Viability study for a sustainable energy policy in informal settlements: The Santa Marta favela case

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Abstract. Architects and urban planners are often challenged by design problems that include public policies for social development. While the use of sustainable energy has been growing, the costs with installation are still a problem to underprivileged communities such as informal settlements. In this sense, energy justice is a relatively new concept. This paper is part of a larger research that aims to propose a framework for a sustainable energy policy. In this paper we use a case study to estimate the capacity for solar energy production. Research steps include data collection, modeling, simulation, and analysis. Results show that the case study has the capacity to produce several times more energy than it consumes, with potential of selling the overproduction to generate benefits to the community. Future research includes a more detailed simulation of the case study's potential using machine learning techniques.

Keywords: Inclusive Design, Favela, Informal Settlements, Affordable and Clean Energy, Sustainable Cities and Communities.

1 Introduction

Informal settlements are widely present around the world, and it is estimated that they house over one billion people (United Nations, 2019). Informal settlements have diverse origins and many times their physical characteristics are a product of the needs, cultural values, and opportunities that their residents encounter (Davis 2006). Informal settlements are a solution for the lack of affordable housing units as their constructions follow an incremental fashion, the units do not follow building or planning codes, and their locations are usually in areas that are not suitable for the formal construction sector (Compans 2007; Salingaros et al. 2006).

In an international context that focuses on climate change adaptation (Sharifi et al. 2021) it is a cruel irony that residents of low-income areas still struggle to have access to essential urban infrastructure. While there are diverse national and international initiatives to foment the use of renewable energy, in a country like Brazil, informal settlements account for 7.8% of the total residences (Instituto Brasileiro de Geografia e Estatistica, 2020).

Essential urban infrastructure includes transport, sanitation, water supplies, electricity, and waste disposal. In this research, we approach the lack of access to electricity in favelas. There is an effort to combat the illegal electricity connections in Brazilian informal settlements and since the 1990s, attempts have been made to formally supply electricity to them. However, energy is a very expensive commodity in an informal settlement. Law 3735/2015 (Câmara dos Deputados, 2015) establishes that energy should be more financially accessible for the population in need. However, few initiatives based on that law were conducted and the need for accessible electricity in informal settlements is still a problem to overcome.

In this research, we study a favela (a Brazilian informal settlement) called Santa Marta and located in the city of Rio de Janeiro, Brazil. The monthly energy consumption at the settlement is 264,858.33kWh (Paradis 2015). Santa Marta favela is well located within the formal city (Minoja 2010) being at a short distance from the downtown, prime neighborhoods, iconic monuments, and touristic attraction of the city. The settlement is physically contained by the high reliefs from the hill where it is located and the formal part of the city.

This paper presents a viability study for a sustainable energy policy in informal settlements.

2 Methodology

In this research, we use a case study, Santa Marta favela, to model its capacity to generate solar energy and to ponder the economic benefits of this clean energy solution. The hypothesis for this paper is that the economy from preventing illegal electric connections justifies the costs for the installation of residential solar energy kits. The research was developed in four main steps: (1) data collection of the case study, (2) modeling the case study, (3) running computational simulations for energy consumption and energy generation for the case study, and (4) analyzing the results and drawing conclusions.

2.1 Data collection and processing

The first step involves data collection from the Santa Marta favela to create a digital 3D model of the settlement. Table 1 shows a description of the collected data, with the type of data, source, and additional important comments. Figure 1 shows examples of the data collected.

Table 1. Santa Marta favela data collection.

Type of data	Source	Comments
Topographic chart	Municipal Archives of Rio de Janeiro	The chart did not include urban information as the favela is not officially recognized by the municipal bureau.
Map of Santa Marta favela	Public Construction Company (EMOP)	Outdated map (from 2012) with building footprints, building uses, building materials, and streets.
Imagery of Santa Marta	site visits (2015, 2016, 2018, 2019)	Imagery helped to update information about changes in the urban fabric and to establish the height of the buildings.


(a) (b) (c)

Figure 1. Examples of data collected from Santa Marta favela: (a) topographic chart, (b) Map of the settlement, and (c) examples of imagery. Source: Made by the authors.

The topographic chart and the map of the Santa Marta favela were not available in digital format. Both were scanned and the distortions were corrected using a LISP routine on AutoCAD. Then the scanned images were used as the base to create a ".cad" file of the Santa Marta favela with topographic and urban information (2D plan). Figure 2 shows the resulting 2D plan.

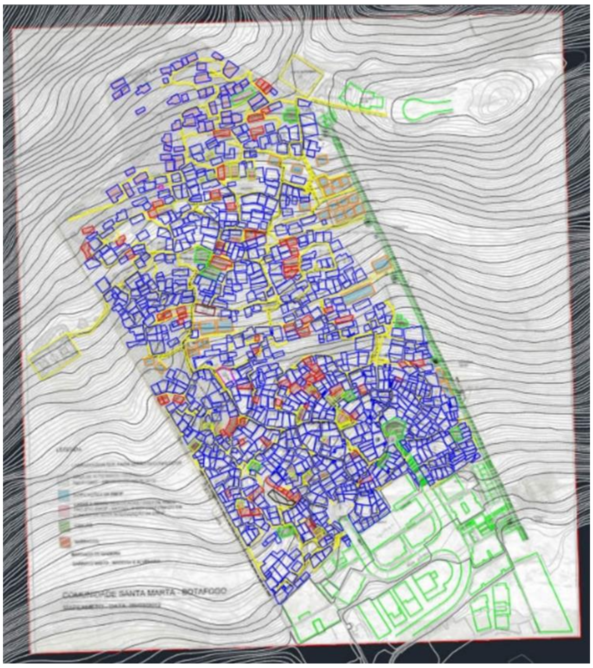

Figure 2. 2D plan of Santa Marta favela. Source: Made by the authors.

2.2 Modelling the case study

Researchers used the case study's data to construct a 3D digital model of the case study. The construction of the digital model used the 2D plan and imagery from the settlement. The 2D plan provided information about the terrain and the location of the buildings while visual data provided information about building heights, which was entered in a spreadsheet file.

The construction of the model used Rhinoceros 3D (Rhino) CAD software and standard Grasshopper (GH) plug-in components of. The contour lines provided the information necessary to generate the terrain surface in Rhino using the command "Surface>Path". To speed up his procedure, a code was developed in GH (Figure 3).

Figure 3. General view of the Grasshopper code developed to aid the 3D modeling process. Source: Made by the authors.

This code imports information on terrain surfaces and building footprints to create the three-dimensional projection. Building height information from imagery is retrieved from the spreadsheet file and projected in the 3D model. Figure 4 shows the finished 3D model.

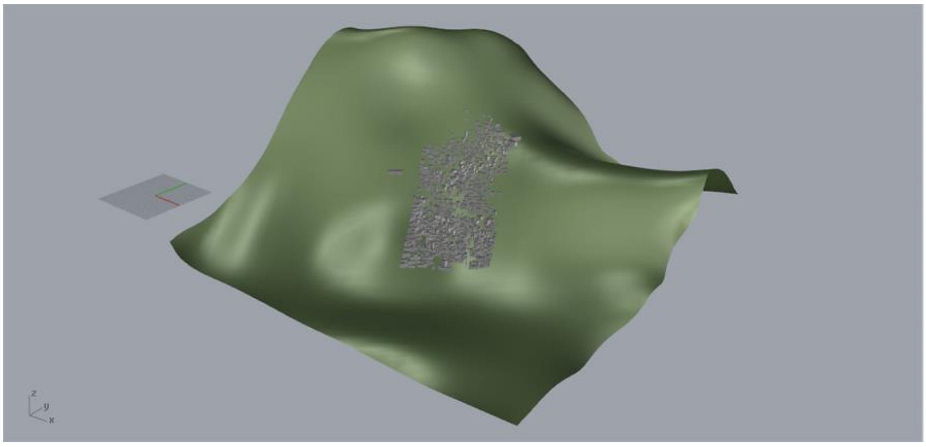

Figure 4. 3D model of Santa Marta favela. Source: Made by the authors.

2.3 Simulation and analysis

The researchers used the 3D model to run solar simulation. This step is important because the case study is located at the side of a hill and researchers were not sure if the area would receive solar exposition due to its topography. Researchers were interested to know if the roofing of the buildings would receive direct solar irradiation.

The simulation was performed using Rhino, GH, and the Ladybug (LB) add-on. The source of climatic data, from the LB website, was a ".epw" file (https://www.ladybug.tools/epwmap/) and the location was the closest to the favela available (Rio de Janeiro - Vila Militar lat: -22.86, lon> - 43.41, tz: -3.0, elev:45.00). A code in GH imports the climate data and crosses it with the 3D model of Santa Marta favela (Figure 5) using the add on LB to analyze solar irradiation during different times of the year. Figure 6 shows the projection of the sun chart over Santa Marta favela, marking the position of the sun in each hour of each day of a one-year period, from 6 am to 6 pm.

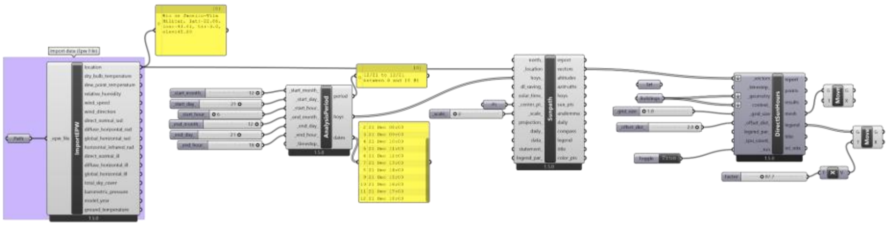

Figure 5. Climatic analysis algorithm. Source: Made by the authors.

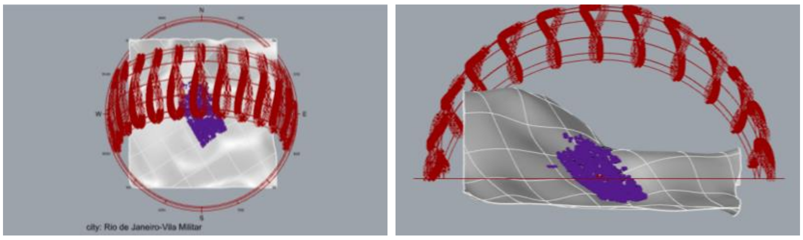

Figure 6. Projection of the sun chart over Santa Marta favela. Source: Made by the authors.

To determine if the settlement had solar exposition on the building roofs, the researchers simulated both solstices as these would be the days where the settlement would receive the highest (Summer - December, 21st) and lowest (Winter - June 21st) irradiation.

For the Summer solstice, the simulation starts at 6:00 am and ends at 6:59 pm. Figure 7 shows the respective projections for sunrise, noon, and sunset and Figure 8 shows the total exposition during that day for Santa Marta favela.

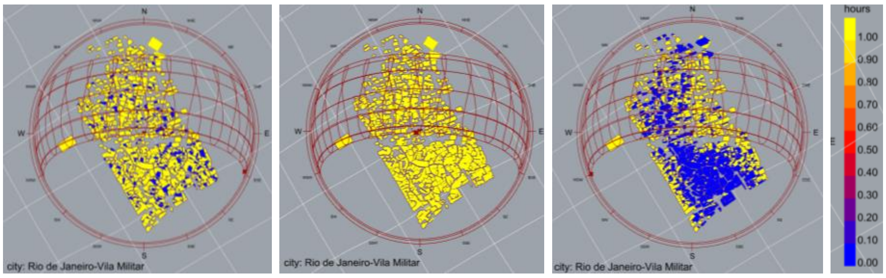

Figure 7. Solar exposition at 6 am (left), 12 pm (center), and 6 pm (right) during the Summer solstice. Source: Made by the authors.

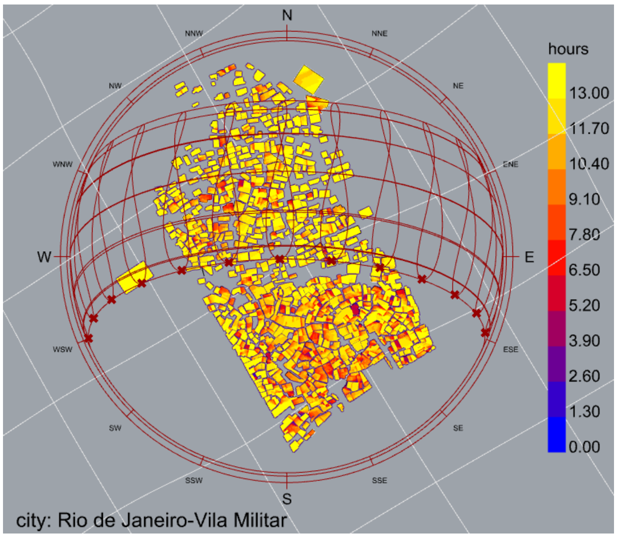

Figure 8. Projection of solar exposition during the Summer solstice. Source: Made by the authors.

For the Winter solstice, the simulation starts at 7 am and ends at 5:59 pm. Figure 9 shows the respective projections for sunrise, noon, and sunset and Figure 10 shows the total exposition during that day for Santa Marta favela.

The solar simulation using LB shows that Santa Marta favela has solar exposition even during the Winter solstice. To determine the amount of energy that could be generated, we followed the steps presented by Neris (2021):

The author (Neris 2021) first determines the production per panel per month (considering a generic panel with potency equals 410W):

$$Emp = p*r*30 \qquad (1)$$

Emp: energy generated per month per square meter; p: panel's potency; r: daily average radiation. To determine the average radiation, we used the Global Solar Atlas, available at (https://globalsolaratlas.info/map?c=

11.523088,7.998047,3). For the city of Rio de Janeiro, r= 4.035kW/sqm. Emp= 0.410*4.035*30*0.19= 9.43kWh/sqm per month.

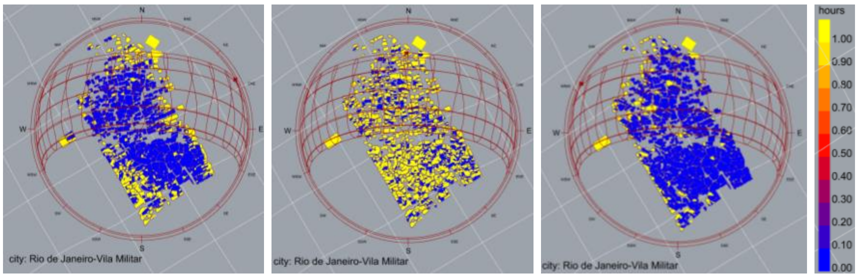

Figure 9. Solar exposition at 7 am (left), 12 pm (center) and 5 pm (right) during the Winter solstice. Source: Made by the authors.

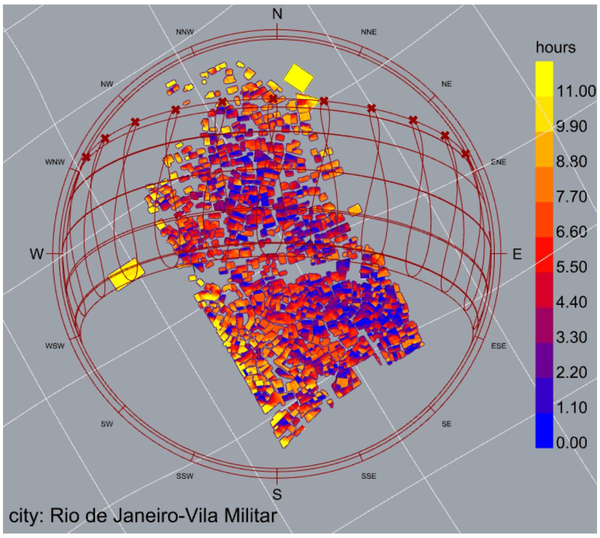

Figure 10. Projection of solar exposition during the Winter solstice. Source: Made by the authors.

Considering that Santa Marta favela has 1177 buildings with a total area of 154,424.33 sqm, the maximum potential energy production in a month for the settlement equals to 1,456,221.43 kWh.

The settlement has the capacity to generate 5.5 times more energy than the amount it consumes, being able to sell the overproduction back to the city of Rio de Janeiro. This could be part of a sustainable energy policy where the profit generated from overproduction could be used to pay for the costs of installment and maintenance of the solar panels.

3 Results

In this paper, we showed the estimation of the capacity for energy production of the Santa Marta favela. First, we generated a 3D digital model of the case study. Then we used this model to verify if the roof of buildings in the Santa Marta favela were receiving sunlight, a necessary condition for the installation of solar panels. These preliminary steps were important to understand the geography of the case study and its potential for the implementation of a sustainable energy policy, related to solar energy production.

The next step was to estimate the capacity of the case study for solar energy production. Results show that Santa Marta has an estimated monthly consumption of 264,858.33kWh and a potential for producing almost 5.5 times that amount (1,456,221.43kWh/month).

4 Discussion

This paper presents a methodology for analyzing the viability of an informal settlement to produce solar energy, where the production surplus cloud be re-soled to generate benefits for the community. Although applied to a specific case study, this methodology can be applied to different scales of similar problems, using the potential to produce solar energy as an instrument for energy justice.

The work shown in this paper is an estimation of the settlement's potential to generate solar energy. The community was not consulted at this stage. For future work, that estimate should be reviewed to reflect the interest of the residents in installing solar panels in their homes. The study will also benefit from a more precise calculation of solar radiation using, for example, machine learning strategies.

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