Sustainability economic study of the islands of the Azores Archipelago using photovoltaic panels, wind energy and storage system

Inês Boga Melo
ines.b.melo@tecnico.ulisboa.pt

Instituto Superior Técnico, Lisboa, Portugal

November 2019

Abstract

Currently, the nine islands of the Autonomous Region of the Azores have fossil fuel-fired power stations as the main source of electric power. Each island has an independent electrical system classified as an isolated micro-system, given its size and location. The goal of this contribution will be to analyse the best set of technologies to have nine sustainable hybrid systems. For this purpose, some factors will be considered, such as actual data production of the island, economic scenarios, growth perspectives of consumption and reliability of supply. The results of these studies will allow us to conclude on the applicability of these systems, quantifying the consequent socio-economic, environmental and fossil energy-saving benefits.
Keywords: Energy Consumption; Isolated Micro Network; Network Stability; Renewable Energies; Fotovoltaic Conversion; Eolic Conversion

1. Introduction

The Azores archipelago is geographically located in a region where three lithospheric plates are connected: the American, the Eurasian and the African. A great deal of geomorphological aspects have to be considered because there are several types of eruptions at the origin of each island. In general, the landscape is characterized by a vigorous and busy orography, with the maximum altitude of the islands quite variable, ranging between 402 m in Graciosa and 2351 m in Pico mountain, the highest point in Portugal. [11]

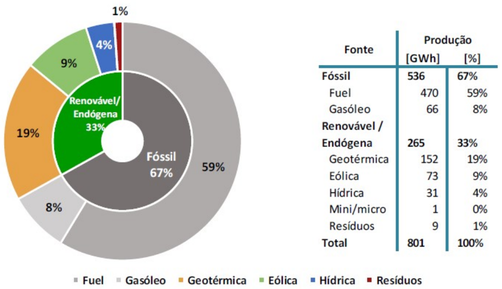
Regarding the climate, the region is in the transition zone between subtropical hot and humid air masses, the subpolar air fresh and drier air masses. Thus, it is considered as a temperate wet, mesothermal temperate climate with characteristics, given the low thermal amplitude, persistent wind, high rainfall, and relative humidity.

The main goal of this dissertation is to find a solution of a hybrid energy system, consisting of wind, photovoltaic energy, and an energy storage system. The focus is maximizing the contribution of generators and minimizing the cost of generating fossil electricity in the nine micro grids of the archipelago. In this case, the energy storage system is used to store energy during periods of high electricity production and return it to consumption during periods of low solar irradiance or wind speed. [17]

Currently, the existing energy systems on the islands depend mainly on the use of fossil fuels that has to be transported to the islands, accompanied by high costs and environmental impacts. In this context, a growing use of renewable energy is a great opportunity to reduce these problems. However, the integration of floating renewables, especially in small and weak island networks, is a technical challenge. Energy storage is a technical solution for decoupling electricity supply and demand, thus providing flexibility. By combining renewable energy and storage systems into hybrid energy approaches, it is possible to replace fossil electricity generation by approximately 100%. In conclusion, the use of renewable sources as an alternative to fossil electricity generation on islands is becoming more and more attractive from the economic and ecological point of view. [19]

2. Background

During 2016 the total energy consumption in Azores was 801 GWh, in which 33% of the energy produced was generated from renewable energy sources and the remaining was produced in fuel oil and diesel plants. From the data presented in the graph of the figure 1, it appears that the largest share of electricity production in the region comes from fossil fuels. At the level of renewable energy production in the region, we can verify that the geothermal plants are responsible for the largest share of production, due to the availability of the resource, the stable production of these plants and their ability to guarantee power to the system. Moreover, 9% of total production come from wind production, with a high degree of intermittency. Finally, hydropower has a seasonal behavior. [1]



Fonte	Produção [GWh]	Produção [%]
Fóssil	**536**	**67%**
Fuel	470	59%
Gasóleo	66	8%
Renovável / Endógena	**265**	**33%**
Geotérmica	152	19%
Eólica	73	9%
Hídrica	31	4%
Mini/micro	1	0%
Resíduos	9	1%
Total	**801**	**100%**

Figure 1: Energy Production in the region [1]

To do the sizing for each island, it is necessary to analyse the general characteristics of each isolated micro-network. Therefore, it is necessary to synthesise various data from each system, namely the evolution of emission values for the network, which were obtained through the documents [8] [4] [3] [7] [2] [6] for the years 2006, 2013, 2018 and 2019. The total emission data rather than consumption data will be selected as the emission data already take into account network losses. All resources currently installed on the islands and the characteristics of each network will be evaluated in order to observe the current power of renewable sources so that it is possible to manage the necessary sizing for each island [1].

All the data that will simulate the production of photovoltaic panels and wind turbines, namely irradiance, temperature, and wind speed will also be addressed. After defining the locations for renewable sources, we are able to size the system of each island. It is intended to install a hybrid power system with a power storage system, so given the distance between the sources, it becomes necessary to install voltage booster substations. Thus, we can observe a single-line scheme of this system that is intended to be implemented in figure 2.

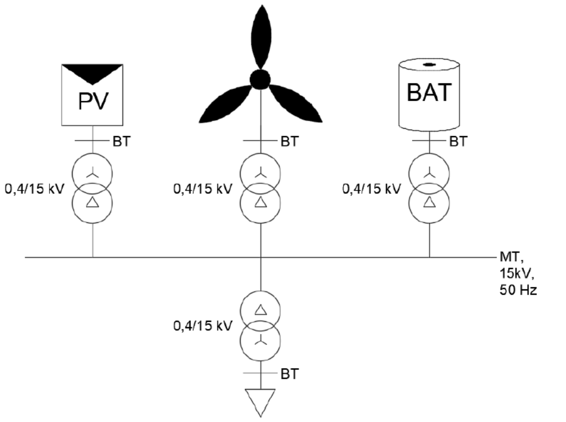


Figure 2: General scheme of the hybrid system to be installed in the Azores archipelago [20]

2.1. Key features of the network

Everything described above will be presented here only for the largest island of the archipelago (São Miguel). In this case, the following steps were used to make the design, indicated in figure 3, analysing the data of each island present in the documents [8] and [5].

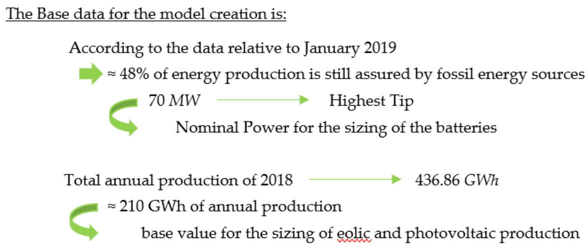


Figure 3: Baseline flowchart for hybrid system sizing

The positions of the various system components are shown in figure 4. The location of the Battery Center is close to the Caldeirão Thermoelectric Power Station, as well as the photovoltaic park, to reduce cable costs. Concerning the wind farm, the objective will be to add the existing park on the Graminhais plateau. The connection to the plant will be made through MT cables with a distance of approximately 30 km.

Figure 4: Hybrid system location on São Miguel island

The figure 5 was obtained from the EDA documents - Electricity of the Azores [8] [4] [3] [7] [2] [6], it is possible to analyse the evolution of energy production and the corresponding evolution of the emission of renewable energies over the years, namely between 2006 and 2019. This graph shows the months of January and August, since they are the critical months in terms of production and for this problem, it is relevant to compare the energy production of a summer month with a winter month, because wind and photovoltaic production fluctuate.

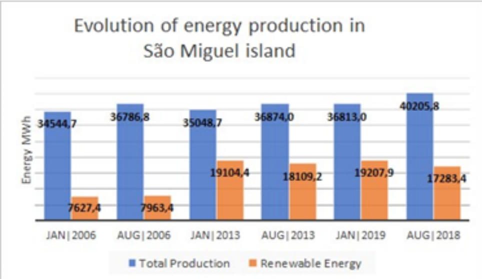


Figure 5: Evolution of total energy production and its amount of renewable energy in São Miguel

2.2. **Data for Wind Turbine Sizing**

For wind data, average hourly data were obtained for one year (figure 6 - [15]). These data were taken from a more central position of the archipelago on Graciosa Island and this is the data which will be used for the sizing of all islands.

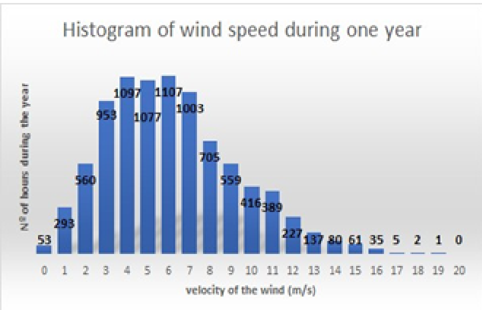


Figure 6: One-year wind speed histogram

It will still be necessary to take into account the existence of a medium voltage cable that will connect the wind farm to the battery plant. The cable will have approximately 30 km as shown in the figure 4.

2.3. **Data for sizing photovoltaic panels**

From the data obtained in [13] we can plot the monthly mean irradiance on the island of São Miguel over a year, as represented in Figure 7. Through the irradiance data, it is possible to estimate the annual photovoltaic energy production. In terms of temperature these values will not influence the efficiency of the panels, as the ambient temperature is mesothermal never reaches values above 45°C allowing the temperature of the photovoltaic module not exceed the operating temperature range.

Figure 7: Monthly average irradiance

3. Implementation

3.1. Technologies for photovoltaic energy production

3.1.1 Polycrystalline Photovoltaic Panels

Crystalline silicon technology is feasible for this type of project, monocrystalline panels have a higher efficiency. However, the cost is higher compared to polycrystalline panels. Both technologies guarantee the project's viability and long-term yield, but for the Azores climate type, where there is good sun exposure, the best option is the polycrystalline panels as they give a good price-quality ratio.

The panels chosen were from SolarWatt [10], because according to the list of solar panels 2019 prepared by *Bloomberg New Energy Finance PV Module Tiering System* [12] are the most guaranteed panels in the world. For this case of study, this is really significant because as the climate of the Azores is very variable it is important to have a good guarantee. SolarWatt panels (Vision 60P model) have the following specifications: Pmp=280Wp, Ump=31.30V, Imp=9.02A, Uc=38.90V, Isc=9.68A, η=17%. This was the model of choice, because are the most commonly panels used that have a maximum power of 280 Wp.

Since the photovoltaic park consists of polycrystalline panels, 5 panels will be connected in series, and connected to these is a charge controller (MPPT of 1500 W) and an inverter (1600 W). Between them, the panel sets will be connected in parallel.

3.1.2 Photovoltaic cells Cadmium Telluride (CdTe)

Cadmium telluride (CdTe) is a direct bandgap semiconductor very well suited to the solar spectrum with a high bandgap of 1.45 eV [16], a really efficient solar cells. These cells have the lowest greenhouse gas emissions per kWh of electricity produced [18].

The solar panels are commercially available as colorless and frameless modules. Transparency ranges from 10% to 50% and is inversely proportional to the power output. When applied to glass, the windows can be single or double glass [14].

This technology is a good option for island applications as the panels will not occupy a useful area of the island. House windows will be replaced by these single or double glass panels.

For the sizing of these panels will be made the following approximations: Each house will have 16 panels, two panels forming a door or a window. Which gives an average of 8 windows or doors per house. Considering that, in each house live 4 inhabitants, the total number of houses is:

$$N^{o}{}_{houses} = \frac{N^{o}{}_{inhabitants}}{4} \quad (1)$$

The CdTe solar panels chosen were those with 30 % transparency (model PS-CT-56) [14] and have the following specifications: Pmp=56Wp, Ump=87V, Imp=0.64A, Uc=116V, Isc=0.68A, η=11.9%.

The connection of the photovoltaic panels in the house, in this case, will be 4 panels in series, and the 4 sets of panels are connected in parallel. Each house will have a charge controller (MPPT of 1500 W) and an inverter (1600 W). It will also have an ABB single-phase distribution transformer (specially designed for aerial distribution residential cargo power) with a power of 5 kVA. Thus, the energy produced by these panels may be directly connected to the distribution network of each island.

3.2. Technologies for wind energy production

The typical power curve of these turbines has a starting speed of 3 m/s, a nominal speed of 14 m/s and cutting speed (maximum operating speed) of 25 m/s. This curve, together with the results shown in figure 6 which represents the wind speed per hour for a year in a histogram, makes it possible to estimate the total monthly wind production over a year.

3.3. Storage

Installing a battery center on each island is very important as it allows for a power factor correction in the network. Reactive energy is an integral part of utility bills and constitutes a significant financial burden. Reactive power consumption can, however, be excluded from the bill by installing a power factor correction system. Power factor correction is done by replacing the reactive power consumption of the grid through battery generation. Reducing reactive energy promotes proper functioning of facility energy, maximizing the installed energy harvest. It should also be noted that the investment in this system can be recovered through the saved reactive energy.

To measure how many battery banks each island needs, it was determined that each island would have an installed battery power equal to the island's peak energy reached in January 2019.[8] Thus, knowing the efficiencies of the AC/DC inverter, of the MPPT, and the capacity of each battery bank, it is possible to obtain the number of banks required for each island.

$$E_{bat} = \frac{E_{tip}}{\eta_{inv} \times \eta_{MPPT}} \quad (2)$$

$$n_{bat} = \frac{E_{bat}}{E_{bank}} \quad (3)$$

Battery banks should be placed in parallel so that the output voltage does not exceed the operating voltage of AC/DC drives (Voltage Range V_{DC} 634 V - 1000 V; Voltage Range V_{AC} 347 V - 520 V; Rated Power P_{DC} 2515 kW). It has been stipulated that an inverter is connected to 40 battery banks. Each AC/DC inverter is connected with an ABB medium power transformer for distribution with a power of 3000 kVA.

Regarding the type of batteries currently used are the most lithium ion and nickel metal hydride (NiMH), since they are the most mature and traditional systems. Lithium-ion batteries are evolving rapidly as the electric car industry drives its development. Nowadays they are the most popular choice for solar energy storage due to warranty, design, and price.

Both can be applied to systems that require high energy density in a short time, and for this case, the most suitable are lithium-ion batteries, given that they perform better but are more expensive. However, other solutions are not only expensive but also have a lower rate of energy management efficiency, making lithium-ion batteries the most reliable choice. Thus, LG Chem's R800 battery bank was chosen, and the nominal characteristics of this battery bank are 725 V of nominal voltage, 60 Ah of nominal capacity, 44.96 kWh of power and a C-rate of 2.

4. Sizing for each island of the archipelago

The sizing of the photovoltaic installation will be done in such a way as to produce approximately half of the production that is currently still provided by the island's thermoelectric plants. Wind energy will be sized to produce the remaining 50% of fossil production. Wind and photovoltaic energy must be balanced as they complement each other in different seasons. On all islands except Flores and Corvo, which produce the least, the sizing will be done with wind turbines with a capacity of 2 MW. The sizing for Corvo and Flores islands will be done with turbines with a capacity of 150 kW.

This sizing will take into account the weather data presented above. Since each island will be evaluated according to its energy production needs, both wind and photovoltaic production.

4.1. Santa Maria

According to the most recent data, annual energy production in 2018 is known to have been 20,64 GWh [5]. By checking data for January 2019 [8], it is concluded that approximately 76% of energy production is still provided by fossil energy sources. It is still necessary to ensure the production of 15.69 GWh for renewable energy, so the sizing made will be based on this value.

4.1.1 Photovoltaic Production

Polycrystalline Photovoltaic Panels

Through the Photovoltaic Geographic Information System [13], it was possible to simulate photovoltaic production with crystalline silicon cells in Santa Maria island. The design chosen was a photovoltaic park with 8.4 MW nominal power. In table 1 there is the details of the photovoltaic park.

Table 1: System design data with polycrystalline photovoltaic panels

No. of panels	30000
PV installed (P_{max})	8400 kWp
Irradiation in the annual plan	1700 kWh/m^2
Annual photovoltaic production	12400 MWh

Photovoltaic cells Cadmium Telluride (CdTe)

Since the Provisional Annual Estimates of Resident Population - Latest data update: June 15, 2018 (INE), state that Santa Maria island has 5652 inhabitants. Given the approximations for the sizing of this technology, referred above, it is concluded that the island has approximately 1413 houses. For this case, the maximum rated power installed is 1266.05 kW. In table 2 you can check the details of this sizing.

Table 2: Data for system dimensioning with Cadmium Telluride photovoltaic panels

No. of panels	22608
PV installed (P_{max})	1266,05 kW
Tilt angle	90º
Annual photovoltaic production	1090 MWh

4.1.2 Wind production

In figure 8 it is possible to observe the annual production of the 2 wind turbines, with August having a very low production and November having the highest production.

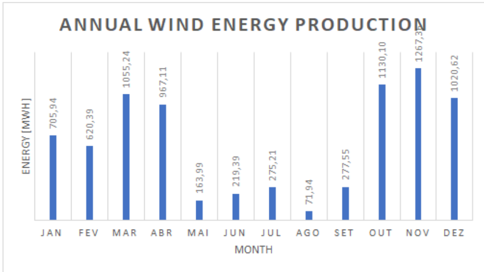


Figure 8: Annual wind energy production on Santa Maria island

4.1.3 General Production

In figure 9 it is possible to observe the total consumption of the island in blue over the 12 months of 2018 and the total production of the various renewable energy sources in orange, which was produced by sources already installed and the suggested sizing estimates.

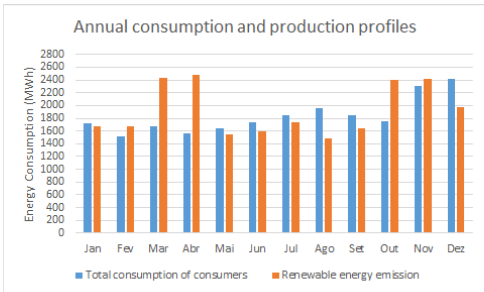


Figure 9: Estimated total renewable energy emission and monthly consumption for 2018 in Santa Maria

4.1.4 Storage

According to the records in the document [8] for January 2019, the highest peak of Santa Maria recorded was 3351 kW. Thus, according to the formulas 2 and 3 it is concluded that this island needs 78 R800 battery banks.

For the other eight islands, the sizing was done in a very similar way. So it will be presented the general production and storage conclusions for the other micro-networks.

4.2. São Miguel

According to the most recent data, annual energy production in the last year of 2018 is known to be 436.90 GWh [5]. Taking into account the figure 3 it is found that it is still necessary to ensure the production of 210 GWh for renewable energy, so the sizing made will be based on this value.

4.2.1 General Production

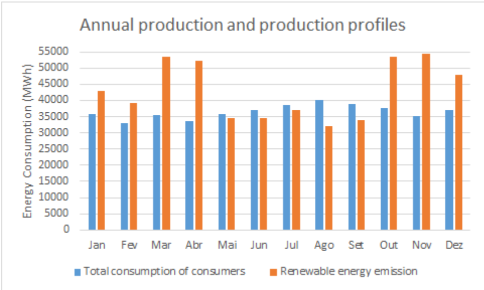


Figure 10: Estimated total renewable energy emission and monthly consumption for 2018 in São Miguel

4.2.2 Storage

According to the records contained in the document [8] for January 2019, the maximum peak of São Miguel recorded was 67763 kW. Thus, taking into account the formulas 2 and 3 it is concluded that this island needs 1573 R800 battery banks.

4.3. Terceira

According to the most recent data, annual energy production in the last year of 2018 is known to be 190.76 GWh [5]. Checking data for January 2019 shows that approximately 59% of energy production is still provided by fossil energy sources. It is still necessary to ensure the production of 113 GWh for renewable energy, so the sizing made will be based on this value.

4.3.1 General Production

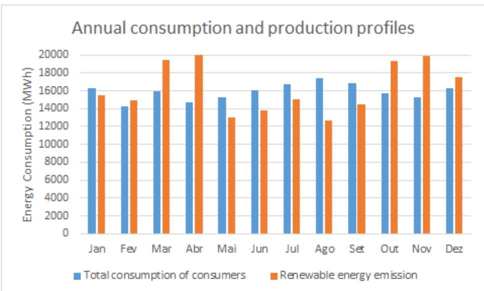


Figure 11: Estimated total renewable energy emission and monthly consumption for 2018 in Terceira

4.3.2 Storage

According to the records in the document [8] for January 2019, it appears that the peak of the third recorded was 29724 kW. Thus, taking into account the formulas 2 and 3 it is concluded that this island needs 690 battery banks.

4.4. Graciosa

According to the most recent data, it is known that the annual energy production in the last year of 2018 was 13439,81 MWh [5]. When checking data for January 2019, it is concluded that 100% of energy production is still provided by fossil energy sources. However, in August 2019 the "Graciólica" project was inaugurated, which will allow 65% of the energy consumed by the island to be secured by a hybrid energy system implemented. Thus the sizing for Graciosa will be based on 35% not yet assured by renewable energy. As this project has already implemented a wind farm with a capacity of 4.50 MW, the sizing will be done with photovoltaic energy only. For batteries, a system with a capacity of 2.60 MWh is currently in place, covering the tip of the island which in January 2019 was 2.27 MW [8].

4.4.1 General Production

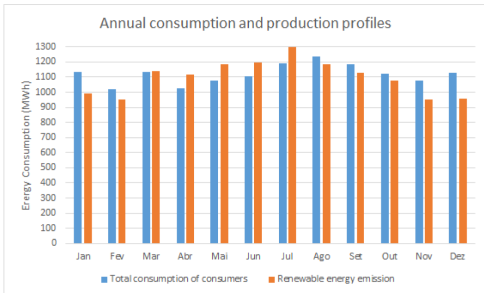


Figure 12: Estimated total renewable energy emission and monthly consumption for 2018 in Graciosa

4.5. São Jorge

According to the most recent data, it is known that the annual energy production in the last year of 2018 was 28901,97 MWh [5]. When checking data for January 2019 [8], it is concluded that approximately 89% of energy production is still provided by fossil energy sources. The production of 25722.75 MWh for renewable energies still needs to be assured, so the sizing will be based on this value.

4.5.1 Storage

According to the records contained in the document [8] for January 2019, the highest peak of São Jorge recorded was 4715 kW. Thus, taking into account the formulas 2 and 3 it is concluded that this island needs 109 battery banks.

4.5.2 General Production

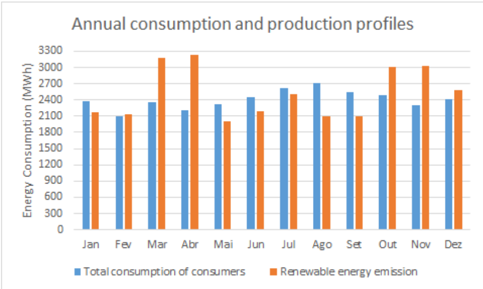


Figure 13: Estimated total renewable energy emission and monthly consumption for 2018 in São Jorge

4.6. Pico

According to the most recent data, annual energy production in 2018 is known to have been 44871.52 MWh [5]. By checking data for January 2019 [8], it is concluded that approximately 85% of energy production is still provided by fossil energy sources. It is still necessary to ensure the production of 38140.79 MWh for renewable energy, so the sizing made will be based on this value.

4.6.1 General Production

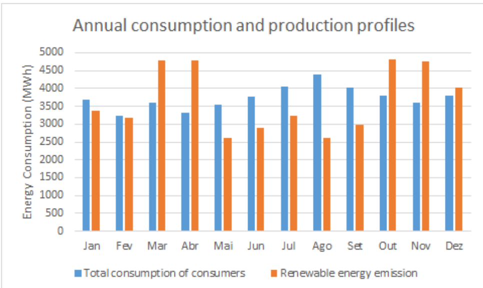


Figure 14: Estimated total renewable energy emission and monthly consumption for 2018 in Pico

4.6.2 Storage

According to the records in document [8] for January 2019, the peak recorded was 7299 kW. Thus, taking into account the formulas 2 and 3 it is concluded that this island needs 169 battery banks.

4.7. Faial

According to the most recent data, it is known that the annual energy production in the last year of 2018 was 46315.50 MWh [5]. Checking data for January 2019 [8] shows that approximately 83% of energy production is still provided by fossil energy sources. The production of 38441.87 MWh for renewable energies still needs to be assured, so the sizing will be based on this value.

4.7.1 General Production

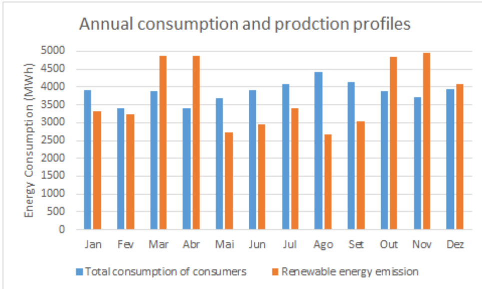


Figure 15: Estimated total renewable energy emission and monthly consumption for 2018 in Faial

4.7.2 Storage

According to the records in the document [8] for January 2019, the maximum peak of Faial registered was 7648 kW. Thus, taking into account the formulas 2 and 3 it is concluded that this island needs 177 battery banks.

4.8. Flores

According to the most recent data, annual energy production in the last year of 2018 is known to have been 11381.60 MWh [5]. Checking the data for January 2019 [8], it is concluded that approximately 39% of energy production is still provided by fossil energy sources. The production of 443.99 MWh for renewable energy is still to be assured, so the sizing will be based on this value.

4.8.1 Storage

According to the records in the document [8] for January 2019, the maximum peak of Flores recorded was 7648 kW. Thus, taking into account the formulas 2 and 3 it is concluded that this island needs 43 battery banks.

4.8.2 General Production

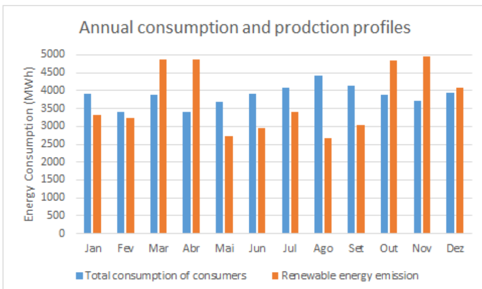


Figure 16: Estimated total renewable energy emission and monthly consumption for 2018 in Faial

4.9. **Corvo**

According to the most recent data, annual energy production in 2018 is known to have been 1562.75 MWh [5]. When checking data for January 2019 [8], it is concluded that this island has no renewable energy sources yet. The energy production is still assured by fossil energy sources. Thus, sizing will be based on the total value of current annual production.

4.9.1 General Production

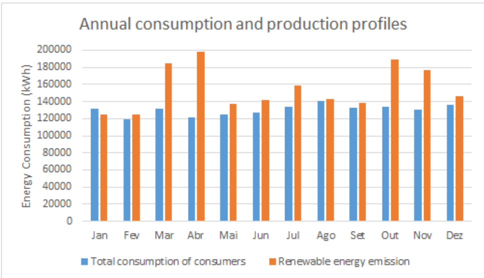


Figure 17: Estimated total renewable energy emission and monthly consumption for 2018 in Corvo

4.9.2 Storage

According to the records contained in the document [8] for January 2019, it can be seen that the maximum crow tip recorded was 295 kW. Thus, taking into account the formulas 2 and 3 it is concluded that this island needs 7 battery banks.

5. Results

To evaluate the economic results will be presented the costs of each technology presented in the previous chapter following the sizing presented for each island. In the end, a conclusion will be state for what is on what is the best solution in terms of economic and socio-economic impacts.

5.1. Total electricity costs and turnaround time of solutions presented

Considering the region's three-hour tariffs shown in table 3. It is possible to obtain a different total cost of electricity per year for each island, depending on its consumption.

During one day there is 4 rush hours, 10 full-time hours and 10 empty hours and in order to account for the energy cost of each island and since it was not possible to obtain the details of the consumption at the different intended times, was made an estimate of the annual consumption at the different tariffs.

Table 3: Tariffs in the Autonomous Region of the Azores - 2019 [9]

Medium Voltage	Rush Hour	0.1251
Active Energy	Full Time	0.1064
(EUR/kWh)	Empty Time	0.0733
Low tension	Rush Hour	0.1452
Active Energy	Full Time	0.1268
(EUR/kWh)	Empty Time	0.0830
Street lighting	Rush Hour	0.2237
Active Energy	Full Time	0.1651
(EUR/kWh)	Empty Time	0.1000

By averaging the current price of electricity in the region it is concluded that the estimate is 128 EUR/MWh. For the sizing of each island, it is possible to obtain the years of return on investment from like it is explained in the formula 4.

$$\frac{TotalInvestment}{TotalCostElectricity/year} \tag{4}$$

5.2. Results Analysis

According to the consumption data of the document [5], it is found that the total consumption for each island of the archipelago. Thus and from the data in table 3 it is possible to conclude about the total electricity revenues for the year 2018.

Table 4: Consumption and total cost of electricity in the Azores in 2018

	Annual Consumption	**Total Revenue**
S.Mar	19.48 GWh	2131kEUR
S.Mig	411.12 GWh	43772kEUR
Ter	176.45 GWh	18662kEUR
Grw	12.72 GWh	1398kEUR
S.Jge	26.80 GWh	2920kEUR
Pic	41.63 GWh	4595kEUR
Fai	43.78 GWh	4735kEUR
Flo	10.86 GWh	1199kEUR
Cor	1.44 GWh	161kEUR

In order to assess the total investment made for each project, was necessary to calculate the NPV (6), LCOE (EUR/MWh) (5) for solution 1 and 2 (table 5 and 6) respectively.

$$LCOE = \frac{I_t(i + cOM)}{E_a} \tag{5}$$

$$NPV = (R - cOM)k_a - I_t \tag{6}$$

Table 5: Summary of data evaluating the investment made on each island for the first solution

Island	NPV	LCOE	Return (years)	Total MEUR
S.Mar	94M	97.84	6.19	13.2
S.Mig	315M	52.12	3.39	148.4
Ter	106M	75.04	4.91	91.7
Grw	12M	33.94	2.14	2.99
S.Jge	12M	103.44	6.58	19.2
Pic	22M	91.57	5.75	26.4
Fai	24M	87.41	5.60	26.5
Flo	8.8M	51.83	3.25	3.9
Cor	0.3M	140	8.70	1.4

Table 6: Summary of data evaluating the investment made on each island for the second solution

Island	NPV	LCOE	Return (years)	Total MEUR
S.Mar	13M	68.19	4.32	9.2
S.Mig	156M	108.07	7.03	307.7
Ter	131M	54.42	3.56	66.5
Grw	13M	21.46	1.35	1.89
S.Jge	11M	107.21	6.82	19.9
Pic	29M	69.37	4.35	20
Fai	30M	67.62	4.33	20.5
Flo	9.7M	39.87	2.50	3
Cor	0.8M	90	5.59	0.9

Concluding all proposed projects are feasible since the Net Present Value is greater than zero, that is, the investment is recovered (the minimum rate of return on capital is reached and even a surplus). It is therefore observed that the turnaround time, given the size of these projects, is low even though this study is still very early. It is already possible to draw some positive conclusions regarding the implementation of the projects.

In some islands, the solution of cadmium telluride panels is more advantageous, however, the power installed with this solution is smaller. Also, this implies greater logistics, as it would be necessary to talk to the residents and change the windows of the houses inhabited by panels, since the photovoltaic park is not concentrated in a good irradiation location, thus making energy management more difficult. Installation prices would also be much higher. It is important to note that the costs mentioned do not include ancillary services to power the plant and substations.

5.3. Socioeconomic Impacts

After presenting a study on various renewable energy sources, it can be stated that the most obvious positive impacts are environmental ones. Although it is also necessary to mention the importance of social and economic impacts for the Azores archipelago.

Emissions associated with raw material processing are also the reason for increased environmental impacts in the freshwater ecotoxicity and eutrophication categories, as well as human toxicity. Recycling metallic resources after decommissioning system components may be an interesting option to reduce the demand for primary metallic resources and thus improve the overall environmental performance of renewable electricity systems. [19]

In short, these isolated hybrid systems can bring more benefits than cons. Industry, the economy and the environment benefit as emissions of CO_2 from the diesel plant are reduced with long term effects. Regarding the security of energy supply, there are improvements in the medium term.

6. Conclusions

Energy production from fossil fuels is sometimes not feasible due to environmental problems, costs and sometimes even difficulty in transport to remote places such as islands. Alternatively, there are renewable energies, and this is where the subject of this dissertation fits.

An isolated micro-network based on the 9 islands of the Azores has been developed. The objective was to replace the diesel thermoelectric power plant with a hybrid power system consisting of wind turbines, photovoltaic panels, and a storage system, and the wind farm is connected to the load in MT. The work developed has made it possible to understand the importance of such projects, considering important factors such as the growth of electricity consumption, availability of endogenous energy sources and the security of electricity supply.

The scaled production systems ensure that the islands' energy needs are met and provide the conditions for local socio-economic development through lower electricity supply costs, greater security of supply and substantially reduced environmental impact.

Acknowledgements

I would like to make a few thanks here to those who provided me with everything I needed over the years, both during the course and in the preparation of this master's dissertation. To my family and friends for their friendship, encouragement, and support. To my dissertation advisors, Prof. João Paulo Neto Torres and Prof. Carlos Ferreira Fernandes, for all the availability in the doubts that arose during this time. Finally, I would like to thank EDA (Electricity of the Azores) and Graciólica for the data available for this study.

References

[1] EDA - CARE *Characterization of Electricity Transport and Distribution Networks in 2016*.

[2] EDA - POEE *Demand and Supply of Electricity, august 2006*.

[3] EDA - POEE *Demand and Supply of Electricity, august 2013*.

[4] EDA - POEE *Demand and Supply of Electricity, august 2018*.

[5] EDA - POEE *Demand and Supply of Electricity, december 2018*.

[6] EDA - POEE *Demand and Supply of Electricity, january 2006*.

[7] EDA - POEE *Demand and Supply of Electricity, january 2013*.

[8] EDA - POEE *Demand and Supply of Electricity, january 2019*.

[9] EDA, Precarious 2019.

[10] Solarwatt - polycrystalline panels 280wp.

[11] Report of the State of Spatial Planning of the Autonomous Region of the Azores, 2003.

[12] Bloomberg new energy finance photovoltaic module tiering system, 2019.

[13] Photovoltaic Geographic Information System, 2019.

[14] Polysolar - ps-ct transparent panels, 2019.

[15] Soda - solar radiation data, 2019.

[16] J. Jean, P. R. Brown, R. L. Jaffe, T. Buonassisi, and V. Bulovic. *Pathways for solar photovoltaics*, volume 8, no. 4, pp. 1200–1219. Energy and Environmental Science, 2015.

[17] Kaldellis, J K , Zafirakis, D , Kaldelli, E L , Kavadias, K . Cost benefit analysis of a photovoltaic-energy storage electrification solution for remote islands, 2009. Renewable Energy.

[18] M. J. De Wild-Scholten. *Energy payback time and carbon footprint of commercial photovoltaic systems*, volume 119, pp. 296–305. Solar Energy Materials and Solar Cells, 2013.

[19] Stenzel, Peter , Schreiber, Andrea , Marx, Josefine , Wulf, Christina , Schreieder, Michael , Stephan, Lars. Renewable energies for graciosa island, azores-life cycle assessment of electricity generation, 2017. Energy Procedia.

[20] Sónia Pinto, Artur Sousa. Sustainable island, 2018. Instituto Superior Técnico.