Methodology for Photovoltaic Plant Modeling with RETScreen Software application

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Abstract

In today's world, the search for new energy generation alternatives is increasing and being far from large metropolitan centers is an aggravating factor for the socioeconomic development of municipalities. In addition to the difficulty and high costs of keeping a city in proper working order, the quality of service provided by electricity concessionaires has low efficiency and high consumption of fossil fuels. In order to contribute to a solution, this work aims to present an alternative developed using the RETScreen Software, through the design of a photovoltaic plant, to meet the energy demands of the municipalities in the state of Amazonas. Through the research, we sought to understand and present the particularities of each proposed chapter and, through computer simulation, to develop a renewable source plant to supply the demand of the municipality of São Gabriel da Cachoeira-AM. Two possibilities of application of the result can be analyzed, where the fulfillment of the demand was carried out in a total and partial way and, with that, obtain satisfactory results such as the reduction of 50% of the consumption of fossil fuel, reduction of 25% to 50 % of emission of polluting gases and to present the potential that the generation of photovoltaic energy has for the Amazon region.

Keywords: Energy, Photovoltaic, Power plants, RETScreen.

1. Introduction

Energy is a fundamental word for the development of humanity, it is present in all segments of a society. In industry, commerce, homes and others in more areas. As for the use in electrical and electronic equipment, it is essential and for the continuity of life as it is known today, there is no way to disregard the use of electrical energy.

Bastos (2014) addresses a concept that states about public policies, aimed at the interest of the people and their advancement, linked to the quality of life of its inhabitants, where the author emphasizes that access to energy is a challenge for managements. government agencies, even for the most developed countries. Energy

is quality of life and with its use it is possible to make progress and develop a nation, village and communities. Due to the great importance that energy has for the well-being and comfort of human beings, in recent years the search for means of energy generation, economy and efficiency to reduce consumption has gained space in the agendas of numerous social events, speeches and energy efficiency programs so that energy generation continues to be carried out with quality and guarantee of new clean sources.

Camelo et al (2015), corroborates this understanding, stating that the search for means and sources of electrical energy, which are less polluting or clean regarding the emission of gases, has been increasingly the agenda in approaches in several countries. And as well expressed by the author, developing clean and renewable energy sources has become increasingly necessary and challenging.

Junfeng et al (2006), 14 years ago, expressed his ideals stating that due to the growing need and dependence of the world population for energy resources and other issues, such as pollution and environmental impacts resulting from the consumption of fossil fuels, it mobilized even more investments for renewable energy generation.

Few known sources are currently considered renewable, and the vast majority of such sources have low efficiency compared to non-renewable sources, such as wind power generation that uses the planet's wind currents to generate electricity.

This energy source needs an average wind speed above 2.5 m/s for deployment, it is also linked to the lack of migratory routes and still has a typical yield of only 10% depending on the energy that enters the system for generation. of electricity. (RODRÍGUEZ, 2020).

Non-renewable sources, on the other hand, present better results in the generation of electricity, but always accompanied by some characteristic factor that makes them necessarily replaceable by a renewable source. According to Malzoni (2010), in 2007 the world energy matrix consisted of 82% of fossil fuel consumption and, comparing with the Brazilian reality, renewable resources were represented by 47% of renewable energy production.

Currently, according to ANEEL data, the Brazilian energy matrix presents energy generation through hydroelectric plants with a percentage of 12% and according to the May 2020 PMO, the installed capacity in the country that the hydroelectric plants represent is equal to 66, 1% of the total, but despite the efficiency, when talking about new projects for the implementation of hydroelectric plants, many criticisms and controversies are raised by various agents external to the interests and one of these are the environmental and anthropological impacts that these cause around their implantation areas due to the large floods coming from its reservoirs and the damming of the water necessary for the generation of energy.

Responsible for generating 2,887 MW, solar energy has gained more space in the Brazilian energy matrix, with the prospect of reaching 2.4% of energy generation in the country by 2024. Even with the representative implementation cost, the energy source can be an alternative, if well explored and with greater resources used, for the generation of clean and totally renewable energy.

According to Mathyas (2018) this energy source is the cleanest and ideal type of generation for Brazil. The same states that photovoltaic energy aligned with a management system, for example the rural electrification program, working together with the productive use of energy strengthens the most needy communities and

contributes to the preservation of the environment.

Mathyas (2018) also concludes that the exploitation of solar energy is ideal for expansion in Brazil due to the intensity of light and heat that are constant throughout the year, both in urban and rural areas.

Corroborating the proposal, the Brazilian Association of Photovoltaic Solar Energy (Abosolar) explains, through its president, Rodrigo Sauaia, that photovoltaic technology has become more reliable for investments after the approval of a normative resolution by Aneel, which in 2012 approved the distributed micro and mini-generation and the electric energy compensation system.

Rodrigo also states that if there is an incentive from the federal government, there is a possibility that in 2030 alternative energy may be responsible for 10% of the generation of electric energy in the Brazilian energy matrix. In 2017, Brazil ranked 10th in the world ranking of photovoltaic energy generating countries and there is a possibility that this indicator will be better.

The solar potential, according to Absolar (2018), is superior to all currently known resources, where without the need to build new plants and only considering the roofs of existing houses in the country, it would be possible to generate approximately 164 GW in energy. installed power.

In amazonas, the PPE – Energy Efficiency Program is the result of investments by the local concessionaire to apply its net revenue. This program consists of directing 0.4% of the company's net operating income to the development of clean energy. One of these projects, started in 2020 is called AMESOLAR, which would include 1000 residential consumers, customers of Amazonas Energia SA, with the replacement of 5000 units of LED lamps and 1000 residential photovoltaic systems subsidizing 50% of the cost of equipment for these facilities.

With more attention focused on the expansion and implementation of energy from solar sources, the country will be able to make better use of this infinite and free resource that is totally safe and sustainable. This theme will still be explored a lot over the years.

Therefore, this work is intended to present a methodology for evaluating the feasibility of building photovoltaic plants using the RETScreen software, to meet the energy demands of geographically isolated municipalities from the main distribution network in the state of Amazonas,where the construction of transmission lines becomes unfeasible due to the need to preserve the local fauna and flora, as well as the different types of land, swamps, floodplain areas, among other obstacles that make investments and the execution of works expensive. for interconnection to the SIN.

Through computer simulation, using the Retscreen Expert software, it is possible to determine with clarity and low cost the relevant factors for the construction of small and local photovoltaic plants, in order to generate clean energy and guarantee the most remote communities the right and equality regarding the use of electricity.

2. Theoretical Framework

2.1. Historical Summary of Energy in Amazonas

Nascimento (2017) highlights that initially the first plants were located on Avenida Sete de Setembro and the work carried out was intended for public lighting and public offices, with electric energy being commercialized with private contracts only in 1898.

Currently in Amazonas, the energy supply is the result of the interconnection to the SIN - National

Interconnected System, which in 2013 occurred to the interconnection of the City of Manaus to the line of the Tucuruí Hydroelectric Power Plant. The Brazilian government initiated the electrical interconnection in order to improve the energy use that began in the Southeast, Midwest and Northeast regions of the country. (MERCEDES et al, 2015).

However, for a long time, Amazonas had thermoelectric plants as a source of electricity generation, burning ethanol from cassava and natural gas from Coari, which made electricity as the structural basis of the community not a reality for the interior of the Western Amazon, making regional integration difficult. (BARBOSA, 2010).

2.2. Energy Installation Difficulties in the Interior of the State of Amazonas

With the largest share of the national energy matrix and totally predominant in the northern region of the country, hydroelectric plants are present in several parts of the Amazon. Fearnside (2019) highlights the fact that hydroelectric power plant installations represent numerous problems that affect locations with social and environmental impacts, with the need to carry out environmental impact studies to verify them.

Another factor that makes the transmission of energy to more remote and isolated areas very difficult is the logistics of the Amazon region. Saliba et al (2014) defines the Amazon as an environmental heritage and highlights its importance to the world. The authors state in their article that any physical project in the Amazon region becomes challenging and requires the utmost care and technology to reduce interference in the ecosystem.

2.3. Power Generation

Currently, the installed capacity in Brazil is equal to 186,603.00 MW generated from 2,367 plants that use the most varied sources of primary energy. (CCEE, 2022). As the main source of electricity generation, hydraulic, thermal, wind and solar resources are listed in order of importance. Figure 1 presents the updated percentages in the main generation sources explored in the country.
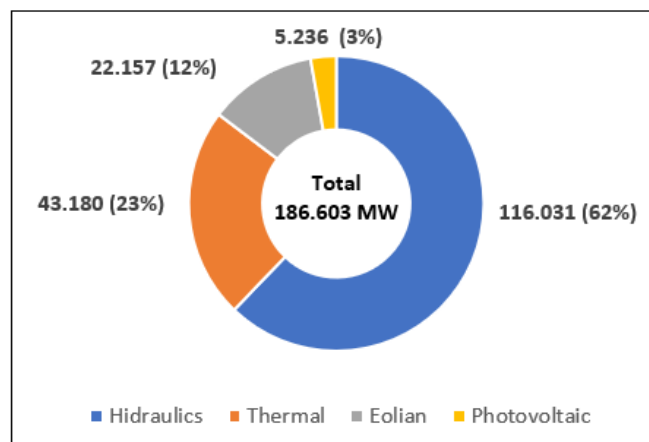

Figure 1. Monitoring by CCEE Source

Predominantly, with 62% of the total energy generation being obtained from water resources, hydroelectric

plants are the plants with the greatest impact on national production and their growth over the last four years has been linear according to the planning of the National Energy Agency. Electric – ANEEL

2.4. Amazon Energy Matrix

Figueiredo (2022) highlights the energy matrix of the state of Amazonas as basically sustained by an electric power generation system almost exclusively in the use of petroleum derivatives and Diesel oil. He also states that such demand represents about 70% of the generation.

According to the updated data from the ANEEL Generation Information System (SIGA) accessed on June 23, 2022, represented in Figure 2, the state of Amazonas has three sources of electricity generation to meet the demand, with a total of 314 projects in operation whose energy sources are biomass, fossil, hydro and solar.

Enterprises Numbers 314					Authorized Power Total 2.446.245,38				
Supply	Authorized Power (kW)	Monitored Power (kW)	QTY	Monitored Power (%)	UF	Authorized Power (kW)	Monitored Power (kW)	QTY	%
UFV	651,48	651,48	93	0,03%	AM	2.446.245,38	2.374.801,38	314	100,00%
UHE	274.710,00	274.710,00	2	11,57%					
UTE	2.170.883,90	2.099.439,90	219	88,40%					

Figure 2. Installed Capacity by State in Operation (Amazonas)

2.5. Solar Energy Potential and Photovoltaic Energy

The oldest energy source on our planet is our Sun and this has been a source of light and heat for all living beings that have passed through this planet. Such a source of energy is capable of providing life if observed from a natural angle, such as carrying out photosynthesis that plants use for survival.

Nascimento (2017) apud ANEEL (2005) explains that solar energy can be used directly as lighting and heating source. This highlights the importance that such a source has when discussing the diversity of applications that can benefit the user of solar energy.

According to Enio Pereira, physicist who coordinates studies for the Brazilian Atlas of Solar Energy, managed by the National Institute for Space Research – INPE, "the potential for generating solar energy in Brazil is gigantic".

Table 1. Average Annual Potential of Solar Energy

Average Annual Solar Energy Potencial	
Region	**Average Global Radiation (kWh/m²)**
Northeast	5.9
Midwest	5.7
Southeast	5.6
North	5.5
South	5

According to the data in Table 1, no Brazilian region has potential below 5 kWh/m², gain more consideration as the scientific community and investors advance in the generation of information, data and technology. Government departments and municipalities responsible for studying the solar potential in Brazil present unanimous results that corroborate a promising future for the exploration of the source in the country.

The fact is that it will be necessary for such a source of energy to be better expanded as it contributes in several ways, providing several benefits, both from an electrical, socioeconomic and clearly environmental point of view (ABSOLAR, 2016).

2.6. Photovoltaic plants

Solar plants or solar complexes, also called solar parks, are large power plants that generate electricity that use photovoltaic panels or other technologies to directly or indirectly convert the chemical energy of photons into electricity. (SOLAR PORTAL, 2022).

In recent years in Brazil, large civil projects have been carried out to meet the energy demand through solar plants. In 2018, the State of Piauí, through SEMAR, Secretary of the Environment of Piauí, stood out after completing the largest photovoltaic plant in Latin America. (SUSTAINABLE CITY, 2018).

According to Portal Solar, there are a total of 4,357 photovoltaic plants in operation in Brazil, generating an estimated power of 3.84 GW, with the development of another 24.8 GW distributed among 81 units under construction (3.1 GW) and other unstarted projects (21.7 GW).

2.7. RETScreen software

According to Siemens (c2022) computer-aided engineering is the use of computer software in performance simulation to improve product designs. Failure prevention and solution development, risk and cost-benefit analysis, performance analysis and functional performance are possibilities that can be verified with the use of specific software in each line of research and analysis.

The RETScreen Clean Energy Management Software platform, made available free of charge by the Government of Canada, enables planning, implementation, monitoring and responses aimed at generating clean energy.

FREITAS et al (2017) apud Restcreen International, (2016); Bastos et al (2015) states that RETScreen is used

worldwide to assess energy production and accumulation, pollutant emission reduction, financial viability and risks for various types of electricity generation systems.

According to the Clean Energy Solutions Center, RETscreen empowers professionals to make decisions, quickly identify, evaluate and optimize the technical and financial feasibility of potential clean energy projects, as well as verify the actual performance of projects already installed, contributing to the identification of points for improvement in the areas of energy savings and production (CENTRO DE SOLUÇÕES DE ENERGIA LIMPA, 2022).

3. Methodology

In order to generate the feasibility assessment using the RETScreen software, the following steps must be followed:

- Insert data into the RETScreen Software based on the searched bibliography.
- Virtual Energy Analyzer.
- Smart Design Identifier.
- Financial Risk Assessor.
- Performance Tracker.
- Develop in practice the construction of a viable energy generation system to meet the proposed objectives, which is a photovoltaic plant to meet a certain demand.
- Measure the results of the report developed by the software and compare them.
- To present results determining the values of costs of implantation of photovoltaic plant and of efficiency in relation to the application of predominant energy generation in the region.

Once the software is started, the steps for the development of results must be met. Each of the stages will be carried out according to the characteristics obtained through the study, such as the intended location of the plant, the type of source intended, the demand to be supplied, etc.

At this stage of the process, it is important to have knowledge already acquired about the city where the proposal is intended to be developed, as well as the generation conditions and demand necessary to meet the needs of the population that is the focus of the study.

These initial data will be the basis for feeding the RETScreen requirements and after processing the information the software will provide results for carrying out the critical analysis of the proposal and its feasibility. Each of the steps for including information in the RETScreen software will be carried out according to the process map shown in Figure 3.
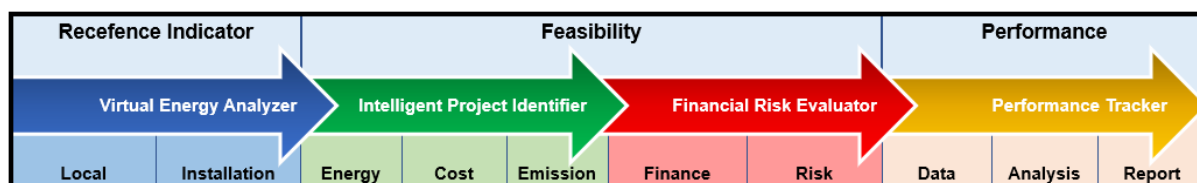

Figure 3 - Model Application Process Map

The development of the simulation is carried out in 4 phases divided into 10 stages of filling in the project data. Each of the phases with their respective steps are detailed below:

Phase 1 - Virtual Energy Analyzer

This phase is subdivided into two stages, these being Local and Installation and aims to apply the knowledge obtained according to the city of interest to implement the project and define the type of generation that will be adopted to meet the demand for electricity to be supplied.

• Stage 1 – Location: In this stage, the definition of the region/location of the object of the study for the implementation of the power generation plant must be carried out. RETScreen provides, through a search tab, the function that directs the user to the map. With images linked to the software's system database and to Microsoft's search engine, Bing, it is possible to select the specific point of latitude and longitude for implantation of the chosen plant.

The software also displays the exact location of the locations where the climatic data of that region were collected so that their references are known. Data such as climatic zone, elevation and conditions of relative unit and temperature will be made available for a preliminary analysis and selection parameter of the implantation position of the proposed plant location.

After selecting the point of implantation of the plant, the average data for the year will be calculated, broken down month by month. Several parameters of interest for use as a source of energy generation will be presented and with this it will be possible to identify which of the sources is more viable for energy generation.

• Stage 2 – Installation: In this stage, it will be possible to define which type of technology is most viable for the development of energy generation in the selected location. This step is divided into two parts where it will be possible, through the analysis charts of benchmarks, feasibility and performance, to understand which technology is viable for deployment.

Related to the generation costs per kWh or MWh, a range of energy generation costs will be presented, which will present an average perspective of the implementation cost for each of the existing generation possibilities in RETScreen. Based on the results obtained through the bibliographic research, it is possible to convert and compare the data with the base values of the software and understand which plant will be designed.

Phase 2 - Intelligent Design Indicator

In this second phase, three stages of the flow will be developed in order to define the type of energy, implementation costs, and the emission of pollutants. It will be possible, through the technology adopted in the previous step, to provide continuity in the equipment that will compose the proposed plant and, through their definition, to obtain the predicted values of implantation of the plant as well as the reductions that it will be able to generate as soon as it starts to be used. of the same.

• Stage 3 – Energy: The energy stage is divided into three parts where the types of fuels and plant application times will be defined, the type of energy and equipment that will be responsible for generating energy and the results that will be obtained with the jobof the defined technology.

In the first part, the type of fuel that would be needed for the power generation of the plant and the period of exportation of the generated energy for consumption must be informed, as well as the sale prices of this energy must be defined. This information will be used for comparison between the proposal and the conventional means.

In the second part, the technology will be defined and among the possible means of producing energy from renewable and non-renewable sources. If the choice option for implementation of the proposal is not available, it is possible for the user to make the inclusion of his choice.

Once the technology is defined, equipment options will be made available through a database pre-defined by RETScreen, such as wind turbines and photovoltaic panels. They are available according to manufacturer, brand and model.

The definition becomes easy to specify, considering that the software itself performs the calculations of the list of equipment needed to implement the plant according to the installed demand that will be necessary to meet the supply demand at the indicated location.

Ending with the third part, RETScreen will perform a comparison that will be able to present a summary of some of the factors that will serve for decision making, such as the initial costs based on the installed capacity of the proposal, the equipment and materials and the cost of sale. of the energy generated, as well as an economic balance in relation to the implementation of the proposed plant and the conventional plant from a non-renewable source.

- Step 4 – Cost: Definitions of the initial costs of the project with increment of existing data referring to the project and execution of the work, as well as costs of maintenance of the operation, such as, payroll of operators.

Based on data obtained from the bibliographic research, it is possible to estimate the costs that will be part of the implementation of the proposed project and the maintenance of this project. With the inclusion of this information, indicators will be generated that will allow the user to carry out a subsequent financial statement and understand the feasibility of implementing the project.

- Stage 5 – Emission: This stage is an analysis of the pollutant and GHG emission reduction indicators generated by the software for project management and decision making regarding the environment.

The results are issued as a function of the comparison made between the amount of energy and the amount of fossil fuel needed to generate this same energy. It is possible to enter some information to specify details regarding the implementation region of the proposal and thereby obtain specific results for the proposed project.

A GHG emission indicator in tons of CO_2 is presented and the graph has two columns to represent the amounts of reduction of pollutants as well as the equivalence with the amount of fuel saved in some measurement methods such as the amount of liters of gasoline and the amount of barrels of Diesel oil.

Phase 3 - Financial Risk Assessor

At this stage, a more in-depth knowledge of financial analysis and risk analysis will be required. Detailed knowledge can be provided to define parameters such as inflation rate, project life, debt ratio, among others

that will compose the data so that a result is generated for the user's critical evaluation.

• Stage 6 – Finance: Breakdown of financial parameters, investment costs, incentives and subsidies that enable an analysis and prospection for the project in the medium and long term.

The annual costs for maintenance of the proposal and the balance with the revenue will be presented, which will provide a cost-benefit indicator related to the plant's cash flow in order to present the return on the initial investment over the lifetime of the project.

• Step 7 – Risks: Sensitivity analysis of project implementation risks based on the results presented by the software based on all the data already included in the project scope, where the risks can be evaluated through two indicators.

As for the impact, it will be informed through a performance analysis indicator that has three subdivisions for the user to choose. Once the form of risk analysis is defined, the class indicators by impact and frequency will be generated automatically.

Phase 4 - Performance Tracker

In this last phase of RETScreen, a summary of all the data entered and generated through the calculations performed by the software will be presented, and with that, the last three steps of the macroflow are presented.

• Step 8 – Data: presentation of the summary of the reported data.

• Step 9 – Analysis: presentation of the indicators generated by the data summary.

• Step 10 – Report: Issuance of a report for presentation. This last item can only be stored upon acquisition of the software license.

The model studied was developed to meet the total local demand as the main source of energy generation and from the results obtained, a critical analysis can be carried out to determine the operation regime being total or partial.

As a percentage of partial service, the value of 70% of demand service was adopted to determine a parameter that will result in a value that will serve as subsidies for a critical and viable analysis, as well as remarkable for practical application.

2.5 Study Municipality

For the development of the research, the energy demand necessary to serve the municipality of São Gabriel da Cachoeira, located in the extreme northwest of Amazonas, was evaluated. The municipality borders the countries Colombia and Venezuela and is located on the banks of the Rio Negro.

The choice of the municipality was due to the geographic isolation in relation to the distribution of energy covered by the SIN and because it is a region whose supply of the electric energy generation service is carried out through thermoelectric plants powered by fossil fuel.

Another factor that contributes to choosing the region that is directly linked to isolation is accessibility to the place. Logistical costs are high to maintain the operation of the local plant through the replacement of parts and fuel necessary for the almost inefficient production of diesel engines. Figure 4 shows a view of the city of São Gabriel da Cachoeira.

Figure 4. Municipality of São Gabriel da Cachoeira

With a population estimated in 2019 by the IBGE of 45,564 inhabitants, it is the thirteenth most populous municipality in the state and currently the electricity supply system has a Thermoelectric Power Plant with an installed capacity of 5,548 kW as its source.

AtFigure 5that the SIN energy transmission route does not include the extreme northwest of the Amazon, thus corroborating the exclusion of more distant municipalities.
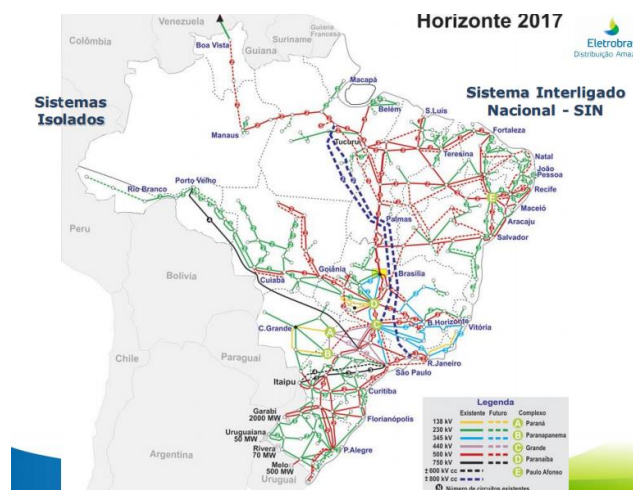

Figure 5. National Interconnected System (SIN)

The Thermoelectric Power Plant (UTE)of São Gabriel da Cachoeira contain four Generating Units (UG) being UG1and UG2, of 1,850 kW each and UG3 and UG4, of 924 kW each.

4. Results and Discussions

4.1 RETScreen Results

Using the RETScreen Software, it was possible to carry out an analysis of the implementation of a Photovoltaic Plant with an Installed Capacity of 6,500 kW. The analysis process started with a reference indicator, determining the location and type of installation desired.

Subsequently, the feasibility with the use of energy was addressed, verification of costs in general and the

emission of pollutants, giving continuity to the financial analysis and risks of implantation of the plant.

To conclude the analysis, the performance of the studied model was verified through the results presented through the simulation of the implantation of the photovoltaic plant that will be discussed below through the indicators generated by the RETScreen software, where each of the phases of results is obtained.

4.1.1 Status

The location for the installation of the Photovoltaic Plant (UF) was defined in the software near the city of São Gabriel da Cachoeira. Currently, the UTE is installed in the city center and is generating a lot of noise, in addition to the emission of gases that directly and indirectly affect the local population.

Although the proposed FU operation does not generate noise or pollutants at large levels, a positioning outside the limits of the urban area of the city was adopted for the modeling, aiming at the possibility of future expansions to supply the growing local demand, as specified in Figure 6.

	Unit	Location of Climate Data	Location of the Facilities
Name		Brazil - Amazonas - São Gabriel da Cachoeira	Brazil
Latitude	'N	-0.1	-0.1
Longitde	'E	-67.0	-67.0
Climate Zone		1A - Very hot - Humid	1A - Very hot - Humid
Elevation	m	93	87

Figure 6 - Latitude and Longitude of the Municipality

The implantation position is located at 87 m above sea level with an estimated address on the BR-307, approximately 7 km from the city center. Figure 7 marks the location of the proposed plant implementation and presents the central point of the municipality of São Gabriel da Cachoeira.
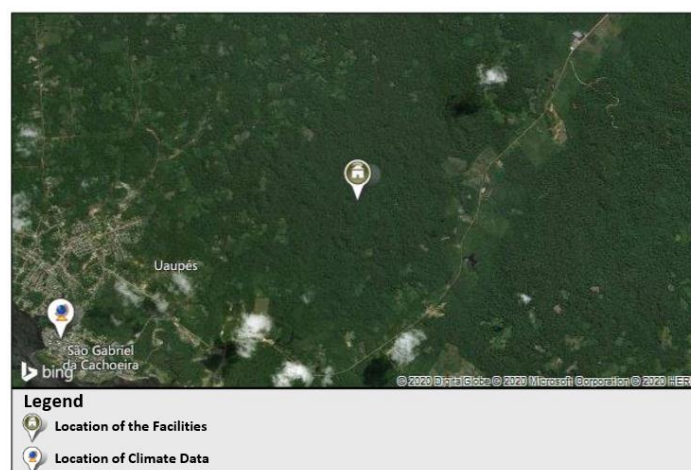

Figure 7. Location of the Proposed Power Plant

4.1.2 Climate Data

By defining the location of the UF implantation object, the support software presented favorable and coherent

data with the indices initially presented. The decisively characteristic fact for the implantation of the UF is the average incidence of solar rays with values that attend the amount of emission necessary for the supply of local energy.

Table 2 of climate data, adapted from RETScreen, showed an average daily incidence of solar radiation of 4.52 kW/m²/d, reaching in September, as shown inFigure 8, the indicator of 5.07 kW/m²/d.

Table 2. Climate data for São Gabriel da waterfall – AM generated by RESTcreem Software – July 2022

Month	Air Temperature	Retative Humidity	Precipitation	Daily Horizontal Solar Radiation	Atmospheric Pressure	Wind Speed	Ground Temperature	Degrees-Day for Heating 18°C	Degrees-Day for Cooling 10°C
	°C	%	mm	kWh/m²/d	kPa	m/s	°C	°C-d	°C-d
January	25,40	92,30	269,70	4,47	99,80	0,60	25,30	0	477
February	25,50	92,10	232,68	4,54	99,90	0,60	25,40	0	434
March	25,50	92,00	252,34	4,59	99,90	0,70	25,40	0	481
April	25,40	92,70	264,00	4,49	99,90	0,70	25,30	0	462
May	25,10	93,10	302,25	4,22	100,00	0,70	25,00	0	468
June	24,90	92,50	266,10	4,00	100,10	0,70	24,60	0	447
July	24,80	91,40	223,51	4,15	100,20	0,70	24,50	0	459
August	25,30	89,60	180,73	4,75	100,10	0,70	25,00	0	475
September	25,60	89,80	178,80	4,07	100,00	0,70	25,30	0	468
October	25,70	90,30	180,73	4,91	99,90	0,60	25,40	0	487
November	25,60	91,40	190,80	4,71	99,80	0,70	25,40	0	468
December	25,50	92,30	231,88	4,40	99,80	0,60	25,30	0	481
Annual	25,40	91,60	2.773,52	4,52	99,90	0,70	25,10	0	5.605
Source	NASA								

This average is higher than the amount measured in Germany, a country that in 2019 ranked third in the ranking of solar energy producing countries and which has a capacity of 500 watts for each inhabitant in its national territory.
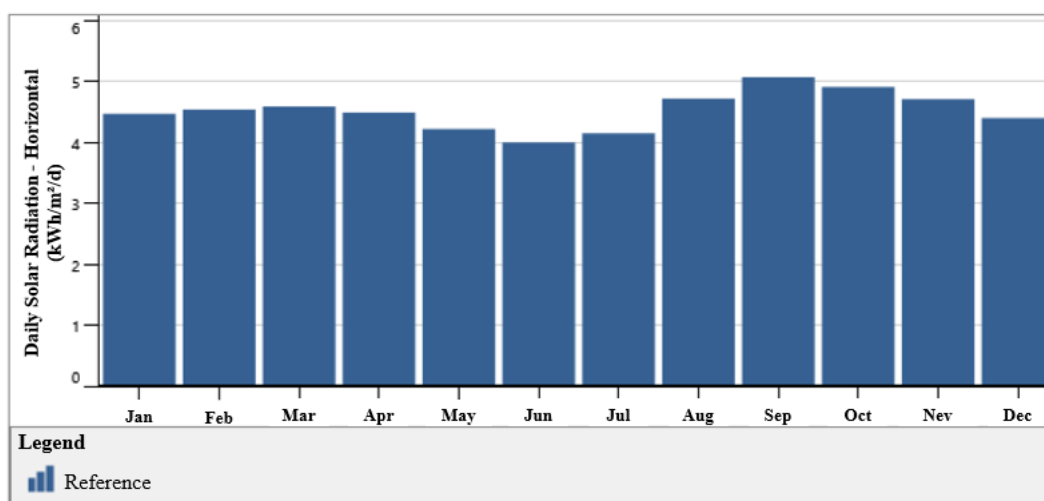

Figure 8. Daily Solar Radiation Climatic Data

It is important to emphasize, when comparing the data between Table 2 and Figure 8, how relevant the solar potential of the region is, reaching an incredible 4.52 kWh/m²/day, enhancing the choice to implement a photovoltaic plant.

4.1.3 Power Generation and Installed Capacity

To develop the study and meet the current installed demand, a load and 6,500 kW of power was determined. To meet the proposed demand, the installation of 22,000 photovoltaic panels from the Canadian Solar manufacturer, mono model – Si – CS3K-300MS – KuPower, was defined.

Each panel has a generating capacity of 300W, thus totaling 6,600kW, an efficiency of 18.05% and a perimeter of 1,662 m². For the implementation of the UF, an area equivalent to 36,500 square meters is estimated to be used.

The utilization factor was set at 85% to maintain the quality of the energy supply, allowing the UF not to carry out work at the production limit and opening space for preventive maintenance without loss of power and electricity exported to the grid.

With the proposed system, it was possible to simulate and determine the amount of 49,144 MWh of energy exported to the grid per year, a value higher than the data auctioned in 2017 for the region.

Table 3. PIES Group A & B – General

Plot's Winner	Groups	Plot	Edital's Price (R$/MWh)	Auction Price (R$/MWh)	Discount (%)	Annual Energy (MWh)	Hiring Period (meses)	Initial Contract Value (R$)	Auction Contract Value (R$)	Monthly Contract Value (R$)	Savings for the Consumer (R$)
Aggreko	A	II	1.487	1.152	22,51	298.442	180	6.229.148.577	4.826.773.278	27.791.980	1.402.375.299
Aggreko	A	III	1.503	1.171	22,10	235.770	180	5.152.156.245	4.013.402.882	23.003.293	1.138.753.363
CONS. ENERGIA DO AMAZONAS	A	A-I	487	276	43,38	132.170	155	831.404.371	470.779.091	3.037.267	360.625.280
CONS. OLIVEIRA-ETAM	B	B-I	1.582	1.155	27,00	165.411	180	3.925.203.030	2.865.745.575	15.920.809	1.059.457.455
CONS. OLIVEIRA-ETAM	B	BI-A	1.610	1.288	20,00	135.380	60	1.089.809.000	871.841.396	14.530.674	217.967.604
CONS. OLIVEIRA-ETAM	B	B-II	1.468	1.063	27,60	318.999	180	7.024.357.980	5.086.439.055	28.257.995	1.937.918.925
POWERTECH	B	B-III	1.482	976	34,14	112.392	180	2.498.474.160	1.645.418.880	9.141.216	853.055.280
CONS. VPOWER - TELEMENIA	B	B-III-A	1.453	1.030	29,11	169.074	60	1.228.322.610	870.740.126	14.512.326	357.582.484
CONS. VPOWER - TELEMENIA	B	BIV	1.349	990	26,61	46.859	180	948.191.901	695.851.951	3.865.828	252.339.950
CONS. VPOWER - TELEMENIA	B	BV	1.356	965	28,84	45.633	180	928.175.220	660.528.081	3.669.616	267.647.139
Total	-	-	**1.378**		**28,19**	1.651.130	-	**29.855.243.094**	**22.007.520.315**	**143.731.003**	**7.847.722.779**
			Average		Average						

According to Table 3, the winning company of the Eletrobras tender to supply energy to Grupo B Lote BIV, where São Gabriel da Cachoeira is located, the value of energy exported to the annual grid is equivalent to 46,859 MWh, which represents 4, 65% increase, impact that results directly in the environment, because the source is totally clean and renewable.

4.1.4 Emission of Gases

The environmental impact generated by the proposed FU was presented with a gross annual reduction in greenhouse gas (GHG) emissions of 93%, a highly expressive value when evaluated in parallel with the software's reference case.

The proposed FU was able to achieve a gross annual reduction in GHG emissions of 33,586 Tons of CO_2, equivalent to 78,108 Barrels of Crude Oil, a renowned reduction in fossil fuel burning and, also, financial for the state of Amazonas.

According to Petrobras data, available on the state-owned company's website, 1 barrel of oil is equivalent to 158.93 liters. Considering also that in 2020 the price of diesel oil closed the year at R$ 5.617 per liter, it is

possible to calculate a monthly savings of more than R$ 5.8 million.

Considering that the electricity supply is hybrid with 70% of the demand being met by the model plant, it is still possible to have a monthly economic gain of approximately R$ 4.01 million and the estimated GHG emission reduction equivalent to the burning of 724 thousand liters of diesel oil.
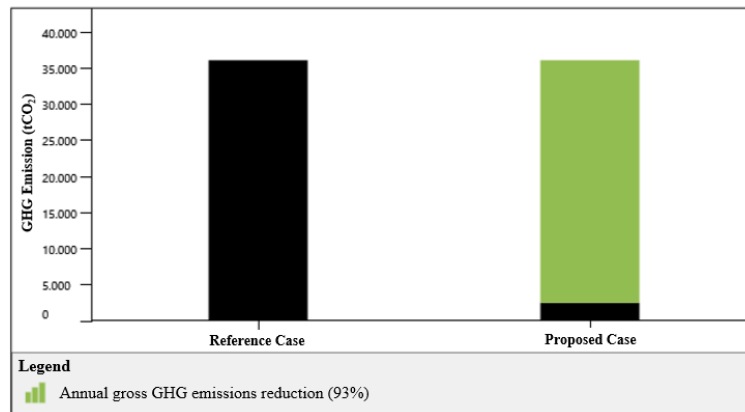

Figure 9. GHG emissions

Through the indicator represented by Figure 9, it is possible to compare the estimated amounts of GHG generated by the proposed plant, on the right, compared to an equivalent thermoelectric plant, on the left, to meet the demand, and the result is more satisfactory and efficient.

4.1.5 Deployment cost and return on investment

According to Portal Solar (2022), the average cost per megawatt to be produced is equivalent to the range of R$ 4 to R$ 5 million, guaranteeing the same conditions of advantages, such as useful life and return on investment.

Considering the example, to corroborate the statement above, as the data obtained from the implementation of the Solar Park of Nova Olinda. Table 4 shows the implementation data of the work, as well as the accumulated commercial dollar value of 2018, equivalent to R$ 3.88. (ADVFN, 2022).

Table 4. Average Cost of Power Generation

Plant	Dollar Condition (2018 Accumulated)	Installed Capacity	Implementation Cost		Average Generation Cost	
	(R$)	(MW)	(US$)	(R$)	R$/MW	
Solar Park NOVA OLINDA - PI	R$ 3,8757	290	$ 300.000.000,00	R$ 1.162.710.000,00	R$ 4.009.344,83	R$ 4,0 Millions

Adopting Table 4 as a parameter, it is possible to estimate the value of implantation of the plant to serve the municipality equivalent to R$ 26,060,741.38 million and adopting the use of partial energy generation to meet 70% of the demand, it is possible to define the return on investment according to Table 5 below.

Table 5. Average Annual Savings From Fossil Fuel Reduction

Initial Investiment	Monthly Savings (70% of Generation)	Total Months to Pay off Debt	Total Months oh Operation Remaining	Annual Reveue (25 years)
R$ 26.060.741,38	R$ 4.067.453,71	6,4	293,6	R$ 47.767.014,83

Due to a 70% reduction in fossil fuel consumption and adopting the 2020 commercial value per liter, the calculated savings when converted into revenue can exceed the initial investment value for implementation in 7 months.

Based on the estimated lifetime of operation for the photovoltaic plants equivalent to 25 years, an annual gross revenue of more than R$ 47.5 million can still be determined. It is known that the values are estimated and that the rates and interest relevant to energy generation and fuel prices vary over the years, but the values may be representative because the variations arising from the segment have an influence on all segments of power generation.

Based on the above, it can be evaluated that, only with the conversion of the savings obtained with the reduction of fuel consumption, the initial investment must be paid off in just 6.5 months, and from the middle of the sixth month of operation, all savings become will be in revenue. The accumulated amount saved in the first 24 months of operation can be determined, as shown below in Figure 10, at approximately R$72 million.
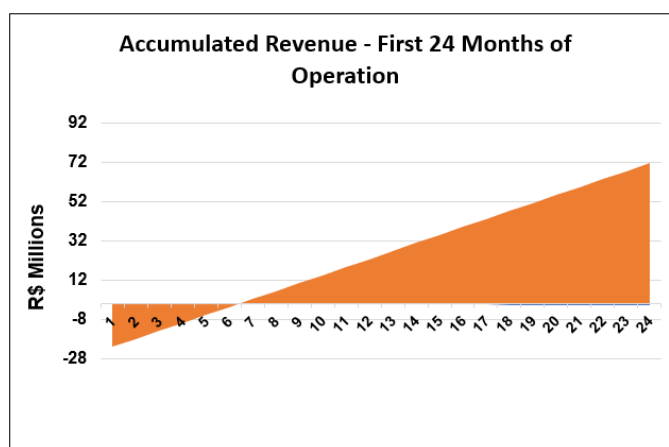

Figure 10. Revenue Accumulated in 24 Months of Operation

Finally, after generating energy during a useful life of 25 years, it is possible to state, as shown in the graph in Figure 11, that with the reduction of operating costs, 46 new photovoltaic plants can be financed for the generation of clean and renewable energy.
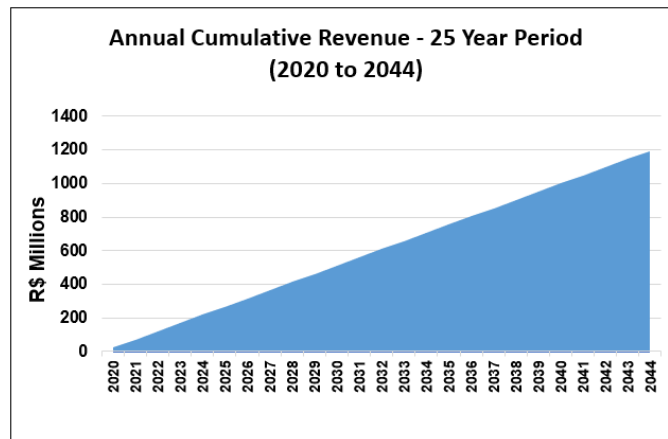
Figure 11. Accumulated Annual Revenue - Estimated Useful Life Period

With the repayment of the debt after the sixth month of operation, the amounts saved with the reduction of fuel consumption can be reinvested in order to generate more development for the local community among other possible applications that would be the burden of inspection and public transparency to better be taken advantage of.

5. Conclusion

The state of Amazonas, being a state with a large territorial area, has great difficulties in providing quality care in the provision of services to the population of the most isolated municipalities. The problems to meet the energy demand are notable and, if still addressed by the means already practiced, will continue to be a barrier to be overcome.

The distance from the numerous Amazonian municipalities makes it difficult to supply fuel, parts, qualified service, among other factors that contribute to the inefficient generation of energy in thermoelectric plants. These factors cause dissatisfaction in the communities due to the various sanctions taken to try to contain the problem, such as energy rationing and in many cases even temporary suspension of the supply service.

It is necessary to develop new alternatives to change these unfavorable conditions to which the society of the interior areas has been submitted. The values obtained through computer simulation are susceptible to variations, however they show a potential for application and that can contribute to meeting medium and small-sized demands.

Despite the energy potential and renewable source already emphasized, the reduction of fossil fuel consumption is already an excellent reason not to measure efforts to develop photovoltaic technologies in the state of Amazonas. Ensuring the minimum emission of polluting gases from the burning of Diesel, as well as minimizing environmental impacts must be observed with greater commitment.

The modeling presented favorable results that optimize the quality in meeting the electric energy demand, fuel reduction for energy generation, GHG reduction, savings that can be used in the implementation of new plants. In addition to these results, the alternative is promising because it is flexible and can be deployed in terrestrial areas under the surface of flooded areas or hydroelectric reservoirs.

When observed from the point of view of operation and maintenance of a photovoltaic plant, it is possible to understand and present the advantages that the system has in relation to the others predominant in the state. Due to simplicity, there is still an efficiency gain with the use of local labor to provide such services, thus reducing the sending of labor from large urban centers and generating new jobs for the local population.

Based on the above, photovoltaic plants present themselves, significantly, as an alternative to meet the energy demands of the State of Amazonas. It is necessary to invest in studies that enable field and practical data for a real determination of the results that are promising and suitable.

It is necessary to make time and resources available for the exploration of solar energy and the potential that the Amazon region has. Better explore the possibility of hybrid generation in conjunction with thermoelectric plants that at the moment partially meet the local need, but fall short in other aspects, such as environmental policies.

There is still much to be done, and with the help of the state, new and promising studies will still aim to optimize and promote the generation of electricity through photovoltaic plants in the Amazon, as this is certainly a future that will soon become a reality. is held for those who start first in the race to develop this powerful technology development opportunity.

6. Acknowledgments

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