RENEWABLE ENERGY IN URBAN LOW-INCOME COMMUNITIES. CASE STUDY OF SANTA MARTA, RIO DE JANEIRO.

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Abstract

In the city of Rio de Janeiro, Brazil, more than 22% of the population lives in informal settlements, overcrowded areas characterized by low standard housing, poor services and infrastructure, inhabited by impoverished people. Brazilian electricity prices are among the highest in Latin America and have shown high volatility in the last years, mainly due to the strong dependence of the electricity sector on hydro sources, which are subject to climate conditions. Without adequate programs, Brazilian low-income families are obliged to compromise their budget to pay the electricity service. In this context, this study aims to assess from a techno-economic point of view, the use of renewable energy technologies in urban low-income communities, focusing on the case study of Santa Marta, in Rio de Janeiro, with the final objective of identifying both competitive and sustainable systems to provide electricity to the community. Results show that solar PV systems are extremely competitive with the electricity supplied by the grid and they could represent a solution for low-income communities thanks to the implementation of adequate business plans and financing methods.

Keywords: Renewable energy, Low-income community, Urban community, PV system, Brazil

1. Introduction

Latin America is the most urbanized region in the world: about 80% of the region's population lives in cities, and it is predicted that, by 2050, over 90% of the population will be urbanized (Atlantic Council, 2014). In most of the cases, cities' economic development was accompanied by an unplanned and disordered urban growth and, moreover, the additional income did not benefit all the dwellers. It is believed that informal settlements embody the inequality and the urban poverty that exist in Latin America and it is estimated that about 25% of the urban population live in slums (IDB, 2015). In Rio de Janeiro, Brazil, similarly to the Latin American region's trend, a large part of the population, estimated to be 22%, lives in urban slums, also called *favelas* (IBGE, 2013). Most of the favelas consist of public or private land occupied with self-build developed by low-income groups of people, on lands that lack of infrastructures and without following an urban plan. Santa Marta is one of the communities belonging to the informal settlements of Rio de Janeiro. In 2008, Light, the utility company serving the area, started regularizing the access to electricity in the community, by replacing the old electricity network, expanding the system and installing meters for monitoring consumptions. According to (Mayrink et al., 2016), in 2009, before the regularization, the illegal connections in the community amounted to the 93%, resulting in 93% of the commercial loss for Light while, in 2015, the irregular connections reduced to almost 0%, resulting in only 5% of economic losses for the company. On the other side, most of the locals saw their electricity bills increasing greatly during these years, passing from a zero cost service to a paid service.

The electricity bills started to become a main concern for the locals since they absorb a consistent part of their incomes (Carvalho, 2016). Moreover, Brazilian electricity prices for consumers, which are subject to the approval of the Brazilian Electricity Regulatory Agency (ANEEL), are among the highest in Latin America. It was estimated that in 2018, the average price reached 0.185 USD/kWh in the residential sector (Enerdata, 2019).

1.1 Objective

Without adequate policies and programs, low-income families in Brazil are obliged to compromise their budget to pay the electricity service. This study aims to find alternative ways to the electricity from the grid in order to provide a more economical, and at the same time sustainable, service to low-income communities, focusing on the case study of Santa Marta. In particular, two different renewable technologies were investigated for their potential in the location: distributed solar photovoltaic (PV) and anaerobic digestion system.

1.2 Methodology and Assumptions

In order to conduct the study, the average monthly electricity consumption data per household were retrieved from the local company (Light, 2019a). It was assumed that consumption increases every year at a rate of 2.53%, based on (Enerdata, 2016), and the electricity prices increase by 0.20% every month. Considering the area's characteristics, hydro and wind resources were excluded. To assess the solar photovoltaic system, in particular, the hourly solar irradiance (W/m^2) and the air temperature (°C) were retrieved by the Photovoltaic Geographical Information System (PVGIS) developed by the European Commission Science Hub (European Commision, 2019). The hourly values were obtained for all the available years in the software whose hourly data were complete, and following, the hourly average values for a year were calculated, so to use them for the energy assessment. The methodology used for the solar calculation is the single diode ideal (three parameters) model, as described by (Crispim et al., 2007).

For the anaerobic digestion plant, the methodology was based on a study conducted for a Brazilian municipality by (R. E. dos Santos et al., 2019). In order to evaluate the profitability of the two projects, the NPV, the IRR, the payback period and the LCOE were evaluated.

2. Literature Review

2.1 Brazilian Legislative Framework for Distributed Generation

When designing a distributed generation system in Brazil, three are three main legislations in force to be considered. The Normative Resolution 482 (RN482), firstly introduced in 2012 by the Brazilian National Agency of Electric Energy (ANEEL), introduced the Net Metering scheme, according to which the system owner can inject into the grid network the surplus of energy receiving in exchange energy in the form of credits that can be used over the next 60 months.(Pillot et al., 2018; Vilaça Gomes et al., 2018).

The Normative Resolution 414 (RN414) establishes the cost of electricity availability, which indicates the amount that has to be paid by the users to the distribution company in order to guarantee the electricity supply even if it is not used. In case of consumers with low-voltage connections (below 2.3 kV), the cost of electricity availability per month is equivalent to the consumption of: (1) 30 KWh if the grid connection is monophasic or biphasic with two conductors; (2) 50 kWh if it is biphasic with three conductors; (3) 100 kWh if it is three-phase (ANEEL, 2010).

The Agreement 16 about the tax on commerce and services (ICMS), first approved under the National Council of Finance Policy (CONFAZ) in April 2015, states the tax exemption for operations related to the circulation of electric energy that are subject to the compensation scheme as described by the Normative

Resolution 482 introduced by ANEEL (CONFAZ, 2018). The ICMS exemption is applied to the quantity that corresponds to the sum of the electric energy injected into the grid plus the active energy credits produced in the consumer unit or in another consumer unit belonging to the same owner. The same exemptions apply to the social contribution for social security financing (COFINS) and the employees' profit participation program (PIS)n and benefits apply only to the compensation of electric energy produced by micro or mini distributed generators.

3. Case Study: Santa Marta Community

The community of Santa Marta is located on the Dona Marta hill, in the Botafogo neighbourhood, in the South Zone of the city of Rio de Janeiro, Brazil. According to the most recent census conducted in 2010 by the Brazilian Institute of Geography and Statistics (IBGE, 2013), Santa Marta has: a total population of 3908 inhabitants, 1176 households, and a total occupied area of 53,706 m^2.

3.1 Electricity Tariff and Consumption

The Santa Marta community is supplied by the utility company Light. In August 2019, the electricity tariff ranged between 0.1621 and 0.2405 USD/kWh, according to the monthly consumption and the consequent applicable taxes (Light, 2019b). The electricity consumption analysis was based on average monthly data registered in the community between 2010 and 2018 provided by (Light, 2019a). The assumed monthly consumption per household is reported in Table 3.1.

Table 3.1: Electricity consumption per household.

	kWh
Jan	162
Feb	217
Mar	193
Apr	163
May	172
Jun	138
Jul	144
Aug	135
Sep	131
Oct	152
Nov	147
Dec	157

3.2 Waste's Characterization

In 2012, Comlurb, the local company that manages waste collection, declared that the total daily amount produced in the favela was equal to 8 tons, thus corresponding to a yearly value of 2920 tons (V. Santos et al., 2012). According to (Comlurb, 2019), the waste collected in Santa Marta is not separated from the garbage collected in other areas, and therefore it was assumed that the composition of the waste produced in Santa Marta is the same as in Rio de Janeiro. According to (Prefeitura da Cidade do Rio de Janeiro, 2015), the organic matter

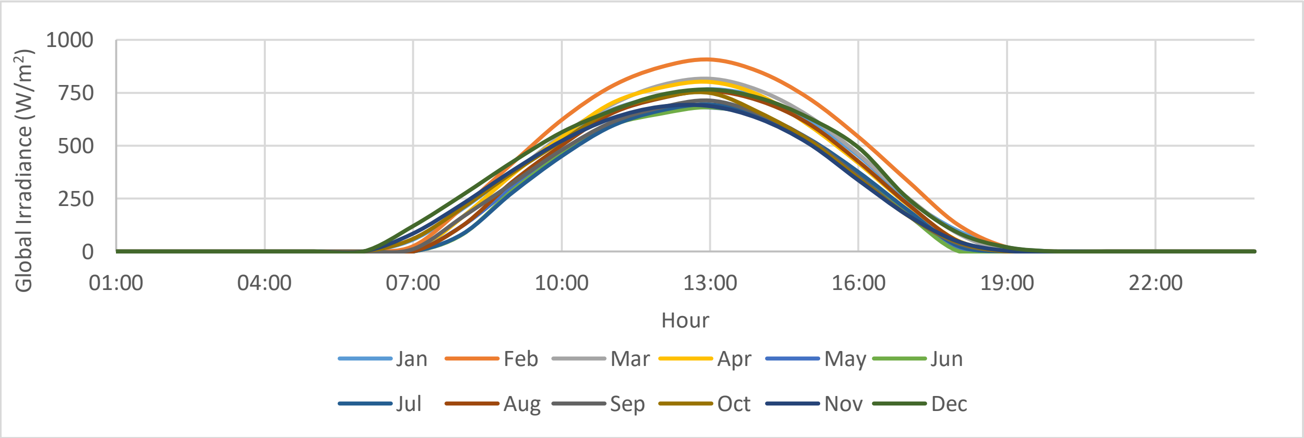

Figure 3.1: Global solar irradiance for a typical day for each month of the year (2001-17). Source: (European Commision, 2019).

represents 52% of the domestic urban waste in Rio de Janeiro.

3.3 Solar Energy

Figure 3.1 illustrates the trends of the global irradiance of a typical day in Santa Marta for each month of the year. It is possible to notice that the month that records the highest irradiance is February, with a peak value of 907 W/m^2, while the month with the lowest peak value (681 W/m^2) is June. As regards the monthly irradiance, the lowest values are recorded in the central months of the year, such as May, June and July, while the highest values are recorded in summer months, such as December, January and February. It was calculated that the daily average irradiance corresponds to 4.64 kWh/m^2, or annually to 1695 kWh/m^2.

4. Energy Assessment

4.1 PV Energy Assessment

The mathematical model adopted in this study to compute the energy produced by a solar module is the single diode ideal model. The behaviour of a PV module depends both on the temperature and the solar irradiation, and it is this duplicity that makes this mathematical model relatively complex. The single diode model involves a number of unknown parameters that vary according to the complexity of the configuration. For this study, it was assumed that the solar cell behaves ideally, thus involving three unknown parameters, as described in the study by (Crispim, 2007).

This model allows for calculating the power produced by a solar module. However, PV modules generate DC power and in order to supply it to the grid or to the final users, it is necessary to convert it in AC power. During the conversion from DC to AC, the power is degraded due to many factors, such as the site characteristics, the system design and the quality of the components; these factors are known as *derate factors*. Equation (1) describes the total energy produced by PV panels based system over a certain period, considering the overall derating of the system.

$$E = \sum_{j=1}^{nj} P_j^{max} \cdot \Delta t \cdot Derate \tag{1}$$

A derate factor of 81.65% was assumed. The derate factor includes also the inverter efficiency, which was assumed to be 97.1%, based on values characterizing common inverters in Brazil (Fronius, 2015). As regards the solar panels, modules of 330 W with an efficiency of 16.97% were used for the calculations (Canadian Solar, 2016). Calculations were performed for a period of 25 years, based on the useful life of PV Modules, assuming a power degradation of 0.5% per year. Based on (Vilaça Gomes, 2018), the useful lifetime of the inverter was assumed to be 12.5 years.

4.2 Anaerobic Digester Energy Assessment

The methodology used to calculate the electric energy produced by the anaerobic digestion system is based on a study conducted for a Brazilian municipality by (R. E. dos Santos, 2019). The lifetime of the project is assumed to be 16 years, starting from 2020. As adopted in the aforementioned study, the annual growth for the produced waste is assumed at 1%. In 2012, Comlurb declared that Santa Marta produced every day 8 tons of waste (V. Santos, 2012); therefore, it was calculated that the total waste collected in the year 2020 would amount to 8.66 tons/day. The energy produced was calculated on a yearly basis, following equations (2)-(7).

$$W_i = W_{i-1} \cdot (1+\lambda)^i \tag{2}$$

$$W_{o,i} = W_i \cdot F_o \tag{3}$$

$$Q_{BG,i} = W_{o,i} \cdot I_{BG} \tag{4}$$

$$Q_{col,i} = Q_{BG,i} \cdot \eta_{col,i} \tag{5}$$

$$P_i = Q_{col,i} \cdot \eta_{conv} \cdot LCV_{BG} \tag{6}$$

$$E_i = P_i \cdot F_C \cdot 8760 \tag{7}$$

The yearly amount of total waste collected was computed through equation (2). The available organic waste W_o (t/y) was calculated according to equation (3), where the organic fraction was assumed to be 52%. The total amount of biogas produced from the anaerobic digester was estimated following equation (4). The average amount of biogas I_{BG} produced by the digester was adopted as 119 m^3/t, based on worldwide installed digesters working at a temperature of approximately 35 °C. The quantity of biogas collected was calculated through equation (5), assuming a collection efficiency of 90%. Lastly, the yearly available power and energy which can be produced from the biogas were computed according to equations (6) and (7). The energy conversion efficiency was assumed at 33%, considering an internal combustion motor. The lower calorific value of the produced biogas was assumed to be 22 MJ/m^3. Finally, the capacity factor was hypothesized to be equal to 80%. The self-consumption of the anaerobic digestion plant was not considered in this study.

5. Economic Assessment

With the aim of assessing the profitability of the realization of both the projects, the Cash Flow (CF), the Net Present Value (NPV), the Internal Rate of Return (IRR), the payback period (PB), and the Levelized Cost of Electricity (LCOE) were evaluated.

$$CF_{i(t)} = R_{i(t)} - C_{i(t)} \tag{8}$$

$$NPV = \sum_{i=0}^{N} \frac{CF_i}{(1+r)^i} \tag{9}$$

$$0 = \sum_{i=0}^{N} \frac{CF_i}{(1+IRR)^i} \tag{10}$$

$$LCOE = \frac{\sum_{i=0}^{N} \frac{C_i}{(1+r)^i}}{\sum_{i=0}^{N} \frac{E_{gen,i}}{(1+r)^i}} \tag{11}$$

Equations (8), (9), (10) and (11) were adopted from (Belyadi et al., 2017; Vilaça Gomes, 2018). The cost of opportunity r (annual discount rate) was assumed at 6%, based on (Pinto et al., 2016; Vilaça Gomes, 2018).

5.1 PV Economic Assessment

Considering the site characteristics, the solar cooperative model seemed to be the most promising one; therefore, the proposal is to implement the PV project through the creation of multiple solar cooperatives inside the community of Santa Marta. This business model for solar distributed generation would bring several advantages when compared to single-household installation: it ensures to reach the cost efficiency, thanks to the larger scale of the project, and it allows to overcome site issue. In fact, it is likely that many of the households in Santa Marta cannot install a PV system on the rooftop, due to shadowing, orientation, and inadequacy of the roof structure. With the cooperative model, the most adequate dwellings would be chosen according to the site characteristics to receive the PV technologies, and at the same time, other households with no site potentiality would be given the possibility to participate and benefit from the project.

Three different financing modes were assumed: in financing mode 1 (FM1), it was assumed that the residents would finance themselves the totality of the investment costs. In financing mode 2 (FM2) a loan was introduced, with the aim of making the system's upfront cost more affordable. In financing mode 3 (FM3), besides offering a credit to the residents, it was assumed that a grant is received from a funder to cover part of the investment cost of the project.

In the case of FM1, the total monthly costs were calculated through equation (12), which was adapted from (Vilaça Gomes, 2018), summing the contributions of the investment costs, the operation and maintenance costs, and the monthly electricity bill.

$$C_i = I_i + O\&M_i + B_i \tag{12}$$

In the case of FM2 and FM3, the total monthly cost has to take into account the installment that the residents have to pay back to the financing entity, according to equation (13).

$$C_i = I_i + O\&M_i + B_i + L_i \tag{13}$$

Investment Price & O&M cost

A fixed investment price per Watt installed was used and it was calculated by summing up the cost of each component, and considering a size of cooperative of about 10 kW, obtaining a value of 1.288 $/W, which was compared with values from the literature and was found to be consistent. The annual O&M cost was set at 1% of the total investment, based on different solar projects (Miranda et al., 2015).

Bills and Revenues

The electric energy bill calculation was mainly based on (Vilaça Gomes, 2018) and it was performed for all the 300 months of the lifetime of the project. The sets of equations (14)-(23) were used to carry on the computation.

$$E_{PV,i,t} = E_{PV,i,t=1} \cdot (1-\delta)^t \quad \forall\, t > 1 \tag{14}$$

$$E_{req,i,t} = E_{req,i,t=1} \cdot (1+\gamma)^t \quad \forall\, t > 1 \tag{15}$$

$$EB_i = E_{PV,i} - E_{req,i} \tag{16}$$

$$CR_i = \begin{cases} EB_i & if\ EB_i > 0 \\ 0 & otherwise \end{cases} \tag{17}$$

$$EB_{neg,i} = \begin{cases} EB_i & if\ EB_i < 0 \\ 0 & otherwise \end{cases} \tag{18}$$

$$X_i = \begin{cases} 0 & if\ i < 61 \\ CR_{i-60} + \sum_{i=1}^{60} EB_{neg,i} & if\ i = 61 \\ CR_{i-60} + EB_{neg,i-1} + X_{i-1} & if\ i > 61\ and\ X_{i-1} < 0 \\ CR_{i-60} + EB_{neg,i-1} & if\ i > 61\ and\ X_{i-1} > 0 \end{cases} \tag{19}$$

$$CR_i' = \begin{cases} CR_i & if\ X_i \leq 0 \\ CR_i - X_i & otherwise \end{cases} \tag{20}$$

$$EB_i' = \begin{cases} CR_i' + EB_{neg,i} + EB_{i-1}' & if\ EB_{i-1}' > 0 \\ CR_i' + EB_{neg,i} & otherwise \end{cases} \tag{21}$$

$$T = \begin{cases} 0.162163 & if\ EB_i' \geq -50\ (\text{or } \mathrm{EB_i'} \geq -\mathrm{d_{cea}}) \\ 0.199985 & if - 300 \leq \mathrm{EB_i'} < -50 \\ 0.240493 & if - 450 \leq EB_i' < -300 \\ 0.236802 & otherwise \end{cases} \tag{22}$$

$$B_i = \begin{cases} |EB_i'| \cdot (1+\beta)^i \cdot T & if\ EB_i' \leq -d_{cea} \\ d_{cea} \cdot (1+\beta)^i \cdot T & otherwise \end{cases} \tag{23}$$

Equation (14) was used to calculate the monthly energy generated by the PV system after the first year, as it was assumed that the power degrades every year. Equation (15) expresses the amount of electricity requested by the users, which was assumed to increase every year. A first monthly energy balance was calculated through equation (16) in order that its value is negative when the energy generated by the distributed PV system is not enough to satisfy the demand. Monthly credits are calculated through equation (17). Formula (18) accounts for the negative balances, that represent the energy required from the grid. Equation (19) allows checking whether a monthly credit has (partly) expired after 60 months or not. From the 61st month, formula (18) evaluates if the credits obtained 60 months before were used to cover the energy required from the users or not; if not, the equation returns a positive value that corresponds to the amount of monthly expired credits, which are subtracted from the current monthly credits as described by equation (20). Equation (21) allows calculating the actual energy balance considering cumulative credits, their lifetime and the energy required from the grid. Equation (23) was used to compute the monthly electricity bill, taxes included; the formulation was done considering the Agreement ICMS 16and the RN414. When the monthly energy balance is lower than or equal to the negative value of the equivalent demand of the cost of electricity availability, then the base to calculate the bill is the monthly energy balance itself, otherwise, the base is the cost of the electricity availability. It was assumed that the grid connections in Santa Marta are monophasic, and therefore the cost of electricity availability is equivalent to the consumption of 30 kWh. The electricity tariff varies according to equation (22); it was assumed that tariffs increase each month at a rate of 0.20%, based on (Lacchini et al., 2015). Lastly, the revenues, used in equation (8), consist of the avoided cost due to the PV system installation, namely the avoided electricity bills. The revenues of the project, which consist in the avoided electricity bills, were calculated considering that the procedure described before applies also for the calculation of the bill without distributed generation, just assuming that $E_{PV,i} = 0$ for every month.

Loan Monthly Installment

The monthly installments were calculated through equation (24), adapted from (Pillot, 2018), where A is the borrowed amount and r_l and N_l the interest and the period of the loan. It was assumed a borrowed amount equal to 80% of the total investment, an interest rate of 9.5% and an amortization period of 8 years.

$$L_i = A \frac{r_l\,(1 + r_l)^{N_l}}{(1 + r_l) - 1} \tag{24}$$

5.2 **Anaerobic Digestion Economic Assessment**

The total annual costs were calculated using equation (25). The project lifetime is assumed to be 16 years based on (I. F. S. dos Santos et al., 2016), with no residual value of the components, starting from the year 2020.

$$C_i = I_i + O\&M_i \tag{25}$$

For the calculation of the investment cost, the prices of each component were summed up based on the study conducted by (R. E. dos Santos, 2019). With respect to the O&M costs, they were assumed to be 7% of the initial investment. The revenues generated by the system consist of the sale of the produced electricity. Annual revenues were calculated through equation (26).

$$R_i = E_{gen,i} \cdot S \tag{26}$$

The energy sale rate is set to be 92.30 USD/MWh, based on the upper limit value set at the first public auction for thermal gas power plants (ANEEL, 2016).

6. Results

6.1 PV Results

The optimum power to install was calculated as to maximize the NPV of the project, resulting in 1.96 kW per household, with an energy production on the first year of 1195 kWh/W.

Table 6.1: Economic Results for the PV project.

Parameter	FM 1	FM 2	FM 3
Equity Investment	2,520$	504$	0$
Monthly Installment	0$	29.64$	29.64$
Grant	0$	0$	504$
NPV	1,913$	1,660$	2,164$
IRR	12.38%	13.87%	22.64%
PB	8 y 8 m	10y 9m	9y 6m
LCOE ($/kWh)	0.1680	0.1767	0.1595

The economic results are reported in Table 6.1 and they show that with any of the financing modes the project is economically viable, as the NPVs are always positive and the obtained LCOEs are competitive with the current tariff. However, one may argue that, due to the socio-economic background of the community, the PB periods are too high and the locals might not be interested in investing in a project whose economic benefits are not immediately visible, but long-term. Moreover, it is likely that most of the families don't have the required budget to participate in the project with FM1 or FM2. As expected, the FM3 showed overall the best results, with the highest NPV and IRR, and the lowest LCOE.

6.2 Anaerobic Digester Results

Table 6.2: Anaerobic digester project results.

Parameter	Value	Unit
Investment	388,066	$
Power	40.54-49.47	kW
Unit Cost	8.24	$/W
Energy	284-347	MWh/year
Energy	0.17	MWh/ton
Energy covered	9.1-6.7	%/year
NPV	-395,276	$
IRR	-22.1	%
PB	>16	years
LCOE	0.2215	$/kWh

Energy and economic results are reported in Table 6.2. It is possible to notice that the NPV is strongly negative, meaning that periodical costs overcome revenues; moreover, the LCOE is higher than the actual tariff. One may argue that, the revenues of the project were calculated based on the electricity sell and not as the avoided cost related to the electricity bill; however, as the energy results showed, the amount of the community energy needs coverable by the biogas plant is such a small percentage that the economic feasibility would have not been reached in any case. Keeping fixed the remaining assumptions, the minimum amount of waste necessary to make the project economically feasible (NPV=0) was investigated, resulting in 35.99 tons/day in the first year of the project, which is almost four times the assumed input value (8.66 t/day) for the community.

7. Sensitivity Analysis

A sensitivity analysis was conducted considering the PV project; the anaerobic digestion system was excluded from the analysis for its unfeasibility. The objective of the analysis was to determine how the economic results (NPV, IRR, PB time, LCOE) change by varying some input parameters, which were defined for each financing mode. For the FM1, a variation between -10% and 10% of the following key inputs were considering:

- Investment unit price (USD/W) of the PV system.
- The system's energy production (kWh).
- The electricity tariff prices (USD/kWh).

Table 7.1: Sensitivity analysis results for FM1.

Variable Inputs	IRR (%)		PB (y & m)		LCOE ($/kWh)	
	-10%	10%	-10%	10%	-10%	10%
Investment Price	13.6	11.2	8&2	9&2	0.1507	0.1843
Energy Production	11.4	12.9	8&9	8&8	0.2018	0.1442
Electricity Tariff	10.8	13.9	9&5	8&0	0.1621	0.1739

Table 7.1 reports the results for the sensitivity analysis of FM1. In all cases, the NPV was positive. Even in the worst cases, so considering a reduction in the production, a decrement of the electricity tariff and an increment of the investment price, the project would still be economically viable. The worst results were obtained for a reduction of the tariffs. For the sensitivity analysis of the FM2, two Scenarios (1 and 2) were created; similarly, for the FM3 two Scenarios (3 and 4) were investigated. Definition of the key input parameters for the different scenarios is reported in Table 7.2.

Table 7.2: Definition of Scenario 1,2,3,4.

Scenario	1	2	3	4
Grant	0	0	15%	10%
Borrowed Amount	100%	60%	85%	60%
Interest Rate	4.03%	13.5%	4.03%	13.5%
Amortization period	12 y	5 y	12y	5y

Table 7.3: Sensitivity analysis results for FM1 and FM2.

	IRR (%)	PB (y & m)	LCOE ($/kWh)
Scenario 1	51.85	4&11	0.1597
Scenario 2	12.16	10&1	0.1770
Scenario 3	-	0	0.1481
Scenario 4	13.93	9&4	0.1684

Table 7.3 reports the results for FM1 and FM2. Even in the worst cases (Scenario 2 and 4), the project shows positive economic results. The best results are obtained for FM3, Scenario 3; however, optimum results are obtained also for FM2, Scenario 2, showing that a grant is not strictly necessary to make the project's costs affordable for the users if a convenient credit line is adopted, involving low interest rates and long loan periods.

8. Conclusion

Solar photovoltaic and anaerobic digestion systems were investigated with the scope of individuating a renewable affordable solution, to improve and reduce the cost of the electricity service for the urban low-income community of Santa Marta, in Rio de Janeiro, Brazil. Results showed that the electricity obtainable by treating the organic waste produced in the community through an anaerobic digestion plant (284-347 MWh/year) would not be enough to cover the demand of electricity required by the locals. Moreover, the economic profitability parameters resulted to be extremely negative, and thus the system doesn't offer a competitive solution for the low-income community. As regards the solar project, results showed that PV systems can represent a competitive solution for low-income communities through the implementation of adequate business models and credits lines. The creation of multiple solar cooperatives inside the community would allow households that don't have the site possibility of receiving the PV technology to still benefit from the system, giving the project the potential to impact the whole community. It was assessed that the optimum installed capacity to satisfy the demand and at the same time maximise the NPV of the project corresponds to 1.96 kW per household, for an investment of 2,520 USD. Three different scenarios for the financing method were created: (1) a self-financing mode, where the users pay 100% of the investment cost; (2) a debt-financing mode, where the users are offered credits to cover part of the upfront costs; (3) a debt and grant financing mode, where the locals, besides the credit, are offered a grant by a donor entity. Results showed that the project would be economically feasible in any of the three financing scenarios; however, not in any case, the project might be considered as convenient by the locals. The sensitivity analysis showed that the best results for the community, are the one involving a credit line that covers the whole investment cost characterized by low interest rates for a relatively long period.

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