generator sets, the Concessionaire must carry out all the necessary works so that they can be integrated into the Microgrid, including replacing the current AVRs with ones that have the ability to gently excite the step-up transformers, replace the current ones. controllers of diesel generation units, unifying them to a model and type, update their components to automate the ignition, shutdown, synchronization and connection to the electrical system, and must ensure that each diesel generation unit has a device that allows the operator to change its mode of operation between local or remote, the latter mode being the one that allows the control of the diesel generation unit from the Central Control System.

For the dispatch strategy we will have the following:

- The Central Control System (CCS) will have the ability to turn diesel generating units on and off by direct command to the unit controller. Upon receiving the start command, the unit controller will execute the tasks that lead the generation unit to start operating and connect to the electrical system, without requiring any action from the operator. Upon receiving the shutdown command, the unit controller will execute the tasks that lead the generation unit to disconnect from the electrical system and stop. In the case of Hyundai generation units, the Concessionaire must develop the procedures and controls in the CCS so that prior to starting, the operations personnel carry out the manual check required for this type of diesel generator.

- The diesel generation units will operate to guarantee a sufficient operating reserve and even more so when the new Battery Energy Storage Systems (BESS) are almost empty.
- The CCS will have the ability to adjust the load sharing between the diesel generation units in parallel and with the BESSs.
- The CCS will have the ability to control the frequency of the electrical system when diesel generating units are the only voltage sources or when they are working in parallel with other voltage sources such as BESSs.
- The CCS will have the ability to control the voltage of the electrical system when diesel generating units are the only voltage sources or when they are working in parallel with other voltage sources such as BESSs.
- The CCS will accept the configuration of maximum and minimum power limits for the operation of each of the diesel generating units, and the times they require during start-up to start generating and the cooling time they require before shutting down.
- The CCS will guarantee a rotating use of the diesel generation units, ensuring that similar diesel generation units have similar work cycles.
- The CCS will have the ability to utilize diesel generating units for electrical system black starting in the event of a general blackout.

Dispatchable Photovoltaic Renewable Generation Plant.

For the integration of this new central, the Concessionaire will confirm the absolute compatibility of the Central Processing and Control Unit and / or Group Control Unit of the CCS with the controllers of the BESS and inverters.

The following will be considered for the dispatch strategy:

- The CCS will operate the BESS inverters in voltage source mode and meeting the operational requirements requested for this equipment.

- The CCS will ensure that the BESS battery banks remain equally charged during operation.
- The CCS will have the ability to adjust the load sharing between the BESSs and other voltage sources such as diesel generating units.
- The CCS will have the ability to control the frequency of the electrical system when the BESSs are the only voltage sources or when they are working in parallel with other voltage sources.
- The CCS will have the ability to control the electrical system voltage when the BESSs are the only voltage sources or when they are working in parallel with other voltage sources.
- The CCS will have the ability to use the BESSs to black start the electrical system in the event of a general blackout.
- The CCS must control the maximum power of the Photovoltaic Field, limiting it to prevent the BESSs from charging beyond their maximum charge level, to prevent the diesel generation units from operating below their minimum power limit and to avoid a shortage of reserve downward operating.
- The CCS may use the BESS to charge any surplus of the renewable generation of the Electricity Company.

Battery Energy Storage System Puerto Ayora. For the integration of this new component, the Concessionaire will confirm the absolute compatibility of the Central Processing and Control Unit and / or Group Control Unit of the CCS with the controllers of the battery banks and inverters.

The following will be considered for the dispatch strategy:

- The CCS will charge the BESS Pto. Ayora with the generation of the Dispatchable Photovoltaic Renewable Generation Plant and some surplus of the renewable generation of the Electric Company.
- The CCS will operate the BESS inverters in voltage source mode and meeting the operational requirements requested for this equipment.

- The CCS will ensure that the BESS battery banks remain equally charged during operation.
- The CCS will have the ability to adjust the load sharing between the BESS and other voltage sources such as diesel generating units.
- The CCS will have the ability to control the frequency of the electrical system when the BESSs are the only voltage sources or when they are working in parallel with other voltage sources.
- The CCS will have the ability to control the electrical system voltage when the BESSs are the only voltage sources or when they are working in parallel with other voltage sources.
- The CCS will take advantage of the BESS for the stability of the grid and / or the economic dispatch, respecting the considerations.
- The CCS will have the ability to use the BESS to black start the electrical system in the event of a general blackout.

Puerto Ayora Photovoltaic Plant. For the integration of the photovoltaic inverters, the Concessionaire must carry out all the necessary work so that they can be integrated into the Microgrid, for example replacing its current communication modules with modules that allow the CCS to directly control each inverter and re-wire the communication to each investor.

The following will be considered for the dispatch strategy:

- The CCS will give preferential and priority dispatch to the renewable generation of this plant. For which, in the economic dispatch of this plant it will be considered with zero variable cost.
- The CCS shall not limit the power of this exchange.
- The CCS, in the case of not being able to dispatch 100% of the renewable generation of this photovoltaic plant on demand, will charge the surplus in the available BESS.
- The CCS may limit the maximum power of the renewable generation of this plant only when the lower admissible technical limit of power of the Dispatchable Photovoltaic Renewable Generation Plant has been reached and in order to prevent the BESS from

being loaded beyond its level. maximum load, that diesel generating units operate below their minimum power limit and that there is a shortage of downstream reserve.

Baltra Wind Farm. For the integration of the wind turbines, the Concessionaire will carry out all the necessary work so that they can be integrated into the Microgrid, including commissioning the manufacturer of the wind turbines to develop an interface so that they can be operated from the Microgrid, for this, the Concessionaire must establish the requirements, such as speed, type of protocol, power parameters and instructions for each wind turbine, which are required. The costs of the development of this interface will be in charge of the Concessionaire.

The following will be considered for the dispatch strategy:

- The CCS will give preferential and priority dispatch to the renewable generation of this plant. For which, in the economic dispatch of this plant it will be considered with zero variable cost.
- The CCS shall not limit the power of the wind turbines.
- The CCS, in the case of not being able to dispatch 100% of the renewable generation of this wind power plant on demand, will charge the surplus in the available BESS.
- The CCS may limit the maximum power of the renewable generation of this wind power plant only when the lower admissible technical limit of power of the Dispatchable Photovoltaic Renewable Generation Plant has been reached and after reaching the lower admissible technical limit of power of the PV Plant Puerto Ayora; this in order to avoid that the BESSs are loaded beyond their maximum load level, that the diesel generation units operate below their minimum power limit and that there is a shortage of descending reserve.
- The CCS will accept the minimum power limit settings for the operation of each of the wind turbines.
- The microgrid design must guarantee that, in the event of loss of communication between the CCS and the wind turbines, there will be no overloading of the BESSs and that the diesel generation units will not operate in reverse power.

Battery System of the PV Plant and Baltra Batteries. The integration will be carried out only for the lead acid battery system, the Concessionaire will ensure that the Central Processing and Control Unit and / or the Group Control Unit of the CCS is compatible with the controller of the battery system. The Concessionaire will carry out all the necessary work so that the batteries can be integrated into the Microgrid, including that the CCS connects to the internal grid of this central to access the Micrex-SX PLC, changes to the programming are not allowed existing PLC.

The Central Control System must respect and must not conflict with the control objectives of the lithium ion and lead acid battery systems.

The following will be considered for the dispatch strategy:

- The CCS will charge the lead acid battery system preferably with surplus generation from the Baltra Wind Farm and the Puerto Ayora PV Plant.
- The CCS will command the dispatch (charge or discharge) of the lead acid battery system.
- The CCS must not conflict with the operating limitations of the lead acid battery system.
- The CCS will take advantage of the lead acid battery system for the stability of the grid and / or economic dispatch, respecting the requirements and limitations mentioned. For the economic dispatch, lead acid batteries will be considered with the same value as for the renewable plants of the Electricity Company.

7.1.1.9. Telecommunications

The operation of the Micro-Grid Central Control System will require that there be telecommunication links between the different Unit Controllers and the Central Processing and Control Unit and / or the Group Control Unit. For which, the Concessionaire will carry out adaptations and / or implementations to the telecommunications infrastructure, either at the physical layer level and / or at the communication protocol level. Which should seek to minimize delays in telecommunications, avoiding as far as possible that the commands to the Unit Controllers go through intermediate elements such as RTUs or SCADAs.

The adaptations and / or implementations proposed by the Concessionaire must not compromise the security of the local IEDs, PLCs and SCADA of each generation center, and must maintain and not affect the functionalities of these and their integrations to the Master-OASYS SCADA, except for the local SCADA of the Puerto Ayora Photovoltaic Plant whose functionalities must be maintained as far as possible.

For the telecommunication link between the main Central Control System and its backup, the Concessionaire must consider that the Electric Company makes available 2 fiber optic wires that it has free in the link between the Santa Cruz Substation and the Baltra Substation.

7.1.1.10. Environmental Aspects

The main location for this project lies within the protected area of the Galapagos National Park (PNG), however protected areas are of different types according to a PNG's classification. The Project's area in the Baltra island belongs to the "Sustainable Exploitation Zone", in which sustainable productive activities are allowed.

As explained in previous sections, the dispatchable PV+BESS power plant and substation will be located in a WWII decommissioned runway in Baltra island, following the recommendation of the territory development plan issued by Galapagos Government Council (CGREG). The centralized automatic control system will have its main equipment in Baltra while a backup will be placed in Santa Cruz diesel power plant.

An environmental impact assessment of the project was performed by the private initiative. Although the location of the assessed project was 2.4 km away from current location, the main findings should hold, given that the current location is highly affected by human activity in comparison with the previous location. It has shattered asphalt ways and concrete platforms.

The environmental assessment pointed to landscape disruption and vegetation and wildlife disturbance as the main negative impacts as result of construction of the project. On the other hand, the positive impacts fall in the social component with increase of local employment, and in the general environment component with air quality improvement by reduction of CO_2 emissions and with decrease of diesel transportation risk and consumption. The assessment concludes that the positive impacts overcome the negative ones.

The project obtained the approval of the technical environmental feasibility of the project, issued by the Administration of Galapagos National Park (DPNG), for the previous location and would get one for the current location when requested. The feasibility is one of the first steps in the way to get the environmental license for the project's construction and operation.

7.1.2. Distributed renewable power generation projects.

Distributed generation has shown an important growth in Latin America in the last years, with installations in Brazil reaching 4 GW of PV distributed generation by 2020. In Ecuador, the current regulatory framework allows PV installations for self-consumption in the residential and commercial sectors, however no money payments for surplus energy delivered to the grid are provided, but surplus is liquidated with subsequent months' energy consumption. (ARCONEL , 2018)

The electricity demand structure in Galapagos indicates that commercial demand accounts for 41% of total demand (ELECGALAPAGOS , 2019), where the touristic sector has a principal role giving its large number of hotels and restaurants. That sort of business can take advantage of distributed generation incentives and financing programs.

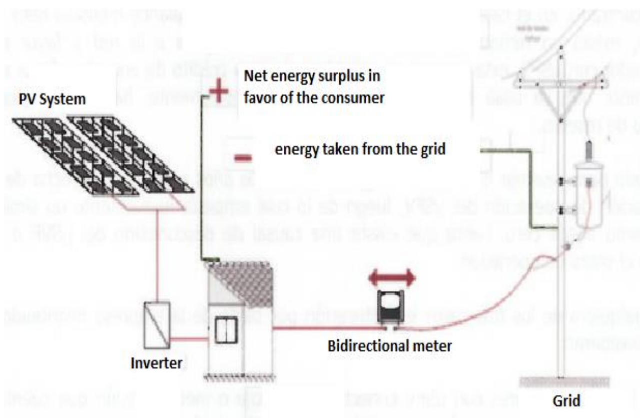
The proposed intervention at the distributed generation activity is that the Program finances projects for distributed energy generation in the tourism/commercial sector, although the agricultural and fisheries sectors are also eligible for accessing these credit lines. Beneficiaries will self-generate reducing its dependence on the power grid and creating systemic benefits such as decrease in diesel consumption for power plants, CO_2 emissions cuts, fewer large investments in centralized power plants, defer investments in electrical distribution system upgrades extending lifetime of lines and transformers, and so on. At the same time, the beneficiaries become sustainable tourism champions at energy use, which aligns with the campaigns for a sustainable touristic sector. The electrical system of the islands will also profit on the distributed generation projects by decreasing the demand curve at noon and early afternoon, also likely reducing some technical losses at distribution level, and by delaying expansion of the power plants and the sub-transmission system (in the case of Santa Cruz – Baltra).

To guarantee stability in the grid with the incorporation of renewable distributed generation, the current regulation (ARCONEL 003/18) establishes the conditions that an installation must fulfil for development, implementation, and participation of consumers with micro-PV generation, up to 100 KW of installed nominal capacity, located on roofs.

This regulation determines the requirements and procedures for connection to the distribution company ELECGALAPAGOS, and the authorization of installation and start-up of the generation. In addition, the operation is regulated in synchronism with the grid and the commercial treatment of the energy produced, the energy for self-consumption and the eventual surpluses discharged into the grid.

It is established that the sizing of the installation should prioritize the self-consumption of the generated energy, reducing the power consumed from the ELECGALAPAGOS grid and thereby reducing demand at peak noon hours. The following diagram shows a typical installation, where it is possible to identify how the system will be connected to the grid, without the need for batteries and with all the equipment that guarantees stability and synchronism.

Figure 38. Connection diagram, Distributed generation



Source: (ARCONEL , 2018)

In order to control the total installed power in distributed generation, the Regulation establishes conditions to have a connection feasibility study from the distribution company. Any installation must be approved under the analysis of a technical report that contains the following information:

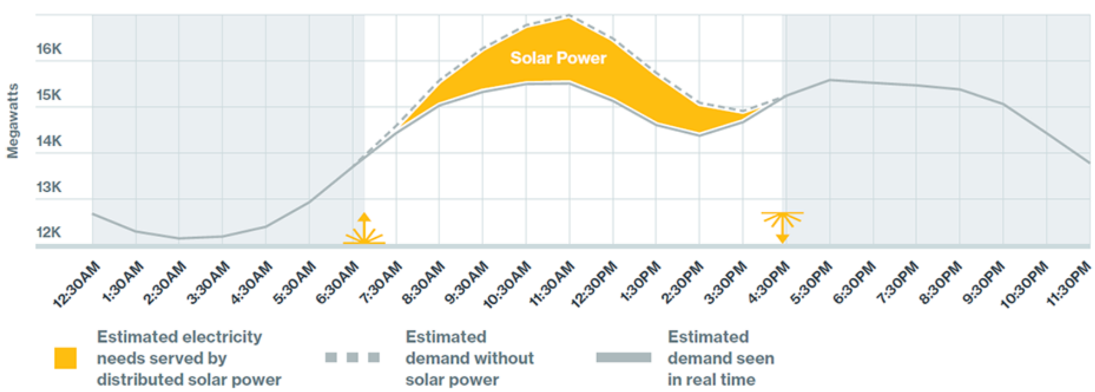
- Single-line diagram
- Equipment specifications
- Connection diagram
- Protection and sectioning study
- Additional technical aspects of protections
- Power and number of panels
- Characteristic of investors
- Short circuit power
- Delivery and measurement point

- Maximum and minimum voltage levels

There is a specific section starting that the owner of the installation must fulfil the protection needs, to ensure the grid will not be exposed to significant variations in voltage, frequency, and excess discharges. This ensures the ability for facilities can be operate without the impact of grid conditions.

The objective of the regulation is to promote that the facilities can reduce the demand curve of the distribution systems (Figure 39), strengthening and improving the efficiency of energy transmission. Distributed projects will be direct connections to the grid, only for the delivery of surpluses and consumption of electrical needs, these facilities guarantee the stability of the network in addition to having the necessary protections that must be installed as part of the photovoltaic system.

Figure 39. Contribution of PV energy at the noon peak



As can be seen in Figure 39, the objective of distributed generation will not be the supply to the distribution network, on the contrary, self-consumption will reduce the peak demand for noon, as there are no batteries, the effect of flattening the demand curve occurs. This does not cause inconveniences to the network, as indicated by the study carried out by

(Hernando, 2018), where it is determined that the distributed renewable penetration is energetically feasible under the conditions of the current electrical network.

Current regulation, in order to ensure that the system complies with the provision of self-consumed energy, establishes the application of the following formula, as a limit of the installed capacity for each user.

$$Capacity\ to\ be\ installed = \frac{\sum_{i=month\ 1}^{month\ 12} Historic\ energy\ per\ month\ i\ (kWh)}{Operation\ factor * 8760\ (h)}\ (kW)$$

Historic energy per month: Energy monthly per consumer. The PV system to be installed does not to exceed this value.

Grid stability studies have been developed through the Plan of Generation Expansion Optimization, with the conditions of the regulation, there are no disturbances in the grid with the incorporation of distributed systems. [15]

The Program will create the enabling conditions to accelerate a distributed generation scheme among the touristic and commercial sectors, by promoting legal reform and incentives, and by building a business case to match technology suppliers, installers, credit opportunities and tourism entrepreneurs. The Program will aim to involve the tourism sector in three of the inhabitant islands and will focus on the hotels with the largest energy consumption; Floreana island was not considered because it does not have a commercial sector that impacts on electricity demand.

[15] have been delivered and are under review by the contractor (IADB), the results will be published in September 2021.

Table 23. Distributed generation (Tourist Sector)

System	Potential Beneficiaries considered (accommodation, food and tourist services)[16] [#]	Distributed PV beneficiaries	Energy reduction[17] [MWh/year]	PV power[18] [kWp]	Energy Impact in the grid	Grid emission factor [tCO2/MWh][19]	Mitigation GHG emissions [tCO2/year]
Santa Cruz-Baltra	117	32	3,183	1,800	8%	0.827	2,632
San Cristobal	57	17	690	394	4%	0.728	502
Isabela	56	16	628	358	8%	0.767	481

Source: Various sources

It is considered that the equipment will be installed with the following progressive plan.

2024	2025	2026
30%	60%	100%

According to the information obtained from primary surveys applied, about the interest of the owners of tourist facilities, it was possible to obtain that: 60.1% of those interviewed are interested in installing equipment that produces energy from renewable sources if there is financing and for 56.8%% they are interested as long as the investment made reduces fixed costs. The installation of the renewable distributed generation systems would take at program execution term.

Besides the demand assessed for the tourism value chain, two specific projects in San Cristobal Island have gained support by the electrical utility, ELECGALAPAGOS, which has carried out pre-feasibility analysis and their initial figures are presented below.

[16] Primary information

[17] ELECGALAPGOS, 2018

[18] Calculation formula, (ARCONEL , 2018)

[19] (IRENA, 2021)

7.2. Outcome 1.2: Outcome 1.2: Reduced energy consumption by the Galápagos livelihoods through energy efficiency

7.2.1. Output 1.2.1: 1.2.1: Improved energy efficient measures to reduce GHG emissions and energy dependency of the Galapagos livelihood.

The implementation of the Program of Refrigerators Renewal – RENOVA – which was performed in a first phase (2012 – 2016) at national level, resulted in 95,645 units being replaced, processing in consequence 6,012.72 tons of scrap metal and recovering 2,733 kg of refrigerant gases (2,557.945 kg of CFC12 and 175.1 kg of R134a)[20].

First phase in Galápagos achieved the replacement of 1,109 refrigerators, mainly in Santa Cruz Island, considering the biggest residential sector, reaching a saving of approximately 430 MWh/year.

The Secretary of the Government has considered that for the next phase of the Program the impulse to the replacement of inefficient equipment must continue in Galapagos, because the use of fossil fuels remains in almost 90% and also due this is an isolated system having reduced electrical generation from renewable sources.

In addition, it has been established that the sectors registering the greater electricity consumption are the residential and commercial ones, where it is important to strengthen the energy efficiency policy, emphasizing in the main uses of the energy in the province: refrigeration and air conditioning.

Objective of the Program for Renewal of Inefficient Energy Consumption Equipment Second Phase: Optimize the electrical energy consumption in the air conditioning (AC) and refrigeration areas, with replacement of 3,200 units (1900 Refrigerators and 1300 AC units) in residential sector and 1,324 units (530 Refrigerators and 794 AC units) in the

20 RENOVA report of first phase, January 2017. Ministerio de Electricidad y Energía Renovable.

tourist/commercial sector of the Province of Galapagos with the purpose to reduce the energy consumption and properly manage waste from these devices (refrigerant and scrap).

Baseline replacement equipment.

The replacement of inefficient air conditioning and refrigeration equipment takes into consideration the ranges of energy consumption for equipment corresponding to level A of electricity consumption, which have the following consumption improvement values.

Table 24. Reference power consumption ranges (efficiency in refrigeration and air conditioning equipment)

Reference power consumption ranges	
Range	**Percentage of improvement [21] (%)**
A	**67.5**
B	**77.5**
C	**92.5**
D	**107.5**
E	**122.5**
F	**132.5**

[21] The percentage is with respect to the national reference energy consumption of equipment without efficiency category

- **Refrigeration Equipment**

The national market began the commercialization of refrigeration equipment of domestic use with a best efficient level, with average saving ranges between 450 (commercial) and 250 (residential) kWh/year, corresponding to the A range, regarding the Ecuadorian Technical Regulation – RTE 035 (First review) (INEN , 2020).

- **Air-conditioning Equipment**

Recent referential data provided by national suppliers report the sales distribution of air-conditioning units in the insular region, with 53% of units of 12,000 BTU/h of Split type. Additionally, there are 25% of window type units, and the remaining units are Split type for the total of the surveyed sample for the two sectors.

Energy savings caused by the replacement air conditioning is quantified in approximately 700 kWh/year, due to the 67.5% improvement in efficiency compared to equipment without category A

Expected results due the replacement of equipment.

Based on the results obtained for the first phase, it is expected to continue with the energy saving via the replacement of old equipment by other with most efficient technology, and below the data and suppositions considered for the next calculations are detailed:

Table 25. RENOVA Second Phase results (Energy Saving)

Sector		Equipment to replace				Saving in Electricity (MWh/year)
	Equipment	Santa Cruz Baltra	San Cristóbal	Isabela	Floreana	
Residential	Air conditioners	820	300	150	30	910[22]
	Refrigeration	1275	350	250	25	475[23]
Commercial	Air conditioners	576	125	85	8	555.8
	Refrigeration	380	95	50	5	238.5[24]
Total						**2,179.3**

Source: (MERNNR, 2020) (Market Study Galapagos, 2020)

After the completion of the Project, the total of replaced equipment yearly will generate a saving of 2,179.3 MWh/year.

It is considered that the equipment will be replacement with the following progressive plan.

2024	**2025**	**2026**
30%	60%	100%

From the evaluation of surveys applied to potential beneficiaries, 79% of the potential market responded that they would be willing to change their air conditioning and product refrigeration equipment for more up-to-date ones that consume less electricity, through the products offered by public and private banks.

[22] Saving evaluated at 700 kWh/ equipment*year (residential/commercial sector)

[23] Savings evaluated at 250 kWh/equipment*year (residential sector)

[24] Savings evaluated at 450 kWh/equipment*year (commercial/tourist sector)

8. Mitigation scenarios and GHG emissions.

8.1. Grid emissions factors

To calculate the mitigation of greenhouse gases due to the projects mentioned in the previous section, both for the incorporation of new sources of renewable generation as well as energy efficiency, the emission factors of each isolated system have been calculated (Baltra-Santa Cruz, San Cristobal, Isabela and Floreana), applying the CDM methodology TOOL07.

This emission factor is referred as the combined margin emission factor (EFgrid,CM,y), which itself is a weighted average of the build margin emission factor (EFgrid,BM,y) and the operating margin emission factor (EFgrid,OM,y). (IRENA, 2021)

To calculate the baseline emissions, TOOL07 proposes to follow six steps:

1. Identify the relevant electricity systems.
2. Choose whether to include off-grid power plants.
3. Select a method to determine the operating margin emission factor.
4. Calculate the operating margin emission factor.
5. Calculate the build margin emission factor.
6. Calculate the combined margin emission factor.

The process followed to calculate the emission factors in compliance with the application of the TOOL07 methodology is presented in an appendix. (IRENA, 2021).

Finally, the combined margin emission factor to be used for each of the four Galapagos Island isolated systems for the year 2020 (base year 2019) is shown in the table below.

Table 26. Galapagos grid emission factors

Isolated System	**Grid Emission Factors** (tCO2/MWh)
Santa Cruz-Baltra	0.827
San Cristóbal	0.728
Isabela	0.767
Floreana	0.805

Source: (IRENA, 2021)

The emission factors of each isolated grid are applied to calculate the projected reduction for each of the islands and in a summary way the contribution of each project in the systems considered will be added.

In the case of calculating emissions from fuel transport from the continent, in accordance with the Guidelines for Measuring and Managing CO2 Emission from Freight Transport Operations (ECTA CEFIC, 2011), the emissions have been calculated from maritime transport fuel to the islands. PUNA ship transports fuel to the islands, which transports 2,400 tons of Diesel. The follow table shows the emission factor used to calculate the transport from mainland.

Table 27. Emission factor due to transport Diesel from mainland

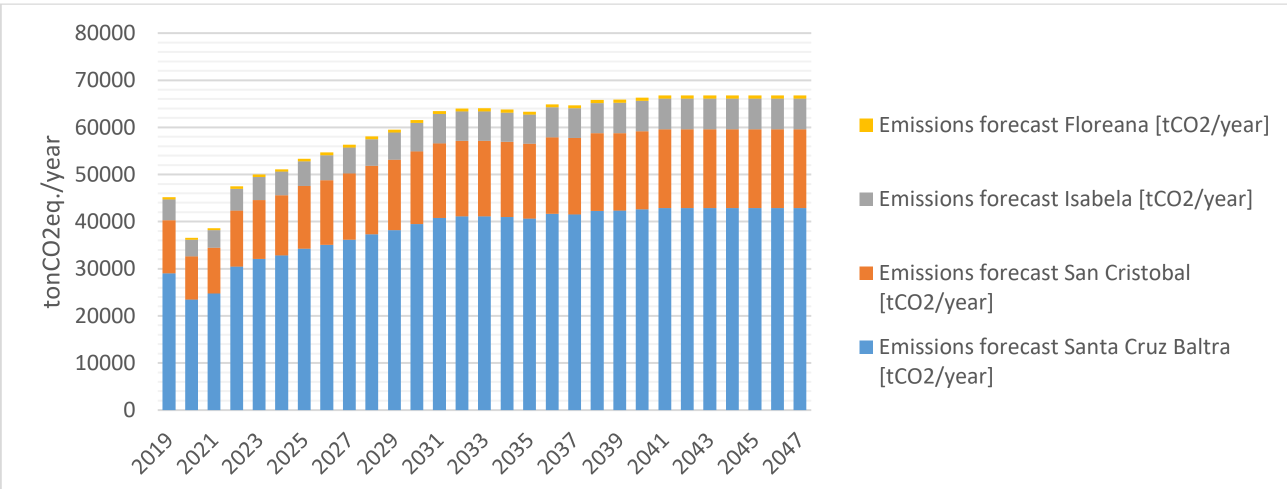
Assumption	**Values**
PUNA ship (2,400 tons of Diesel)	5 gCO_2/tonne-km
Mainland-Galapagos distance	1.000 km
Diesel density	0,850 kg/liters
Volume factors transform	1 gallon=3.78 liters

Source: (ECTA CEFIC, 2011)

8.1.1. Business as Usual Scenario.

The emission trend scenario takes into consideration the study about forecast of demand for each island (see section Demand Forecast), which applying the grid emission factor is calculated the BAU scenario, the following figure shows the trend scenario, as a result of demand forecast in each island.

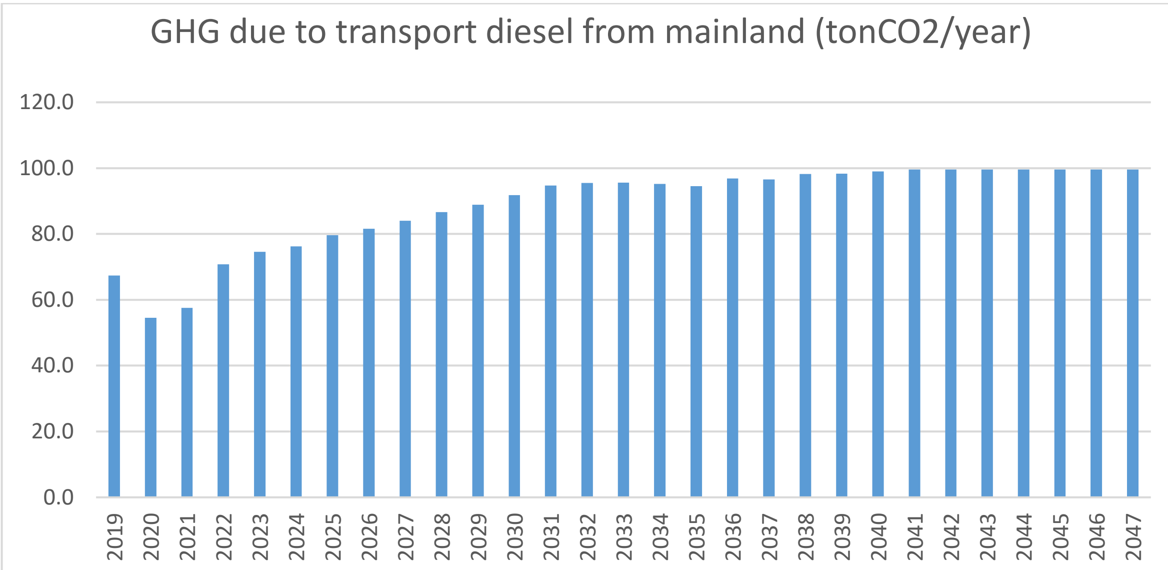
Figure 42. Emissions Forecast (tCO_2 equivalent)



Source: Demand forecast based on (IRENA, 2021)

Emissions due to the transport of fuel from the continent to the islands, generates a trend scenario, due to its increasing rate of consumption, the following figure shows this trend based on the projection of the demand and need for fuel in an assumption that islands would generate all electricity from diesel.

Figure 43. Emissions Forecast by diesel transport from mainland (tCO_2 equivalent)



Source: Feasibility study based on (ECTA CEFIC , 2011)

8.1.2. Mitigation Scenario Component 1

Reduced energy dependency of the Galapagos livelihoods through increased low-emission energy access and power generation.

The following table shows the forecast of renewable generation in the Conolophus project, as a result of the feasibility study for the construction of the project of 14.8 MWp PV solar plant, 10.2 MW / 40.9 MWh battery energy storage system and an associated control system. (ELECGALAPAGOS, 2020)

Table 28. Conolophus generation forecast

Year	Demand Forecast [MW/year]	Renewable Energy share (Conolophus)	Generation forecast MWh
1	41.658,91	55%	22912,40
2	44.271,51	52%	23021,19
3	46.876,01	49%	22969,24
4	49.480,56	47%	23255,86
5	52.213,54	45%	23496,09
6	54.988,95	42%	23095,36
7	57.801,08	40%	23120,43
8	60.668,49	38%	23054,03
9	63.641,25	37%	23547,26
10	66.696,03	35%	23343,61
11	69.830,74	33%	23044,14
12	73.042,96	32%	23373,75
13	76.329,89	30%	22898,97
14	79.688,40	29%	23109,64
15	83.115,00	27%	22441,05
16	86.605,84	26%	22517,52
17	90.156,67	25%	22539,17
18	93.762,94	24%	22503,11
19	97.419,70	23%	22406,53
20	101.121,64	22%	22246,76
21	104.863,15	21%	22021,26
22	108.638,22	21%	22814,03
23	112.440,56	20%	22488,11
24	116.263,53	19%	22090,07

25	120.100,23	19%	22819,04

Source: Authors based on (ELECGALAPAGOS, 2020)

Applying the emission factor for the Baltra Santa Cruz system, indicated in this section, the following emission reduction is obtained.

Table 29. Conolophus mitigation.

Mitigation of emission in 25 years (GCF Program)
472,323 [t CO2eq.]

Source: Authors

Distributed renewable power generation projects.

The reduction of emissions due to distributed generation is analyzed for each of the islands by applying the emission factor and the expected generation in all installed systems.

Table 30. Mitigation due to Distributed generation

System	**Energy reduction[25] [MWh/year]**	**Grid emission factor [tCO2/MWh][26]**	**Mitigation GHG emissions [tCO2eq/year]**	**Mitigation GHG emissions in 25 years (GCF Program) [tCO2eq.]**
Santa Cruz-Baltra	3,183	0.827	2,632	57,339
San Cristobal	690	0.728	502	10,942
Isabela	628	0.767	481	10,492
TOTAL			**3,616**	**78,773**

Source: Authors based on (IRENA, 2021)

[25] ELECGALAPGOS, 2018

[26] (IRENA, 2021)

Reduced energy consumption by the Galápagos livelihoods through energy efficiency.

For the mitigation analysis of the replacement of energy inefficient equipment, the average emission factor of all the systems is considered. The nest Table shows mitigation per year by sector and total emission reduced at 25 years program.

Table 31. Mitigation due to replacement (energy efficiency)

Sector	Device replaced	Saving in Electricity [MWh/year]	Mitigation [tCO2eq/year]	Mitigation GHG emissions in 25 years (GCF Program) [tCO2eq.]
Residential	Air conditioners	910[27]	725	13,747
	Refrigerator	475[28]	380.27	7,210.5
Commercial	Air conditioners	555.8	447.3	8,481.5
	Refrigerator	238.5[29]	191.6	3,633
TOTAL		**2,179.3**	**1,744.2**	**33,072**

Source: Authors

[27] Saving evaluated at 700 kWh/ equipment*year (residential/commercial sector)

[28] Savings evaluated at 250 kWh/equipment*year (residential sector)

[29] Savings evaluated at 450 kWh/equipment*year (commercial/tourist sector)

Mitigation of total emissions (Component 1)

Values showed below corresponds to the sum of the prioritized and evaluated projects in this feasibility report.

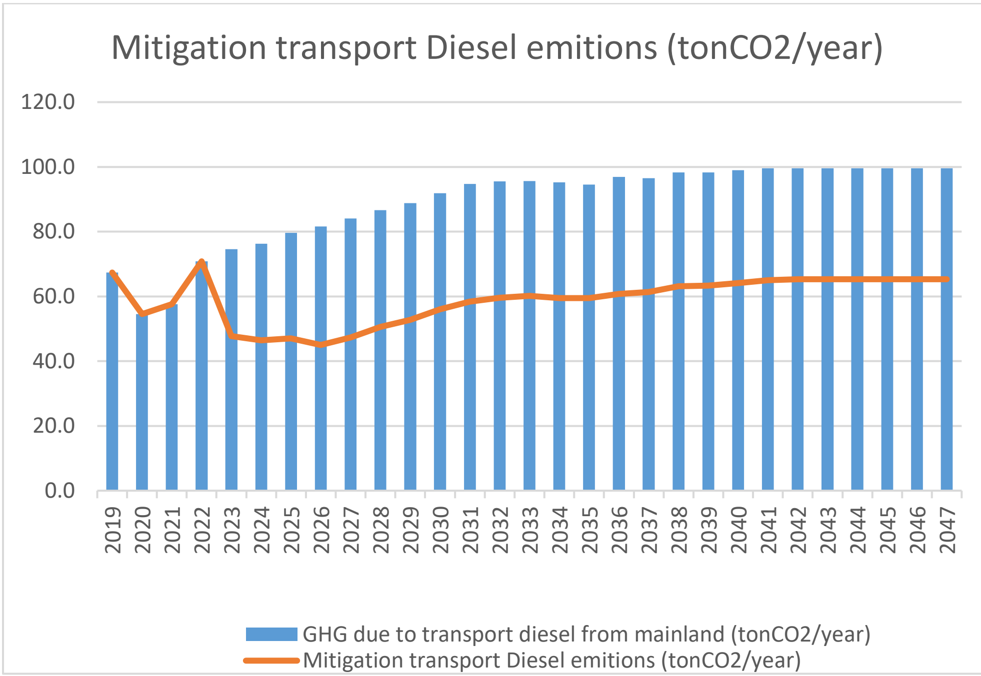
Table 32. Total mitigation Component 1

Projects	Mitigation of emission 25 years. [tCO2eq.]
Centralized generation (Conolophus)	472,323
Distributed generation	78,773
Energy efficiency	33,072
TOTAL Mitigation	**584,169**

* Equipment will be installed progressively during the first 3 years; degradation of PV system is calculated in 0,5% per year.

Additionally, because of the reduction in consumption of Diesel that must be transported to the Islands, there will be a reduction as indicated in the following figure. Emissions reduction related to the decrease in tonnage of imported fuel by boat was estimated using the "Guidelines for Measuring and Managing CO2 emissions from Freight Transport Operations" (ECTA CEFIC , 2011).

Figure 44. Mitigation by transport of fuel [tCO2/year]



Source: Authors based on feasibility study and (ECTA CEFIC , 2011)

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