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A Technical Study of Solar and Biogas Energy Usage in Electric Vehicles in Ilhabela, Brazil

Estudio técnico del uso de energía solar y biogás en vehículos eléctricos en Ilhabela-Brasil

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Abstract

Currently, Hybrid Power Systems (HPS) provide an excellent opportunity for generation of electricity. This paper presents the study of a hybrid system considering two energy sources (solar - biogas) available in the Ilhabela island in the state of São Paulo – Brazil. This system will supply electricity to electric vehicles. The study is based on the calculation of the energy demand of the electric vehicles on the island. Then the capacity of biogas production in Ilhabela is determined. Subsequently, in order to know the energy produced and the amount of biogas needed by the microturbine, an energy analysis of this plant is carried out. Lastly, the energy needed to be generated with the photovoltaic plant is calculated. The results show that, considering a market insertion index of 4% of electric vehicles, the average energy demand is 46.327 kWh/month. On the other hand, the amount of biogas produced on the island is twice what is needed to generate 16.200 kWh/month. Finally, the solar plant will produce 30.127 kWh/month.

Keywords: Biogas, Electric Vehicles, Solar Energy, Ilhabela.

Resumen

Actualmente, los sistemas híbridos de generación de energía se han mostrado como una excelente oportunidad para la generación de electricidad. En este trabajo se presenta el estudio de uno de estos sistemas considerando dos fuentes de energía disponibles (solar – biogás) en la isla Ilhabela en el estado de San Pablo – Brasil, con miras a dotar de energía a vehículos eléctricos. Este estudio se basa primeramente en el cálculo de la demanda de energía de los vehículos eléctricos en esta isla. Luego se determina la capacidad de producción de biogás en Ilhabela. Posteriormente se efectúa un análisis energético de la planta con una microturbina a biogás para conocer la energía producida y la demanda de biogás. Como último paso, se calcula la cantidad de energía necesaria a ser generada con la planta fotovoltaica. Los resultados muestran que, considerando un índice de inserción de mercado del 4 % de los vehículos eléctricos, la demanda energética media es de 46 327 kWh/mes. Por otro lado, la capacidad de producción de biogás en la isla es dos veces mayor a la necesaria para generar 16 200 kWh/mes. Finalmente, la planta fotovoltaica producirá 30 127 kWh/mes.

Palabras clave: biogás, vehículos eléctricos, energía solar, Ilhabela.

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1. Introduction

Energy is considered a fundamental input in productive activities, having an important role in the development process of humanity. Access to modern forms of energy, particularly to electricity, brings a series of social benefits that improve the quality of life of the population [1].

One of the sectors with the highest energy consumption is transportation. In 2014, this sector worldwide was responsible for 28% of global energy demand and 23% of global CO_2 emissions, which come from the consumption of fossil fuels. In relation to the use of oil, this sector consumed 65% of the final global demand [2].

On the other hand, in a scenario of growing concern about climate change, less polluting alternatives are sought for the transport of people and cargo. In this sense, electric vehicles (EV) are being widely disseminated. According to the projections of Bloomberg New Energy Finance [3], in 2040 more than half of the new cars sold in the world will be electric. Unlike combustion vehicles, EVs do not emit greenhouse gases during operation.

However, the energy that feeds their electric motors can originate from different sources of energy, some of them highly polluting, such as coal and oil, making the adoption of EVs less effective as a measure to reduce greenhouse gas emissions. From the perspective of a full cycle analysis, the electricity available to charge the batteries must be generated from renewable or clean sources so that these vehicles have zero emissions [4].

In this sense, hybrid power generation systems or HPGSs are a good alternative. According to Thibaud et al. [5], these types of systems use more than one energy source to supply a variety of different loads. Typically, these systems work in isolation taking advantage of the renewable resources available on site, but they can also be used in conjunction with conventional sources of power generation.

According to Justo Roberts, when sized correctly, HPGSs present technical, economic and environmental advantages in relation to systems using a single renewable source or traditional systems [6].

This article proposes the technical analysis and sizing of a HPGS (solar-biogas) for application on the Ilhabela-SP-Brazil island, considering energy potentials currently available on the island and that are not being exploited. The goal of the proposed system is to generate charging stations for a specific fleet of electric vehicles. For this study, different degrees of EV penetration are considered in relation to the current fleet of automobiles.

For a structured analysis of this proposal, a bibliographic review of battery EVs (BEVs) and their relation to renewable energy sources is carried out. Afterwards, the methodology describes the technical analysis and sizing of the system step by step. Finally, the results are analyzed and discussed and the conclusions about the analysis developed are obtained.

1.1. Electric vehicles with battery

Briefly, a battery electric vehicle (BEV) can be described as a vehicle whose wheels are driven by an electric motor, which in turn is powered by electric current stored in a battery bank. Its main components can be seen in Figure 1.

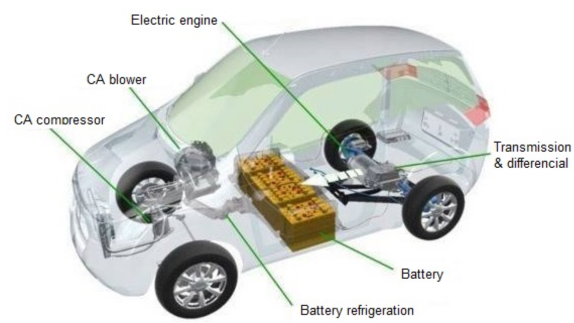

Figure 1. Basic components of an electric vehicle [7].

The charge of a BEV's batteries is largely obtained through the use of a conventional residential electrical outlet. However, the high recharge periods and the need to perform loads faster and more frequently, resulted in the advent of public charging stations [8]. These stations can be independent or connected to a network of stations with state-of-the-art devices [9].

1.2. Use of renewable energy sources in the BEV

The literature is quite diverse in terms of integration between EVs and renewable energy sources [10–12]. The models that study this integration tend mainly to measure the capacity of relationship between them, as well as the impacts on the performance of the electric network [13]. Up next are some applications using biogas and photovoltaic solar energy.

1.2.1. Use of biogas in BEV

Biomass energy differs from other renewable sources, such as solar and wind, by the fact that it can be easily stored and consumed when necessary. Biofuels, such as ethanol produced from sugarcane, are the most common form of biomass used in vehicles.

This fuel is burned directly in internal combustion engines (ICE). However, electricity from biofuels tends to provide a higher return on investment compared to use in final processes such as the one mentioned above [14].

Several recent studies indicate that the use of bioelectricity in a vehicle is more effective than the conversion of biomass into biofuels. Schmidt et al. [8]

evaluated the production and use of various types of biofuels in Austria, compared to bioelectricity. The results indicate that emissions of greenhouse gases, the effects of land use and the required amount of biomass stocks are reduced compared to using EV biofuels.

On the other hand, Campbell et al. [15] conclude that the gross average production, in kilometers traveled per hectare of biomass production, is 112% higher for bioelectricity than for biofuels. In addition, the net average compensation of greenhouse gases for the switchgrass production (grass of the genus Panicum L.) is 108% greater in bioelectricity than that of biofuels [13].

1.2.2. Use of photovoltaic energy in BEV

Over the years, several methods of charging BEV using photovoltaic panels (PVs) have been proposed. The most prominent is the combination between PV and the electricity grid. In this way, they use photovoltaic energy whenever possible, but switch to the grid when photovoltaic energy is insufficient or not available [16].

The connection to the network of BEV charging stations, together with photovoltaic solar energy, allow a greater interaction between the EV and the network, enabling the flow of energy from the vehicle to the network, with a technology called vehicle-to -grid (V2G) [17]. Thanks to being connected to the network, the photovoltaic generation does not necessarily have to occur in the same physical space of the charging station, since the energy can be transported through the distribution systems.

Another approach is to use the PV system outside the power grid. This system is known as PV-standalone [18]. This approach requires the use of batteries for the storage of the energy generated during periods with high solar radiation. The use of batteries in this type of systems raises the costs of both initial investment and maintenance.

1.3. Photovoltaic solar energy (PV)

Solar energy is the largest source of renewable energy available in nature, originating in the radiation coming from the fusion reactions of the hydrogen and helium nuclei inside the Sun.

On the other hand, photovoltaic systems are characterized by high reliability and low maintenance, as their high initial cost is often compensated by the low operational cost. Through the PV effect, the solar cells contained in the panels convert solar energy directly into renewable, safe and non-polluting electricity [19].

The basic component of solar energy is the photovoltaic cell. This is composed of two layers of semiconductor material. The layers, one of type N, with excess of electrons and another of type P, with deficit of electrons, are joined, forming a PN junction. When there is the incidence of photons coming from sunlight, the electrons acquire energy, and then, with the presence of an external conductor, the migration of the electrons generates an electric current. If the cell does not suffer from solar incidence, electrons and gaps remain trapped behind that barrier [20]. Figure 2 shows the operation of the PV panel.

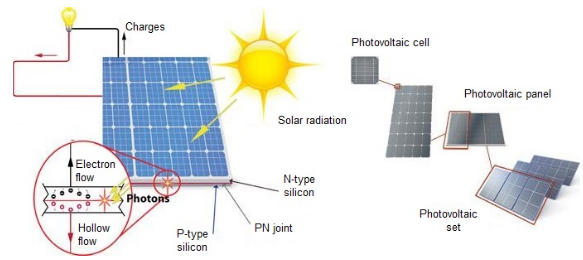

Figure 2. Operation of the PV panel [18].

In the industrialization process, the photovoltaic cells are interconnected in series-parallel arrays forming the PV modules (Figure 2). The most used PV modules are based on poly or monocrystalline technology [21]. But recently, fine films are becoming popular, especially for large installations [22].

Generally, in photovoltaic installations the modules are organized in series circuits, in order to reach the necessary DC voltage. To obtain a higher power, several chains are connected in parallel. The behavior of a PV system under different intensities of solar irradiation and temperature can be understood by examining its characteristic currents of current-voltage (IV) and voltage-power (PV).

There will always be a single point of operation in which the power will be maximum, that is, the point of maximum power (PMP) at a certain temperature and irradiation. The PMP is not fixed; it varies continuously according to temperature and solar irradiation. Because of this dynamic, a tracker to find the point of maximum power is necessary to ensure that the maximum power of the array of PV panels is always extracted (Figure 3) [16].

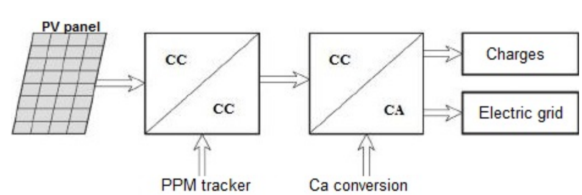

Figure 3. Block diagram of a PV system showing its main components, including the PPM [23].

1.4. Solar energy in Brazil

According to Pereira et al. [24], the annual average of global irradiation presents a good uniformity in Brazil.

The averages are relatively high throughout the territory. The values of incident global solar radiation in any region of the Brazilian territory vary between 1500 and 2500 kWh/m^2/year, and are higher than in most European countries, such as Germany (900-1250 kWh/m^2/year), France (900-1650 kWh/m^2/year) and Spain (1200-1850 kWh/m^2/year), places where solar energy projects are widely used.

Despite the favorable conditions for the development of this type of technology, in Brazil it is still incipient [25]. According to the Ministry of Mines and Energy (MME) [26], at the end of 2016, Brazil had 24 MW of installed power in centralized photovoltaic power plants. However, such power is not yet enough to place Brazil among the twenty world leaders in the production of this type of energy, all of them with an installed capacity exceeding 1 GW [27].

Despite the low installed power in large photovoltaic power plants, Brazil has managed to emerge in the use of solar energy thanks to distributed generation, these being the main promoters for the use of this technology.

The regulation, elaborated in 2012 by the ANEEL (National Electric Energy Agency) through Normative Resolution N.° 482 and perfected in 2016, brings important incentives to the installation of small-sized power plants based on renewable sources, such as solar and wind energy. As part of this regulation, the Electric Power Compensation System was instituted, which allows the accumulation of generation surpluses in relation to consumption, thus generating credits that can be used within a period of five years [28].

The number of distributed power generation connections at micro scale (up to 75 kW of installed power) and mini (greater than 75 kW and less than 5 MW) is on the rise in Brazil, reaching 10 561 connections registered in 2017, against just four in 2012, with an installed capacity of 114.7 MW, with solar energy responsible for 70% of this total [29].

2. Materials and methods

2.1. Profile of Ilhabela Island

Located on the coast of the state of São Paulo (see Figure 4), Ilhabela is an island populated by 32 197 inhabitants. With a total area of 347.5 km^2; 85% of the territory of the island corresponds to units of environmental conservation. The remaining 15% corresponds to areas suitable for urbanization. Its road structure is installed along the entire coast, connecting the central part of the city with the most remote neighborhoods. This island has a fleet of 17,449 vehicles, of which 7041 are automobiles [30].

Figure 4. Location of Ilhabela, on the coast of the state of San Pablo [31].

Because it does not have its own large-scale electric power generation, electricity in the municipality of Ilhabela is supplied by means of submarine cables, which transmit the energy from the continent to the island. In this way, if the demand for electricity on the island grows considerably, the supply will have to be reinforced, either through the expansion of the submarine cable network, or through the introduction of power generation plants. The latter is one of the proposals of this work, since it proposes the use of photovoltaic solar energy in conjunction with a biogas thermoelectric plant, which would be installed on the island.

According to the Municipal Plan of Ilhabela, currently, 6.5% of the urban population of the municipality has its sewage collected, being thrown directly into the sea without an effective treatment, with a simple removal of coarse waste. A system of wastewater treatment stations is in the implementation phase, and projections are that, by 2025, 3,795,000 m^3 of waste will be produced and, by 2030, 4 345,000 m^3 [32].

According to Lamas, methane (CH_4) present in biogas produced from the anaerobic treatment of sewage waste, is approximately 21 times more damaging to the atmosphere than carbon dioxide (CO_2) [33]. Therefore, the energy use of biogas becomes interesting, since it reconciles the generation of renewable energy and environmental sanitation.

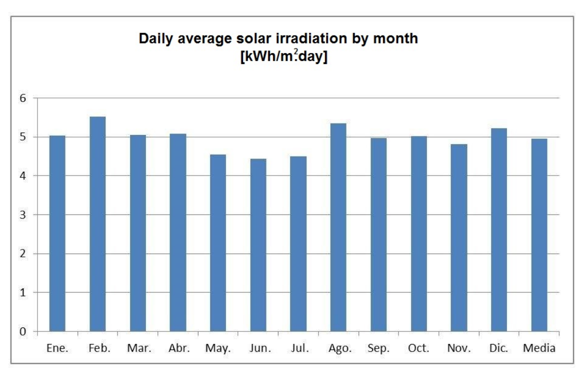

Figure 5. Monthly average daily solar irradiation (kWh/m^2/day) on Ilhabela Island

On the other hand, according to the data obtained from the Sérgio S. de Brito Solar and Wind Energy

Reference Center (CRESESB, in Portuguese) [34], Ilhabela has a solar irradiation pattern with intensity variation depending on the season. February is the month with the highest average solar radiation (5.56 kWh/m^3/day) and June the month with the lowest average, with only 3.92 kWh/m^3/day. Figure 5 shows the daily-monthly solar radiation.

2.2. Energy consumption of a BEV

In this study, BEV performance is analyzed in terms of the fuel consumption rate (TCE). That is, the TCE is calculated as the ratio between the power consumed and the distance traveled [35]. Equation 1 is used for this calculation.

$$TCE = \frac{Energy\ consumed\ (kWh)}{Distance\ travelled\ (km)} \tag{1}$$

The lower the TCE, the better the energy efficiency. The autonomy of the BEV is calculated with Equation 2.

$$Auto = \frac{Energy\ fully\ charged\ BEV\ (kWh)}{TCE\ (kWh/km)} \tag{2}$$

The average distance traveled by a vehicle in Brazil is similar to the one verified in the state of Louisiana (USA), estimated at 35 km/day [36].

According to the projection of the Energy Research Company (EPE, acronym in Portuguese) [37], EVs will represent 1.7% of the national fleet by 2025, and 4.5% by 2030.

The calculation of electrical consumption per km in a BEV fleet can be calculated with Equation 3 [38].

$$CelEVB = P_M \times n \times D \times TCE \tag{3}$$

Where:

PM – market penetration of the BEV;

n – total number of cars in the fleet considered;

D – average distance traveled by a BEV in the period of one day;

TCE – electric consumption rate per km.

2.3. Energy analysis of the biogas plant

The environmental peculiarities of the place where this project is intended to start require that the use of biomass produces the least possible impact. Thus, gas microturbine technology offers solutions with low NO_x emission rates, which represents a great impact for the greenhouse effect. The manufacturer of the Capstone 30 microturbine guarantees an NO_x emission rate of less than 9 ppm in exhaust gases. Thus, the environmental advantage obtained with the use of this technology is evident, since compared to the technology of conventional internal combustion generating groups (Otto cycle), these have an emission of 3000 ppm, [39].

For this study, the Capstone 30 microturbine is selected, a model already used in other works with biogas from wastewater from San Pablo – Brazil [40] and in cogeneration processes [41]. The characteristics of this turbine are presented in Table 1.

Table 1. Characteristics of the CAPSTONE C30 microturbine [39]

Model	C30
Power (kW)	30
Efficiency (%)	26
Exhaust gas flow (kg/s)	0,31
Exhaust temperature (°C)	275
Heat Rate (MJ/kWh)	13,8

2.3.1. Biogas composition

The biogas generated from the anaerobic digestion of biomass from wastewater has the composition presented in Table 2 [40].

Table 2. Composition of biogas

Component	Volume (%)	PCI (kJ/kg)
CH_4	66,5	50
CO_2	30,5	-
$O_2 + N_2$	0,5	-
H_2O	2,5	-
Total	100	22,2

2.3.2. Biogas production

According to França Junior [42], the average rate of biogas generation is 170.9 m^3 per 1000 m^3 of treated waste. Therefore, it is possible to calculate the biogas values that can be obtained for the wastewater treatment station (ETE) of Ilhabela with Equation 4.

$$m_{biogas} = tx_{biogas} \times m_{residue} \tag{4}$$

Where:

m_{biogas} – volume of biogas generated [m^3/year];

tx_{biogas} – average rate of biogas generation (0,1079 m^3 biogas/m^3 residue);

$m_{residue}$ – volume of treated waste [m^3/year].

With the result of equation 4, the flow values in [kg/s] can be obtained with Equation 5.

$$m_{bio} = \frac{m_{biogas} \times \gamma_{biogas}}{31\ 104\ 000 (s/año)} \tag{5}$$

Where:

m_{bio} – biogas flow [kg/s];

m_{biogas} – volume of biogas generated [m^{3}year];
γ_{biogas} – specific mass of biogas with composition 65 % CH_4 y 35 % CO_2 (1,1518 kg/Nm^3) [43].

2.3.3. Energy analysis

The methodology adopted for the energy analysis of the biogas plant is that used by Llerena [44]. This analysis is detailed below step by step.

2.3.4. Control volume of the Brayton cycle

In Figure 6, the gas cycle is observed. This cycle has a compressor, a combustion chamber, the turbine and the heat exchanger.

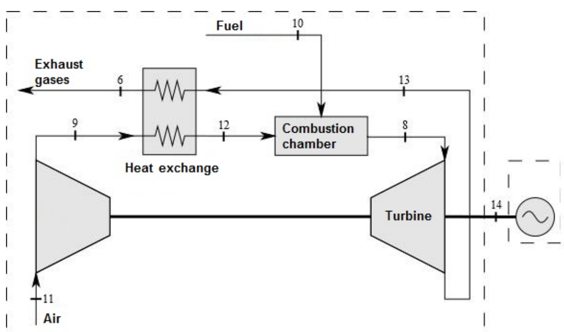

Figure 6. Control volume of the Brayton cycle [41].

In this study the ISO conditions of the microturbine of the GTW Handbook are maintained [45]. Considering that the efficiency of the electric generator is 95%, the power is obtained in point 14 with Equation 6:

$$\dot{W}_{14} = \frac{P_{generator}}{\eta_{generator}} \tag{6}$$

Where:
P – electric power in the generator [kW].

Now, the biogas flow is calculated with Equation 7:

$$HR \cdot P = PCI_{biogas} \cdot m_{biogas} \tag{7}$$

Where:
HR – Heat Rate [MJ/kWh];
P – power at the turbine output [kW];
PCI – lower calorific value of biogas [kJ/kg];
M – biogas flow [kg/s].

With the flows of the biogas and the exhaust gases, the air flow is calculated with Equation 8:

$$\dot{m}_{11} = \dot{m}_6 - \dot{m}_{biogas} \tag{8}$$

2.3.5. Compressor control volume

According to Çengel and Boles [46] the compressors have an isentropic efficiency that varies between 80 and 90%. In this study, the highest efficiency was used.

Point 9

The air flow at the compressor outlet is equal to the air flow at the compressor inlet, so we have Equation 9:

$$\dot{m}_9 = \dot{m}_{11} \tag{9}$$

According to the GTW Handbook [45], the pressure ratio is 4:1. With this data, the pressure in point 9 is calculated. For this, Equations 10 and 11 were used:

Pressure in point 9:

$$P_9 = P_{11} \cdot Rp \tag{10}$$

Relative pressure in point 9:

$$Pr_9 = P_{11}\frac{P_9}{P_{11}} \tag{11}$$

With Equation 12, the enthalpy is obtained at point 9 [44].

$$h_9 = \frac{h_{9s} - h_{11}}{\eta_{cpmp}} + h_{11} \tag{12}$$

Point 12

According to Carvalho [47], there is a 3% loss in the outlet pressure in the heat exchanger. According to the same author, in the case of temperature, there is a difference of 324 °C. Thus, the pressure and temperature at point 12 are calculated with Equations 13 and 14, respectively.

Pressure in point 9:

$$P_{12} = P_9 - (P_9 \cdot 0,03) \tag{13}$$

Temperature at point 9:

$$T_{12} = T_9 + \Delta T \tag{14}$$

To calculate the air flow at point 12, Equation 15 was used.

$$\dot{m}_{12} = \dot{m}_9 \tag{15}$$

2.3.6. Control volume of the combustion chamber

Point 8

The flow of the exhaust gases at point 6 is equal to the flow of gases at the outlet in the combustion chamber. Thus, Equation 16 was used to calculate the gas flow at point 8.

$$\dot{m}_8 = \dot{m}_6 \tag{16}$$

According to Carvalho [47] there is a pressure loss of 3% in the combustion chamber. Thus, Equation 17 was used to calculate the output pressure of the CC.

$$P_8 = P_{12} - (P_{12} \cdot 0,03) \tag{17}$$

According to Saravanamuttoo et al. [48], the CC can have an efficiency of 99%. Now, with the law of conservation of energy we have Equation 18

$$\dot{m}_8 \cdot \dot{h}_8 = \dot{m}_{12} \cdot \dot{h}_{12} + (PCI_{biogas} \cdot \dot{m}_{biogas}) \cdot \eta_{CC} \tag{18}$$

2.3.7. Turbine control volume

Point 13

For calculating pressures in the turbine, the same air ratio as the compressor was considered. Thus, the relative pressure at point 13 is calculated with Equation 19:

$$Pr_{13} = Pr_8 \frac{P_{13}}{P_8} \tag{19}$$

The energy balance is calculated with Equation 20:

$$(h_8 - h_{13a}) \cdot \dot{m}_8 = \dot{W}_{14} + \frac{(h_9 - h_{11}) \cdot \dot{m}_{11}}{\eta_{comp}} \tag{20}$$

The efficiency of the turbine is calculated with Equation 21.

$$\eta_{turbine} = \frac{\dot{W}_{generator}}{PCI_{biogas} \cdot \dot{m}_{biogas}} \tag{21}$$

2.4. Sizing of the PV system

2.4.1. Calculation of the necessary photovoltaic power

Through the calculation of the nominal power (generated from solar radiation) necessary to meet the average daily consumption of the loads, and with the data of the energy supplied by the biogas plant, the area of the solar panels to be installed can be estimated.

This calculation shows, approximately, the capacity of the system dimensioned to meet the demand, supplying energy in equal quantity to that requested by the loads (EV Fleet).

Through the application of Equation 22, the nominal installed power required to meet the demand is determined [49]:

$$P_{FV} = \frac{E}{n_V n_R HSP} S_f \tag{22}$$

Where:

E – energy demand requested by the load;

S_f – safety factor for resistive and thermal losses in photovoltaic cells, with an adopted value of 1.15;

n_v *and* n_R – efficiencies of system components;

HSP – Peak-Sun-Hours.

The average daily solar irradiation can be referred to in terms of "peak sun hours" (HSP). This value refers to the equivalent number of daily hours that a given region should undergo (1 kW/m^2) to receive the same amount of solar energy. Thus, the number of HSP is numerically equal to that of the average solar irradiation (kWh/m^2.dia). With this value it is possible to estimate the total area to be occupied by the photovoltaic modules. In this way, through the division of installed power by the efficiency of the modules, the resulting area is found [46]. Equation 23.

$$A_{total} = \frac{P_{FV}}{E_{ff}} \tag{23}$$

Where:

A_{total} – area of the modules (m^2);

PFV – average power required (kW);

Eff – efficiency of the modules(%).

2.4.2. Costs of photovoltaic solar energy

In Brazil, the total installation cost is composed of the following elements: PV modules (43%), inverters (24%), physical structure and protections (16%) and installation (17%) [50].

According to data from the Greener report [51], the average price of installed kW of photovoltaic solar energy in Brazil in 2017 was between 8 R$/kW, for smaller systems, and 4.62 R$/kW for major systems. Other values are in accordance with Table 3.

Table 3. Prices [45]

Power (kW)	2	4	8	12	30	50	75	150
Price (R$/W)	8	6,84	5,95	5,65	5,26	5,1	5,01	4,62

3. Results and discussion

3.1. Analysis of energy consumption

Taking into account the fleet of 7041 automobiles, and based on the projection of the EPE. By means of the calculation of the TCE and with Equation 3, the monthly energy consumption of the EV fleet can be calculated, according to their degree of market penetration. The results are presented in Table 4.

Table 4. Consumption of electric power of the BEV in relation to market penetration

BEV market penetration	N. of electric vehicles	Average energy consumption (kWh/month)
4%	282	46 327,21
2%	141	23 163,60

From Table 4 it can be seen that a higher EV penetration means a higher energy demand. This increase also represents a more powerful photovoltaic solar plant and consequently a larger installation area will be necessary.

3.2. Energy analysis of the biogas plant

The results of the energy analysis of the microturbine using biogas are shown in Table 5.

Table 5. Summary of the energy analysis

Point	T [°C]	P[kPa]	Flow [kg/s]	h [kJ/kg]
6	275	101,32	0,31	490
8	831,9	393	0,31	1167,15
9	184,3	405,3	0,3041	459,67
10	25	101,32	0,0059	-
11	25	101,32	0,3041	298,6
12	508	393,24	0,304	801,9
13	594,6	96,25	0,31	825,77

According to Table 5, the microturbine needs a flow rate of 0.0059 kg/s of biogas to provide its nominal power of 30 kW. With Equations 4 and 5, and with the flow projections of 3 795 000 m^3 /year in 2025 and 4 345 000 m^3/year in 2030 in the Ilhabela sewerage system, a production capacity of 0,0152 kg/s in 2025 and 0.0174 kg/s of biogas in 2030 is reached, with both values above the consumption need of the microturbine, making this type of energy feasible from the technical point of view.

Thus, with the biogas plant operating 18 hours a day, at full capacity (30 kW) at times when there is no solar irradiation, there is an average generation of 16 200 kWh/month. With this monthly energy value, and with the energy consumption of the BEV fleet, according to Table 6, the need for additional generation of energy by the photovoltaic system was calculated (it is considered that this system will work the remaining 6 hours).

Table 6. Energy to be served by the PV system, given the operation regime of the biogas plant

BEV market penetration	Energy biogas (kWh/month)	Energy of the PV solar system (kWh/month)
4%	16 200,00	30 127,21
2%	16 200,00	6963,6

With the information presented in the previous table, the PV systems suitable for the energy supply in the two scenarios were sized.

3.3. Analysis of the sizing of the photovoltaic plant

By means of Equation 22, the photovoltaic power needed to supply the additional energy demand was calculated to supplement the energy already provided by the biogas system. Because it is an island, with a tourist and ecological vocation, the area occupied by photovoltaic generation is a very important factor for the implementation of this technology. With Equation 23, and adopting an efficiency of 15% in the PV modules, typical in models of polycrystalline silicon technology available in the market, the total area of installation of the modules was calculated. The results are presented in Table 7.

Table 7. Power and area occupied by dimensioned PV systems

BEV market penetration	Power (kW)	Installed area (m^2)
4%	305,20	2 034,69
2%	70,54	470,30

For the same generation capacity in the biogas system (30 kW), the area occupied by the PV system grew by more than four times. Taking into account the environmental impact caused by the occupation of relevant portions of the area by the PV system, and the possibility of distributed generation, the application of this technology leads to a choice between the construction of a larger photovoltaic plant or a larger number of small plants, suitable for residential-sized facilities.

3.4. Analysis of installation costs

The cost of the biogas generator system with the Capstone 30 microturbine, was already used in similar works by Coelho [40], where a value of R$ 8568.62 per installed kW was reached. Thus, the investment in a complete 30 kW system with this type of technology would cost R$ 257,058.60.

In relation to the photovoltaic plant, considering the two options (centralized and distributed), and with the current costs of the market, the investment for the installation of this PV system were also calculated. Adding these two costs, the total costs of the HPGS was obtained, which are presented in Table 8.

Table 8. Total investment for the HPGS

% VEB	Distributed PV		Centralized PV	
	R$	Config.	R$	Config.
4%	2 344 647	77 x 4 kW	1 667 096	2 x 150 kW
2%	739 583	18 x 4 kW	610 487	1 x 70 kW

4. Conclusions

Due to the peculiarities of being an island, its tourist and ecological potential, renewable sources of energy are the ideal solution for current and future energy demands of Ilhabela, which will have to occur at some point due to the challenges imposed by the advent of BEV.

It is concluded that the installation of the biogas plant is technically feasible, since the capacity of biogas production on the island will be 0.0152 kg/s in 2025 and 0.0174 kg/s in 2030, that is, twice as much as what is necessary for the plant to work at its maximum capacity (0.0059 kg/s). The biogas plant will have a production of 16 200 kWh/month.

From the photovoltaic plant it is concluded that, if the fleet of electric vehicles is doubled, and the generation capacity of the biogas system is maintained (16 200 kWh/month), the installed power of the supplementary PV system will increase by more than four times its capacity, as well as its installation area. It is also concluded that the adoption of centralized PV systems led to a 28.9% reduction in total investment in a more long-term scenario. In the scenario for 2025, with 2% market penetration of the BEV, the option for the centralized PV system led to a 17.5% reduction in the total cost of installing the HPGS. These differences in capital cost per watt installed between the larger and smaller systems are due to the scale gains in the PV equipment market.

Finally, if on the one hand, centralized photovoltaic generation has a lower cost of installation, on the other, distributed generation is a better promoter of social development, by moving local labor and favoring small businesses, in addition to the benefit of the compensation of energy generated by users of residential distributed generation, with significant reduction in electricity expenses.

References

[1] K. Reiche, A. Covarrubias, and E. Martinot, "Expanding electricity access to remote areas: Off-grid rural electrification in developing countries," *WorldPower2000*, pp. 52–60, 2000. [Online]. Available: https://goo.gl/4d6m7k

[2] T. Hirota, "Task 17 pv for transport draft task workplan for 2018-2020," Waseda University, Tech. Rep., 2017. [Online]. Available: https://goo.gl/jDegU4

[3] Bloomberg New Energy Finance, "Electric vehicle outlook 2017," Bloomberg Finance L.P, Tech. Rep., 2017. [Online]. Available: https://goo.gl/BNtKZe

[4] A. Poullikkas, "Sustainable options for electric vehicle technologies," *Renewable and Sustainable Energy Reviews*, vol. 41, pp. 1277–1287, 2015. DOI: https://doi.org/10.1016/j.rser.2014.09.016.

[5] J. J. Roberts, S. Thibaud, and P. O. Prado, "Proyecto de un sistema híbrido de generación con energías renovables para un establecimiento rural aislado," in *XI Latin-American Congress on Electricity Generation and Transmission "Bioenergy for Electricity Generation" and "Ecological Issues in Power Plants", At São José dos Campos, Brazil*, 2015. [Online]. Available: https://goo.gl/omxcph

[6] A. Cassula, P. O. Prado, J. L. Silveira, and J. J. Roberts, *Energía: Investigaciones en América del Sur,*, 1st ed. Editorial de la Universidad del Sur, 2017, ch. Dimensionamiento de Sistemas Híbridos de Generación de Energía, pp. 109–136. [Online]. Available: https://goo.gl/yBQo3y

[7] T. Wilberforce, Z. El-Hassan, F. Khatib, A. A. Makky, A. Baroutaji, J. G. Carton, and A. G. Olabi, "Developments of electric cars and fuel cell hydrogen electric cars," *International Journal of Hydrogen Energy*, vol. 42, no. 40, pp. 25 695–25 734, 2017. DOI: https://doi.org/10.1016/j.ijhydene.2017.07.054.

[8] V. Gass, J. Schmidt, and E. Schmid, "Analysis of alternative policy instruments to promote electric vehicles in austria," *Renewable Energy*, vol. 61, pp. 96–101, 2014. DOI: https://doi.org/10.1016/j.renene.2012.08.012.

[9] E. Talebizadeh, M. Rashidinejad, and A. Abdollahi, "Evaluation of plug-in electric vehicles impact on cost-based unit commitment," *Journal of Power Sources*, vol. 248, pp. 545–552, 2014. DOI: https://doi.org/10.1016/j.jpowsour.2013.09.009.

[10] K. Seddig, P. Jochem, and W. Fichtner, "Integrating renewable energy sources by electric vehicle fleets under uncertainty," *Energy*, vol. 141, pp. 2145–2153, 2017. DOI: https://doi.org/10.1016/j.energy.2017.11.140.

[11] M. Honarmand, A. Zakariazadeh, and S. Jadid, "Integrated scheduling of renewable generation and electric vehicles parking lot in a smart microgrid," *Energy Conversion and Management*, vol. 86, pp. 745–755, 2014. DOI: https://doi.org/10.1016/j.enconman.2014.06.044.

[12] W. Liu, W. Hu, H. Lund, and Z. Chen, "Electric vehicles and large-scale integration of wind power – the case of inner mongolia in china," *Applied Energy*, vol. 104, pp. 445–456, 2013. DOI: https://doi.org/10.1016/j.apenergy.2012.11.003.

[13] D. B. Richardson, "Electric vehicles and the electric grid: A review of modeling approaches, impacts, and renewable energy integration," *Renewable and Sustainable Energy Reviews*, vol. 19, pp. 247–254, 2013. DOI: https://doi.org/10.1016/j.rser.2012.11.042. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S1364032112006557

[14] L. D. D. Harvey, *Energy and the New Reality 2: Carbon-free Energy Supply*, Earthscan, Ed., 2010. [Online]. Available: https://goo.gl/RzPzu4

[15] J. E. Campbell, D. B. Lobell, and C. B. Field, "Greater transportation energy and ghg offsets from bioelectricity than ethanol," *Science*, vol. 324, no. 5930, pp. 1055–1057, 2009. DOI: http://doi.org/10.1126/science.1168885.

[16] A. R. Bhatti, Z. Salam, M. J. B. A. Aziz, K. P. Yee, and R. H. Ashique, "Electric vehicles charging using photovoltaic: Status and technological review," *Renewable and Sustainable Energy Reviews*, vol. 54, pp. 34–47, 2016. DOI: https://doi.org/10.1016/j.rser.2015.09.091.

[17] F. Mwasilu, J. J. Justo, E.-K. Kim, T. D. Do, and J.-W. Jung, "Electric vehicles and smart grid interaction: A review on vehicle to grid and renewable energy sources integration," *Renewable and Sustainable Energy Reviews*, vol. 34, pp. 501–516, 2014. DOI: https://doi.org/10.1016/j.rser.2014.03.031.

[18] S. J. Chiang, H. J. Shieh, and M. C. Chen, "Modeling and control of pv charger system with sepic converter," *IEEE Transactions on Industrial Electronics*, vol. 56, no. 11, pp. 4344–4353, Nov 2009. DOI: https://doi.org/10.1109/TIE.2008.2005144.

[19] J. L. Silveira, C. E. Tuna, and W. de Queiroz Lamas, "The need of subsidy for the implementation of photovoltaic solar energy as supporting of decentralized electrical power generation in brazil," *Renewable and Sustainable Energy Reviews*, vol. 20, pp. 133–141, 2013. DOI: https://doi.org/10.1016/j.rser.2012.11.054.

[20] M. G. Villalva and J. R. Gazoli, *Energía solar fotovoltaica: conceitos e aplicações*, ERICA, Ed., 2012. [Online]. Available: https://goo.gl/CJKrDF

[21] M. Benaouadj, A. Aboubou, M. Becherif, M. Y. Ayad, and M. Bahri, "Recharging of batteries/-supercapacitors hybrid source for electric vehicles application using photovoltaic energy in a stand-alone point," in *2012 First International Conference on Renewable Energies and Vehicular Technology*, March 2012. DOI: https://doi.org/10.1109/REVET.2012.6195264, pp. 161–166.

[22] J.-H. Song, Y.-S. An, S.-G. Kim, S.-J. Lee, J.-H. Yoon, and Y.-K. Choung, "Power output analysis of transparent thin-film module in building integrated photovoltaic system (bipv)," *Energy and Buildings*, vol. 40, no. 11, pp. 2067–2075, 2008. DOI: https://doi.org/10.1016/j.enbuild.2008.05.013.

[23] N. Altin and T. Yildirimoglu, "Labview/matlab based simulator for grid connected pv system," in *4th International Conference on Power Engineering, Energy and Electrical Drives*, May 2013. DOI: https://doi.org/10.1109/PowerEng.2013.6635804, pp. 1316–1321.

[24] E. B. Pereira, F. R. Martins, S. L. de Abreu, and R. Rüther, *Atlas Brasileiro de Energia Solar.* SWERA, 2017. [Online]. Available: https://goo.gl/8Sr1tG

[25] CCEE. (2015) 3° leilão de fontes alternativas (3° lfa). Camara de Comercialização de Energia Elétrica. [Online]. Available: https://goo.gl/Sy8iWg

[26] MME, *Boletim mensal de monitoramento do setor elétrico*, Ministério de Minas e Energia, 2017.

[27] R. L. Nascimento, "Energia solar no brasil: situação e perspectivas," Camara dos Deputados. Brasil., Tech. Rep., 2017. [Online]. Available: https://goo.gl/gmSddm

[28] ANEEL, *Resolução normativa n. 687, Altera a Resolução Normativa n 482, Módulos 1 e 3 dos Procedimentos de Distribuição - PRODIST*, Agencia Nacional de Energia Elétrica. Brasil Std., 2017. [Online]. Available: https://goo.gl/T6PiFn

[29] ——, *Nota Técnica n. 0056/2017-SRD/ANEEL, Atualização das projeções de consumidores residenciais e comerciais com microgeração solar fotovoltaicos no horizonte 2017-2024*, Agencia Nacional de Energia Elétrica. Brasil Std., 2017. [Online]. Available: https://goo.gl/uq4L3i

[30] IBGE, *Conheça cidades e estados do brasil*, Instituto Brasileiro de Geografia e Estatística, 2017. [Online]. Available: https://goo.gl/nCPqGJ

[31] Itapemar Hotel. (2017) Mapa de bolso - ilhabela. [Online]. Available: https://goo.gl/zW4mFS

[32] P. M. de Ilhabela, *Plano Municipal Integrado de Saneamiento Básico*, Governo do Estado de São Paulo, 2015. [Online]. Available: https://goo.gl/4WVGst

[33] W. Q. Lamas, "Análise termoeconômica de uma mini-estação de tratamento de esgoto com auto-suficiência energética," Ph.D. dissertation, Universidade Estadual Paulista, Faculdade de Engenharia de Guaratinguetá, 2007. [Online]. Available: https://goo.gl/8jqqJu

[34] CRESESB. (2018) Potencial solar - sundata v 3.0. Centro de referência para energia solar e eólica Sérgio Brito. [Online]. Available: https://goo.gl/Ae2cUG

[35] G. M. Fetene, S. Kaplan, S. L. Mabit, A. F. Jensen, and C. G. Prato, "Harnessing big data for estimating the energy consumption and driving range of electric vehicles," *Transportation Research Part D: Transport and Environment*, vol. 54, pp. 1–11, 2017. DOI: https://doi.org/10.1016/j.trd.2017.04.013.

[36] R. Baran and L. F. L. Legey, "The introduction of electric vehicles in brazil: Impacts on oil and electricity consumption," *Technological Forecasting and Social Change*, vol. 80, no. 5, pp. 907–917, 2013. DOI: https://doi.org/10.1016/j.techfore.2012.10.024.

[37] J. B. Soares, "Matriz elétrica brasileira e matriz elétrica brasileira e as rei's," in *Empresa de Pesquisa Energética, Ministério de Minas e Energia*, 2016. [Online]. Available: https://goo.gl/q5GnBS

[38] E. F. Choma and C. M. L. Ugaya, "Environmental impact assessment of increasing electric vehicles in the brazilian fleet," *Journal of Cleaner Production*, vol. 152, pp. 497–507, 2017. DOI: https://doi.org/10.1016/j.jclepro.2015.07.091.

[39] V. Pecora, "Implantação de uma unidade demonstrativa de geração de energia elétrica a partir do biogás de tratamento do esgoto residencial da usp," Master's thesis, Universide de São Paulo (Instituto de Eletrotécnica e Energia). Brasil, 2006. [Online]. Available: https://goo.gl/n35Ysr

[40] S. T. Coelho, S. M. S. G. Velazquez, O. S. Martins, and F. C. de Abreu, "Sewage biogas convertion into eletricity," in *Anais do 6. Encontro de Energia no Meio Rural, 2006, Campinas (SP, Brasil)*, 2006. [Online]. Available: https://goo.gl/X6LWYt

[41] J. C. Galarza, O. Llerena, and J. L. Silveira, "Thermodynamic and economic analysis of cogeneration system applied in biodiesel production," in *XI Latin-American congress electricity generation and transmission - CLAGTEE 2015*, 2015. [Online]. Available: https://goo.gl/9KuUc6

[42] A. T. França Junior, "Análise do aproveitamento energético do biogás producido numa estação de tratamento de esgoto. 2008," Master's thesis, Universidade Estadual Paulista (UNESP). Brasil, 2008. [Online]. Available: https://goo.gl/yAA3zq

[43] D. F. da Costa, "Geração de energia elétrica a partir do biogás do tratamento de esgoto. 2006," Master's thesis, Escola Politécnica, Universidade de São Paulo. Brasil, 2006. [Online]. Available: https://goo.gl/U8u5qM

[44] O. Llerena, "Análisis energético, exergético y económico de un sistema de cogeneración: Caso para una planta azucarera de san pablo," *INGENIUS*, no. 19, pp. 29–39, 2018. textscdoi: https://doi.org/10.17163/ings.n19.2018.03. 2018.

[45] GTW. (2012) 2012 gtw handbook. Gas Turbine World. PequotPublishing Inc. [Online]. Available: https://goo.gl/qmjxen

[46] Y. Cengel and M. Boles, *Termodinámica*, M. G. Hill., Ed., 2015. [Online]. Available: https://goo.gl/XCTYQU

[47] H. M. de Carvalho, "Desenvolvimento matemático para avaliação de desempenho de turbinas a gás de um eixo," Master's thesis, Universidade Federal de Itajubá. Brasil, 2006. [Online]. Available: https://goo.gl/cSeUzQ

[48] H. I. H. Saravanamuttoo, G. F. Crichton Rogers, and H. Cohen, *Gas Turbine Theory*, P. Hall, Ed., 2001. [Online]. Available: https://goo.gl/smXkp6

[49] M. M. Mahmoud and I. H. Ibrik, "Techno-economic feasibility of energy supply of remote villages in palestine by pv-systems, diesel generators and electric grid," *Renewable and Sustainable Energy Reviews*, vol. 10, no. 2, pp. 128–138, 2006. DOI: https://doi.org/10.1016/j.rser.2004.09.001.

[50] D. I. Marinoski, I. T. Salamoni, and R. Ruther, "Pré-dimensionamento de sistema solar fotovoltaico:estudo de caso do edifício sede do crea-sc," in *I Conferêcia Latino-Americana De Construção Sustentável X Encontro Nacional de Tecnologia do Ambiente Construído. São Paulo. ANTAC*, 2004. [Online]. Available: https://goo.gl/QxnFCa

[51] Greener. (2017) Em 12 meses, preço dos sistemas fotovoltaicos cai 24%. Greener. Pesquisa, Estrategia, Inovação. [Online]. Available: https://goo.gl/iLbso8