Harvesting the Sun: Energy Innovation for Resilient Communities

Summary

In Colombia, non-interconnected areas represent approximately 52% of the national territory (Superservicios, 2017). Where mainly these areas are characterized by having a low population density, low levels of energy consumption, low ability to pay by the inhabitants, high costs of provision or implementation of public services and one of most determining and repetitive factors is that these areas usually inhabited by indigenous communities and ethnic minorities. The objective of the following degree project is to provide a design solution to provide electricity service to an indigenous community of the Atlantic taking into account the needs and obstacles of the area that will be reflected and resolved below. For this, a solution will be provided by means of photovoltaic energy since this type of electric energy generation is considered one of the most viable and economical for the most remote areas or with difficult access as it represents the territory where the system is expected to be established. We will provide design alternatives for photovoltaic solution in favor of what is more viable and optimal to achieve the approval and implementation of the project.

Finally, all the information required for the implementation of the system design will be provided, covering all the necessary technical aspects and the pertinent recommendations for the maintenance and optimal performance of the system will be given.

Key words: Energy, renewable resources, photovoltaic solar energy, renewable energy, solar panels, environment, ZNI.

Abstract

In Colombia, non-interconnected areas represent approximately 52% of the national territory (Superservicios, 2017). Where mainly these areas are characterized by having a low population density, low levels of energy consumption, low ability to pay by the inhabitants, high costs of provision or implementation of public services and one of the most determining and repetitive factors is that these areas are often inhabited by indigenous communities and ethnic minorities. The objective of the following degree project is to provide a design solution to provide electrical service to an indigenous community of Atlántico, taking into account the needs and obstacles of the area that will be reflected and resolved below. For this, a solution will be provided by means of photovoltaic energy and that this type of electric power generation is considered one of the most viable and economical for the most remote areas or those with difficult access, as represented by the territory where the system is expected to be established. Design alternatives for a photovoltaic solution will be provided in favor of what is most viable and optimal to achieve the approval and completion of the project. Finally, all the information required for the implementation of the system design will be provided, covering all the necessary technical aspects and the pertinent recommendations will be provided for its maintenance and optimal performance.

Keywords: Energy, Renewable Resources, Photovoltaic Solar Energy, Renewable Energy, Solar Panels, Environment, Non-interconnected zone

1. Introduction

The indigenous community of the Mokaná reservation is made up of descendants of the Muisca ethnic group that inhabited the department of Atlántico, the land is sacred and therefore their economy is based on agriculture, fishing and commercial exchange with neighboring populations of the goods they produce. Despite being part of a national ancestral culture, they no longer preserve the same traditions and their rituals have changed or have been modernized due to the armed conflict and large industries that forced them to leave their territory and mix with other communities, thus losing their ancestral identity.

In terms of location, the Mokaná resguardo is located in the village.

- There are two ways to get to this reservation, the first is from Taburá to the Juan De Acosta pass, with means of transportation such as car, motorcycle or on foot. At this point there are two transportation options, a planchón or a canoe to go to the other end of the Magdalena River. At the end of this stretch, one must choose the road to the Cutupil trail and take a 30-minute drive (by car or motorcycle) or a two-hour walk. The second route is from the municipality of Galapa, passing through the village of El Jobo and leaving through the village of El Vaiven in a vehicle or motorcycle.

According to the "Plan de Salvaguarda Étnica del Pueblo Cutupil" presented by the Fundación Andina in 2014, the inhabitants of this reservation live in precarious conditions, as the houses are mainly built in bahareque and the roofs are made moriche palm or guadua. Each house may be inhabited by two or three families of four members. Bathrooms and kitchens are located outside the house, and artisanal methods such as wood-burning stoves or ovens are used for food preparation.

Currently, the national government and environmental corporations are promoting the implementation of solar photovoltaic projects for the implementation of electricity service coverage in areas that are not interconnected to the national electricity system, in order to promote development in these communities and to meet the electricity supply in the national territory.

Since the sun is one of the main sources of energy we have on earth and its main feature is that it is inexhaustible and technological progress in the last decade has allowed electricity generation from this source is increasingly efficient and the cost of implementation is lower. Therefore, solar photovoltaic energy is increasingly implemented in isolated projects in areas not interconnected to the grid in Colombia.

Considering the characteristics of the Mokaná reservation, as a ZNI (non-interconnected zone): average temperature of 39.21°C, a warm semi-humid climate and an average irradiation of 4,575 kWh/m2 per day, the feasibility of an electricity generation system favors the option of photovoltaic cells, which optimize space, take advantage of irradiation, and are usually more economical and efficient.

This document developed by the Andean Foundation analyzes the subsequent design of a solar photovoltaic system for the indigenous community located in the Mokaná reservation in Taburá. Given that this type of communities do not have public gas and sewage services and in some occasions they do not have electricity service or it is only partially available, produced by non- conventional renewable energy sources (FNCER), these conditions are mainly due to the lack of inclusive regional plans due to the difficult access to the community and also due to the great distances that separate these communities from urban areas.

The solar system to be implemented is a form of electricity generation through the use of photovoltaic panels composed of silicon photoelectric cell modules that transform the photons captured from solar radiation into electricity, which is used for the general use of electrical equipment in the home.

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2. Objectives

2.1. General Objective

Design a system of electricity generation from photovoltaic solar energy for the electricity supply of the Mokaná indigenous reservation located in the municipality of Taburá - Atlántico.

2.2 Specific objectives

- Analyze the different elements that make up the installation and its environment to ensure its correct operation and eliminate factors that may negatively affect the performance of the project.
- To propose the alternative to be considered for the development of the design of the solar photovoltaic system depending on the location.
- Develop the modeling of the photovoltaic system supported by solar project modeling software (Helioscope).
- Evaluate the economic impact of the project according to the elements to be implemented and the project model.

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3. Identification of the problem

3.1 Research question

How to design a solar photovoltaic system for the Mokana indigenous reservation?

3.2 Context of the problem

A study was carried out in the Colombian Atlantic Coast to study in depth the use of panels
In this study, they analyze the photovoltaic solar panels in rural and urban areas.
The study found that 90% of the dwellings were houses and 7% were apartments,
In addition, 65% of the housing units are located in urban areas and 35% in rural ar eas.
In addition to the above, they identified that 80% of the houses are built with bricks and the roofs
The remaining 20% of the walls are made of adobe, palm roofs or roofing,
It all depends on the area where it is located. Now, with respect to the elec trical infrastructure for
In 2015, 2.3% of the homes without energy service were in rural areas. Our purpose
The purpose of the above is to exemplify the housing conditions also identified in the Mokaná resguardo.
of Mokaná.

On the other hand, a study conducted by the company FOCUS INC, which refers to projects implemented in Colombia integrating solar photovoltaic energy, mentions a project carried out in the 80s, the project was conducted between Telecom and the National University, in which they installed photovoltaic generators of 60 Wp (watt peak) in rural areas for radiotelephones. In addition, the development of approximately 370 projects for the installation of solar photovoltaic systems implemented in the departments of La guajira, Atlantico, Bolivar, Cordona and Sucre, carried out by the Colombian Institute of Electric Energy, are mentioned (Gómez, Murcia, & Cabeza, 2017).

Regarding our career, our challenge is to develop a viable, economical and useful design, in order to implement a solar photovoltaic system in the Mokaná reservation, which generates electric energy that they can use for their benefit, taking advantage of the knowledge we have acquired as energy and chemical engineers, to develop this type of system and thus contribute to the development of this community, starting by identifying the problem, the solution alternatives and modeling the system.

Now, in reviewing the case of the department of Atlántico, it was found that it is included in the SIN (National Interconnected System), since in the reports of the IPSE (Institute for Planning and Promotion of Energy Solutions for Non-Interconnected Zones) it is not taken into account, and it is not taken into account because most of populations are urban and have energy (IPSE & CNM, 2020). However, the Mokaná reservation is located in an isolated rural area with difficult access, which places it outside the SIN National Interconnected System), and also makes it difficult to interconnect as the other 23 indigenous reservations of Taburá - Atlántico, as well, in turn most lack basic services (public sewage services, garbage collection, they only have electricity in some homes, they have septic tanks and supply water from cisterns, they cook on firewood and garbage is disposed of and burned in the open) (Min interior, 2018).

According to its geographic location and cultural characteristics, the Mokaná reservation has its own internal organization, which limits the action and execution of projects of the departmental or regional government and therefore their needs are more explicit in terms of the lack of basic services available in large cities or towns, drinking water, natural gas for cooking and electricity in homes are services that this population does not have. Being a small population and not having these basic services, their daily activities are limited to a great extent, even affecting the economic activities of the inhabitants of the resguardo. In order to identify limitations that may arise, the following diagram was made:

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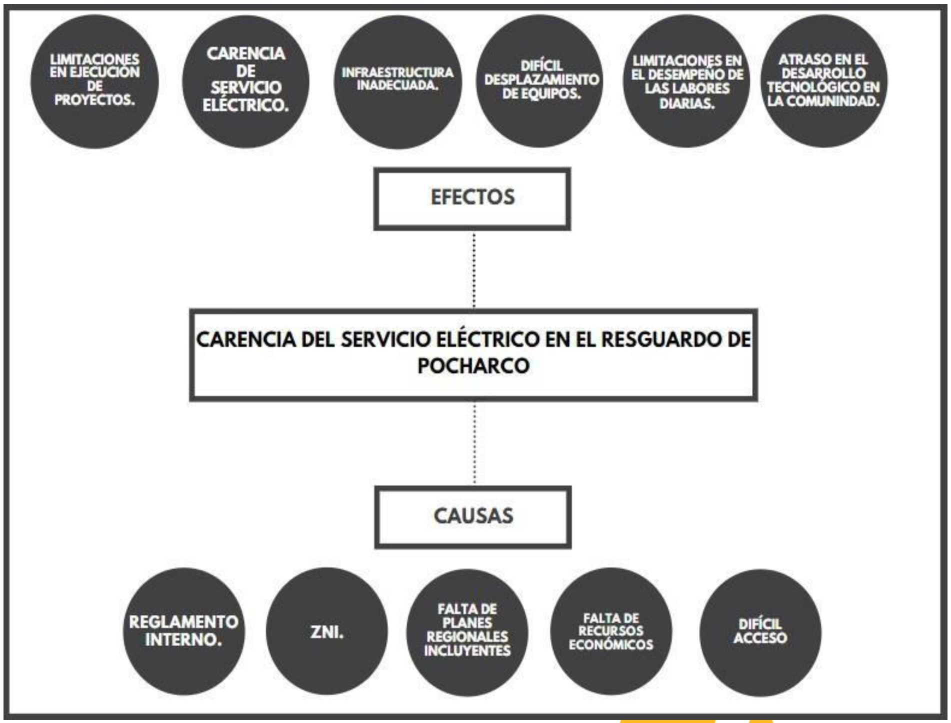

Figure 1. Problem tree (causes and effects).

Own elaboration.

One of the advantages of the municipality of Taburá is that it has an average irradiance of 4,575 kWh/m2 per day, which is quite good for a photovoltaic project, this irradiance is recorded by the entity Energie Repowering the Future with data obtained from IDEAM. Taking into account the above information, we propose in this project on-site generation by means of photovoltaic solar panels with the objective of electricity generation for the community of Mokará. In this way the community will be able to have the service of electric energy in a more accessible way than the interconnection with the SIN, or the generation from liquid fuels such as gasoline.

4. Analysis of product requirements or specifications

For the development of the project, the following requirements are established that allow structuring in a clear and precise way the product that corresponds to the final delivery.

Introduction.

1. Establish solar photovoltaic generation designs.

The client requests the design of two models of electricity consumption in to select the most convenient in terms of economics and efficiency of the system. The first model corresponds to an autonomous system of solar photovoltaic electricity generation per residential unit that must have a battery bank that is charged during solar hours for the night energy supply, the second option corresponds to a centralized design of the photovoltaic system, in other words the isolated generation of energy and distributed to all homes for consumption, this isolated system has a night backup that costs batteries installed in isolation in each house as in the system per residential unit. Another point to consider is that this electricity generation is not connected to the national grid and therefore requires battery backup. The design of the system is still under evaluation since it has not been possible o define the implementat on costs of each one.

2. The requirements defined for the corresponding project design are: cost, system reliability, location and ease of system maintenance. The requirements mentioned above are defined below.

The requirements were defined autonomously, these are reflected as costs, according to the design that best suits the needs, which could also be reduced according to the place of purchase of the inputs, the way of transportation and the time of implementation.

The reliability of the system is understood as the constancy of the service 24 hours a day, which can be backed up with a battery bank that allows supplying energy during the night hours.

Location of the system, if it is going to be on site or in a centralized location, it must be in a clear place, without shadows and that receives the greatest amount of solar radiation to transform a large part of the energy so that it can be used.

Ease of system maintenance, which can be accomplished by having viable access to the system, training of the inhabitants of the reserve for the adjustment of the structure in general, verification of the entire electrical system, revision of inverters and other elements.

Finally, the requirements to be taken into account are the photovoltaic cells, which can be defined according to the supplier, the required capacity, costs and useful life.

3. System performances requested by the customer or defined by us (quantifiable performances/value/unit):

Installed capacity of the system: the estimated demand requested by the client is 210 kWh/month per house. The following table shows the energy demand of the shelter and the power (W) to be installed, 1.56 kWh/day, in order to cover this demand, this data is for one house, to obtain the total demand of the shelter, the demand per house is multiplied by the 29 houses that correspond to the totality of the shelter.

Cálculos por unidad residencial			
	Día (kWh/día)	kWh/mes	kWh/año
W Demanda	7,01	210,15	2521,80
W a instalar	1,56	46,7	560,4

Table 1: Own design. Energy demand and projection of the power to be installed.

Coverage: As shown in the table above, the system design should be able to cover 100% of the demand of the indigenous reservation. This is in accordance with the client's demand, which requires the design to have a battery backup for nighttime supply, as mentioned above.

System performances vary depending on the model to be implemented. For the on-site generation system (per residential unit), 7.01 kWh/day must be generated with an installed power of 1.56 kWh, this data is obtained from the following equation:

$$\text{Pins}= \frac{Ed}{Hsp}$$

Donde:
Pins: Potencia a instalar
Ed: Demanda de energía díaria
Hsp: Horas sol promedio

The data corresponding to the radiation levels present in the area are important for the sizing of the structure to be used.

The following table presents the insolation characteristics present and the average time of highest light intensity per month during the twelve months of the year.

Variable	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Insolation, kWh/m²/day	4.61	4.58	4.67	4.42	4.44	4.61	4.79	4.85	4.79	4.46	4.34	4.34
Clearness, 0 - 1	0.48	0.46	0.45	0.43	0.44	0.47	0.49	0.48	0.47	0.44	0.45	0.47
Temperature, °C	19.27	19.82	19.82	19.67	19.44	18.93	18.84	19.73	20.20	19.68	19.16	19.03
Wind speed, m/s	2.08	2.14	2.11	1.99	2.07	2.47	2.57	2.32	2.12	1.95	1.92	2.15
Precipitation, mm	95	111	171	218	202	141	94	99	139	230	219	145
Wet days, d	11.8	12.5	16.3	20.0	19.6	15.4	12.7	13.3	15.4	20.7	19.8	16.1

Table 4. General characteristics of the site. Gaisma

According to the table above, the average number of sunshine hours correspond to 4,575 solar hours per day. With an average ambient temperature of 19.21 °C. The temperature is used for the sizing of the DC system.

The quality of the energy delivered must also be perceived, this is known as system reliability and corresponds to the adequate supply, through the battery system that guarantees uninterrupted energy service during the night.

4. Describe what are the inputs and outputs of performance.

Entradas		Salidas
Equipos		Montaje
Irradiación Solar		Energía Electrica
Baterías	Diseño	Almacenamiento de energía nocturno.
Necesidades o requerimiento a suplir		Cantidad de energia requerida por hogar
Diseño de red de conexiones		Conexiones del sistema a las viviendas

Table 2: Own elaboration. Inputs and outputs of the system.

5. Frame of reference:

In relation to our objective of designing a solar photovoltaic system in the community of Mokaná, an indigenous reservation of the Atlántico, we defined the variables involved in the system that allow us to make decisions when choosing the best design option, which are presented below:

5.1 Theoretical framework:

5.1.1 Solar energy:

The sun is a star formed by diverse elements in gaseous state, it presents in its interior high pressures and temperatures of several million degrees, producing spontaneously and interrupted a process of nuclear fusion, which is called solar energy. The energy generated by the sun to the earth is insignificant because of the distance between them, which is equivalent to 150 million km, however, this does not compare with all forms of energy used on earth, since solar energy is approximately 10,000 times greater than that known by humans. Also, another fact to highlight is the amount of solar energy received per unit of surface and unit of time, since this represents the average energy that reaches the outer layer the earth's atmosphere and is equivalent to 1,353 W/m^2, known as "solar constant". Similarly, the energy corresponds to an electromagnetic radiation, formed by wavelengths and a propagation speed of 300,000 km/s, these waves correspond to ultraviolet (UV), visible and infrared (IR) equivalent to a transported energy capacity of 7%, 47% and 46% respectively. Solar radiation reaching the earth's surface represents about 900 W/m^2, but the distribution of this energy is not uniform when it reaches the earth and depends on the time of day, latitude of the location, the orientation of the reciprocal surface and the climate (Solar, E. 2020).

5.1.2 Solar energy applications:

In order to make the best use of solar energy, it must be transformed and various technologies have been developed for this purpose:

- The first is a solar thermal system, its objective is to transform solar energy into electrical energy, the process it adopts is not a direct conversion of solar energy into electrical energy, on the contrary, it is an indirect conversion, which uses radiation to heat a heat transfer fluid that will evaporate the water, this will expand in a steam turbine, converting its thermal energy into mechanical energy, which then the electric generator converts into electrical energy. For the use of solar thermal energy, we find technologies such as: parabolic trough concentrators (PTC), central tower systems, Fresnel mirrors, among others (Villaseñor, R. 2018).

- The second technology, and possibly the most widely used, refers to the solar photovoltaic system, which consists of the use of radiation for electricity generation, a transformation that is carried out using silicon-based cells. This physical phenomenon is due to the interaction of light radiation with the electrons present in the semiconductor materials (Solar, E. 2019).

5.1.3 Solar photovoltaic system:

There are several types of photovoltaic systems and these vary according to the configuration, depending on whether the use is in rural or remote areas, for residential consumption in the city or industrial consumption. In order to understand a little more about the different configurations, the company SUN SUPPLY makes the following descriptions:

1. Grid-connected systems (on grid): This configuration is based on the implementation of solar panels that feed buildings or houses during the day, where there are two operating options: the first one is a low consumption of the infrastructure, by

Thus, the panels must deliver to the grid and distribute to other infrastructure because the total energy generated by the panels is not consumed; the second operation is a high energy consumption of the infrastructure that the panels are not able to supply, in this case they must take power from the grid to supply the infrastructure.

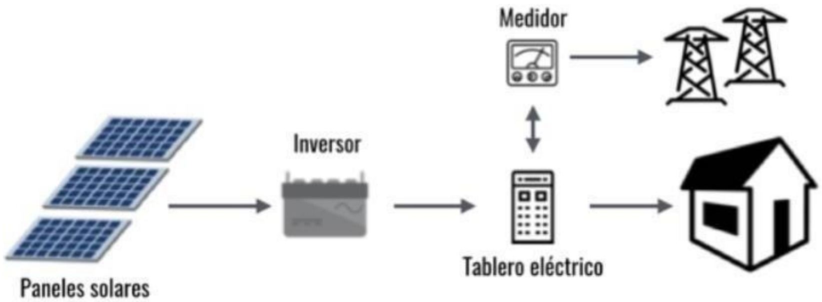

Figure 2. Grid-connected solar photovoltaic system.
Retrieved from: http://www.sunsupplyco.com/tipos-de-sistemas-solares/

2. Hybrid or grid-backed systems: The photovoltaic system has a backup, hybrid power inverter configuration that integrates the energy produced from the panels, the energy stored in the batteries and the energy generated from the external source. The external source is comprised between a wind turbine, a diesel generator or the electrical grid.

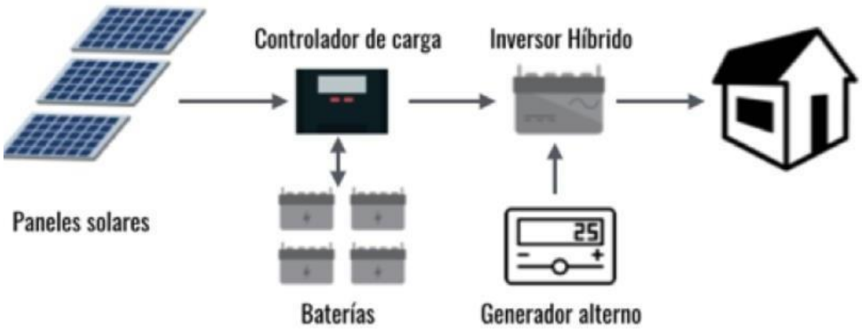

Figure 3. Hybrid solar photovoltaic system with batteries.
Retrieved from: http://www.sunsupplyco.com/tipos-de-sistemas-solares/

3. 100% autonomous off-grid system: The configuration of this system has a battery bank that allows energy storage, in addition, this energy can be used both day and night, this configuration can provide energy to direct current loads (DC) or alternating current loads (AC), alternating current loads group household appliances.

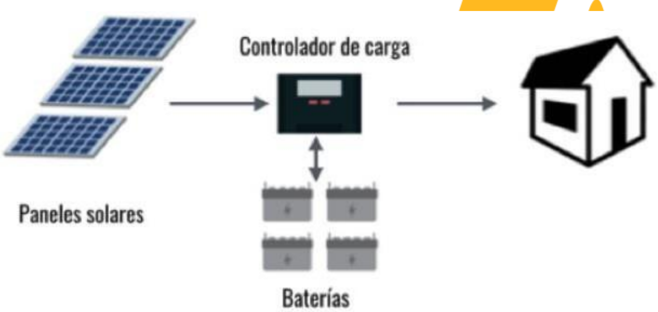

Figure 4. Solar photovoltaic system with batteries for DC loads.
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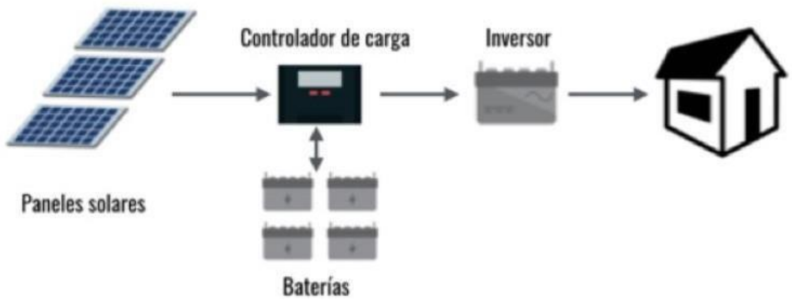

Figure 5. Solar photovoltaic system with batteries with inverter for AC loads.
Retrieved from: http://www.sunsupplyco.com/tipos-de-sistemas-solares/

5.1.3.1 The composition of the photovoltaic system:

- Photovoltaic solar cell: Photovoltaic cells are grouped and interconnected together to form photovoltaic modules. These are a device that has photovoltaic characteristics when exposed to light, absorbs by the material and is capable of transforming the energy of photons into electrical energy, with which a current and voltage is obtained (Mascotte, E. H., Chavez, R. I. M., Estudillo-Ayala, J. M., Hernandez, J. M. S., Guryev, I., & Morales, R. A. L. 2016).

- Photovoltaic module: They are the primary renewable energy source unit in photovoltaic systems, converts the sun's energy into electrical energy upon exposure to the sun and consists of a group of interconnected photovoltaic cells. There are two types of photovoltaic modules, crystalline silicon and thin film, among the crystalline silicon module there are two types, the first is monocrystalline, which differs because all its cells are the same color, the second type is the polycrystalline, this differs because they have a variety of shades and colors between the cells that make it up. Several modules together make up a generator (Style, O. 2012).

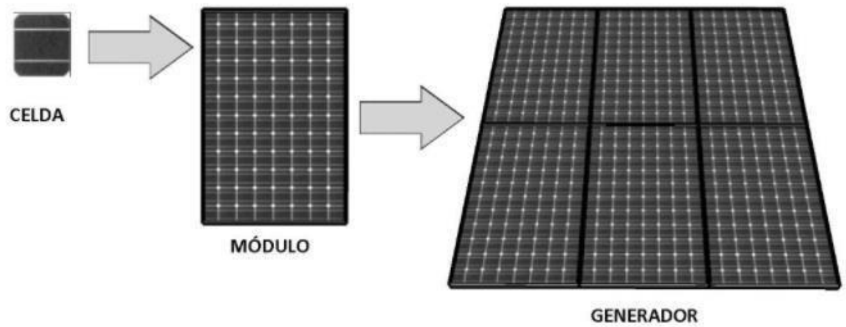

Figure 6. Cell, module and generator of a solar photovoltaic system.

Retrieved from: Style, O. (2012). Stand-alone solar energy: planning, sizing and installation of a stand-alone photovoltaic system. Oliver Style.

- Charge regulator: It is a controller located between the generator (module) and the accumulator (battery), its function is to protect the battery against overcharging by regulating the energy coming from the module and according to the state of charge of the battery, if the sun is at its maximum generation and the battery is low, the regulator increases the current reaching the battery, on the contrary, if the battery is well charged, the regulator decreases the current reaching the battery. Another function of the regulator is to protect the battery against discharge, understood in such a way that if the energy consumption is very high and the battery is in a low state of charge, the regulator disconnects the load to reserve it until the battery can be recharged. The regulators have four types of stages to charge the batteries (initial charge, absorption charge, float charge and equalization charge), as well as four types of regulators (series, parallel, pulse width modulation and maximum power point) (Style, O. 2012).

- Battery: The battery is the electrical energy storage unit used in the case of an off-grid system, the batteries are responsible for storing the energy generated by the modules during the day and can be used at night, there are different types of batteries, including: Vented Lead-Acid Batteries (VLA) (Style, O. 2012). Batteries can be divided into two main groups which are: Monoblock batteries, (flat plate, reinforced plate, Gel and Agm batteries) and stationary model batteries, (OPZS, OPZV, TOPZS AND EPZS.). a). Monoblock model batteries: They are used in low power models since they do not support the starting peaks of motorized equipment. The average life of these batteries is 3-4 years, however if they are used with motorized equipment, the useful life is reduced to 1 year. They are flat plate, reinforced plate, Gel and Agm batteries. b). The stationary model batteries are formed by independent glasses of 2V each one, with capacity of load near the 4500Ah. T he vessels are connected together and form 12V, 24V, and 48V systems. They use a technology that allows deep discharge.

Categoría	Nombre común	Notas
Arranque	Batería de arranque	***Generalmente no aptas para SFA's***
	SLI *(Starting-Lighting-Ignition)*	
	Batería de automóvil / coche / carro	
Híbrida	Batería de arranque modificada	**Aptas para SFA's**
	Batería solar	
	Batería marina	
Ciclo profundo	Batería de tracción	**Aptas para SFA's**
	Batería de recombinación (VRLA)	
	Batería de Gel (electrolito cautivo)	
	Batería AGM (electrolito cautivo)	
	Baterías de placas tubulares de ácido liquido o gel (OPzS o OPzV)	

Table 3. Lead acid batteries.

Taken from: Style, O. (2012). Stand-alone solar power: Planning, sizing and installation of a stand-alone photovoltaic system. Oliver Style.

- Inverter: A component that converts the low-voltage direct current from the batteries into alternating current at a higher voltage. Inverters mostly have an efficiency of 85% to , and there are inverters for grid-connected photovoltaic systems (hardwired inverters) and stand-alone photovoltaic systems (direct-connected inverters) (Style, O., 2012).

- Wiring: there is solar cable for panel connection and cable for equipment connection, generally the type of wiring to be used in a solar photovoltaic system are copper, the types are: a copper wire (for alternating current), a copper cable (they are suitable for circuits in continuous and high currents), cable with three conductors in the same sleeve and copper welding cables (to carry high currents) (Style, O. 2012).

Figure 7. Copper and copper cable.

Retrieved from: Style, O. (2012). Stand-alone solar energy: planning, sizing and installation of a stand-alone photovoltaic system. Oliver Style.

Figure 8. Cable with three conductors in the same sleeve and copper cable for soldering.

Retrieved from: Style, O. (2012). Stand-alone solar energy: planning, sizing and installation of a stand-alone photovoltaic system. Oliv er Style.

5.2 Frame of reference:

In this section, information on other photovoltaic system projects carried out in non-interconnected zones (ZNI) is compiled:

- Members of 250 families in the municipality of Fonseca, in La Guajira, benefited from the installation of solar panels in their homes. This project had an investment of $4,543 million pesos from the Ministry of Mines and Energy, through the Financial Support Fund for the Energization of Non-Interconnected Zones. Each household will have the capacity to use a refrigerator, a television, a radio, a blender, a cell phone charger and a small water pump, in addition to what is needed to power four outlets and four light bulbs (De Frente. 2019).

- An agreement for nine billion pesos was signed by the deputy national director of the Department of Social Prosperity, DPS, Nemesio Roys Garzón, with the National Unit for Disaster Risk Management (UNGDR), for the construction of new integral solutions in Wayuu communities, residents of the municipalities of Uribia, Maicao and Manaure. Its main purpose is to contribute to the fight for the eradication of the crisis faced by the department, due to different causes, the integral solutions consist of a solar energy operated system, whose components are a deep triple purpose well, from which water will be extracted for human consumption, irrigation and animal consumption (Ariño, J. 2016).

5.3 Regulatory framework:

- Laws, decrees and resolutions involved in a photovoltaic power generation .

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Figure 9. Normative table.

Source: Own elaboration.

6. Constraint analysis

- **Restriction of information:**

For the development of this idea, there is a limitation of the information of the indigenous community, since mainly due to the current health problems, it is not possible to collect information on . Also, due to time issues and the location of the reservation, outsourced information was obtained for the development of this document.

- **Geographic Restriction:**

The area is difficult to access due to lack of road infrastructure and unstable geographical conditions, which would represent a major constraint when trying to introduce the equipment to the field to install the photovoltaic system.

For this purpose, a detailed logistical work will be carried out with the route of the equipment in the field to facilitate its delivery and the normal development of the project.

- **Infrastructure restrictions:**

In the project area, it is identified that in order to install a photovoltaic system in the houses, these do not have the minimum structural resistance since many of them are handmade with rudimentary roofs that are not suitable for the installation of the equipment. In addition, the area has an internal low voltage network of which we do not have full knowledge of its current state and functionality, so it is expected that in order to perform a centralized generation in the area it would be necessary to adapt new networks, which imply a high cost, in addition to the soil study for the installation of the structure.

An analysis of both installation alternatives was carried out and it is preferred to perform the generation per household by adapting an external system in the houses, which would have the complete system in them, minimizing the structural restriction in the houses.

- **Environmental restrictions:**

Although there are not many environmental restrictions in the area, it is identified that the vegetation in the area could represent a restriction due to the fact that at the moment of implementing the photovoltaic system it could generate important shadows that would produce losses in the generation of one or several panels, causing inefficiency of the system.

For this purpose, the photovoltaic system will try to be at a considerable height where th e shadows that can be generated on the ground do not represent an obstacle in the generation, guaranteeing the maximum possible efficiency.

- **Restrictions on qualified personnel:**

The people in the area do not have adequate technical training for the installation, operation and maintenance of the equipment. This could lead to equipment deterioration or severe damage due to improper handling.

In order to avoid these situations, local personnel will be trained in the management of the photovoltaic systems so that they themselves will be in charge of keeping the equipment in optimal operating conditions, thus mitigating significant operating costs since the area is difficult to access and it is not feasible for an external person to be in charge of these functions.

- **Social and political constraints:**

The project is subject to the adoption and approval by the corresponding governmental entities, which if not carried out in an adequate manner, the administrative management of the project would prevent it from being carried out for the benefit of the population.

By making an excellent, solid and efficient proposal, it will be possible to overcome the pertinent evaluations for the execution of the project, for which it is important to adequately develop the studies and simulations involved in this project.

7. Alternative solution

The strength of the structure has to withstand an average wind speed of 2.15 m/s to avoid damage to the supporting structure of the panels.

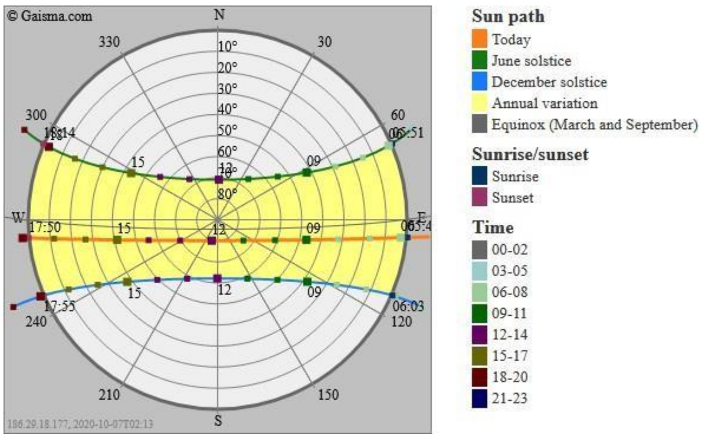


Figure 10.

Due to the movement diagram in addition to the location of the following Magna Sirgas coordinates from origin Bogotá latitude 3.6480598 longitude -75.0433196 the generation points are referenced from the most important reference points on site such as the solstices and equinoxes.

It is estimated that the consumption

EQUIPOS	W	#HORAS	CANT.	DÍA(kwh/dia	MES	AÑO
TV	100	8	1	0,80	24,0	288
PLANCHA	1200	0,3	1	0,36	10,8	129,6
VENTILADOR	60	8	2	0,96	28,8	345,6
BOMBILLO	60	8	6	2,88	86,4	1036,8
Licuadora	350	0,2	1	0,07	2,1	25,2
nevera	80	24	1	1,92	57,6	691,2
equipo de sonido	50	0,3	1	0,02	0,5	5,4
sumatoria	1900	48,8	13	7,01	210,15	2521,80
Cantidad de viendas	29					

Table 5. Consumption of hypothetical household appliances used in each dwelling.

7.1 Possible solutions

The following solution alternatives are considered, with respect to a process of performance, equipment and implementation materials, as well as an approximation of total costs:

- Alternative 1: It is defined as a model of photovoltaic electricity generation per residential unit; considering an independent system for each dwelling, where other considerations to be evaluated include the capacity of the equipment, the quantity of each one, the exposure to solar irradiation, extension of the wiring, and distribution to each dwelling. The reason for this alternative is to evaluate the economic viability of the implementation versus alternative 2, also considering the maintenance of the system.

- Alternative 2: Defined as a centralized model of the solar photovoltaic system; for this option, the location of the infrastructure was taken into account (a central place in the shelter or suitable for energy distribution), the number of equipment, the efficiency of each one and the cost of implementation were estimated as in alternative 1.

To justify the above, we present a series of tables with the following content: 1). The options by equipment and their characteristics, 2). Equipment costs for each type of option, 3). The ratio of the quantity of each equipment according to the model, 4). The selected option of each equipment.

PANELS				
BRAND	**W**	**Efficiency**	**Warranty (years)**	**Dimensions**
ZNSHINESOLAR	420 - 445	19.32 - 20.47	12 - 25	2094x1038
VERTEX	480 - 505	20.1 - 21.1	25	2040x1130
JINKO SOLAR	450 - 470	20.04 - 20.93	12 - 25	2182x 1029

Table 6. characteristics of each panel option.
Source: Own elaboration.

INVESTORS			
BRAND	**W**	**Efficiency**	**Dimensions**
IP1000-24	1000	94.5	163× 219.5
BEP1000S	1000	90	150 x 367
Wcc 12v 1000w	1000	89	180 x 387

Table 7. characteristics of each inverter option.
Source: Own elaboration.

BATTERIES			
BRAND	**AH**	**CYCLES**	**DEPTH**
ead-Acid Batteries 12V 730Ah (VRLA-GEL)	109	12000	60
6V 421Ah Bae block	182	12000	80
Lithium ion	105	3600	80

Table 8. characteristics of each battery option.
Source: Own elaboration.

Controllers					
BRAND	**NOMINAL CURRENT**	**EFFICIENCY**	**W CONSUMPTION**	**VOLTAGE** .	**TEMPERATURE**
MC2450N10	50A	98	1320W	12/24 V	-35/45
GSC-F1224-30	60A	97	1440 W	12/24V	-35/50
OLMO 30A	30A	98	780 W	12/24V	-20/50

Table 9. characteristics of each ontroller option.
Source: Own elaboration.

COSTS				
Team	**Description**	**Price**	**Quantity**	**Total**
Panel				
Op. 1	ZNSHINESOLAR	$ 629,000.00	1	$ 629,000.00
Op. 2	VERTEX	$ 592,000.00	1	$ 592,000.00
Op. 3	JINKO SOLAR TIGER	$ 649,000.00	1	$ 649,000.00
Controller				
Op. 1	MC2450N10	$ 615,000.00	1	$ 615,000.00
Op. 2	SAT GSC-F1224-60	$ 509,228.00	1	$ 509,228.00
Op. 3	OLMO 30A	$ 386,100.00	1	$ 386,100.00
Battery				

Op. 1	ead-Acid Batteries 12V 730Ah (VRLA-GEL)	$ 3,108,900.00	2	$ 6,217,800.00
Op. 2	6V block 421Ah Bae	$ 2,525,952.00	4	$ 10,103,808.00
Op. 3	Lithium Ion Pylontech	$ 2,817,000.00	1	$ 2,817,000.00
Inverter				
Op. 1	IP1000-24	$ 819,000.00	1	$ 819,000.00
Op. 2	BELTTT 1000W	$ 650,000.00	1	$ 650,000.00
Op. 3	Wcc solar 100W	$ 657,912.00	1	$ 657,912.00
Cable				
Op. 1	#10	$ 212,900	100	$ 212,900.00

Table 10. Costs per option for each equipment.
Source: Own elaboration.

NUMBER OF TEAMS PER ALTERNATIVE.		
TEAM	**STAND-ALONE SYSTEM UNITS (29 HOUSES)**	**CENTRALIZED SYSTEM UNITS**
PANEL	116	106
CONTROLLER	29	29
BATTERY	58	58
INVESTOR	29	29
CABLE (MTS)	5.104	5.104+THE CABLE TO CENTRALIZED SYSTEM.
STRUCTURE	29	26.5
Total, Equipment	313	318.5

Table 11. Quantity of equipment per alternative.
Source: Own elaboration.

PANELS				
BRAND	**W**	**Efficiency**	**Warranty (years)**	**Dimensions**
VERTEX	480 - 505	20.1 - 21.1	25	2040x1130
INVESTORS				
BRAND	**W**	**Efficiency**	**Dimensions**	
IP1000-24	1000	94.5	163× 219.5	
BATTERIES				
BRAND	**AH**	**CYCLES**	**DEPTH**	
ead-Acid Batteries 12V 730Ah (VRLA-GEL)	730	12000	80	

CONTROLLERS						
BRAND	**CURRENT NOMINAL**	**EFFICIENCY**	**CONSUMPTION DE W**	**VOLTAGE**	**TEMPERATURE**	**DISPLAY**

SAT GSC-F1224-60	60A	97	1440	12 - 24	-35; 50	LCD

Table 12. Selected teams.
Source: Own elaboration.

It should be taken into account that it is necessary to include the external infrastructure of the system and the transformers for the system centralization alternative.

In order to have a better clarity of the appropriate alternative, the following table is presented:

Criteria.	Alternative 1.	Alternative 2.
	Requirements.	
Easy maintenance system	It is a more accessible system, faster to perform maintenance because it is smaller and can have within reach all components within reach.	Being a large system, it is more complex to perform maintenance, the amount of panels together, makes it more difficult to reach their connections and / or components and fix any damage.
Durable	The average durability of the system is 20 years, and the maintenance of the allows it to be kept in good condition. conditions.	Difficult access to the system for maintenance means that it is not as frequent and deteriorates more rapidly, although the system has a average durability of 20 years.
Costs	This alternative is more economical because it requires less equipment for assembly.	The costs of this alternative increase, since it requires other equipment such as transformers, which alternative 1 does not require.
Space	The space required is approximately 4.08 m long by 2.26 m wide per house.	The space required is approximately 59.89 m long by 4.08 m wide for the centralized system.
Ease of operation	It has access to all equipment, is easy to maintain and does not require more space.	It has limited access, is difficult to maintain and requires more space.
Access	The system will be located at the side of each residenceallowing for optimal access.	The system will be close to the village, but because of its connections and equipment, the space is more extensive and will be restricted by its load hazard.
Location	It is located near the residence, in a clear place.	Due to the complexity of the system, it must be at a prudent distance from the community.
Irradiation	The irradiance is equivalent 4.575 as in alternative 2.	The irradiance is equal to 4.575 as in alternative 1.
Quantity of equipment	The system requires two less elements than alternative 2.	In addition to the panels, the inverter and the controller the system requires two other elements (transformer and extra wiring).

Useful life.	The useful life is approximately 20 years, the same as alternative 2, because the two systems implement the same options of each equipment, the difference is their accessibility for the realization of the maintenance.	The useful life is approximately 20 years, the same as alternative 1, because the two systems implement the same options of each equipment, the difference is their accessibility for maintenance, because the centralized system is more complex for maintenance.
	Yields.	
Efficiency	78,0%	67,1%
Losses of system	Temperature: 11%. AC System: 0.4% AC System: 0.4% AC System: 0.4% AC System: 0.4% AC System: 0.4% Reflection: 3.3%.	Temperature: 11%. AC System: 14.2%. Reflection: 3.3%.
Power	DC: 1.52 kW AC: 1.14 kW	DC: 44.9 kW AC: 33.8 kW
Reliability.	90%	45%

Table 13. Performance and requirements compliance for each alternative.
Source: Own elaboration.

Alternative	Advantages	Disadvantages
1	Cable distance losses are considerably lower. No major civil works are required other than a small system. panel fasteners. Costs are lower than alternative 1.	The number of panels is greater than that implemented in alternative 2.
2	The number of panels is less than that implemented in alternative 1.	This system must implement a low voltage network for the distribution of energy to the dwellings. This alternative requires more equipment than alternative 1. The space implemented in the centralized system is 12 (twelve) times longer than the alternative. 1. System costs are higher than alternative 1 due to the excess cable required for this alternative. alternative.

N

Identification advantages and disadvantages of each alternative.
Source: Own elaboration.

Criteria.		Alternative 1.	Alternative 2.
Requirements % Requirements	Easy maintenance system	5	3
	Durable	4	3
	Efficient	4	2
	Costs	4	3
	Space	5	2
	Ease of operation	4	3
	Access	4	3
	Location	4	3
	Irradiation	5	5
	Quantity of equipment	5	4
	Useful life.	4	3
Yields	Efficiency	4	3
	System losses	4	3
	Power	2	4
	KWh/KWp	3	4
	annual production	2	5
Total weighting		63	53

Table 14. Weighting of each alternative.
Source: Own elaboration.

7.2 Best alternative selected

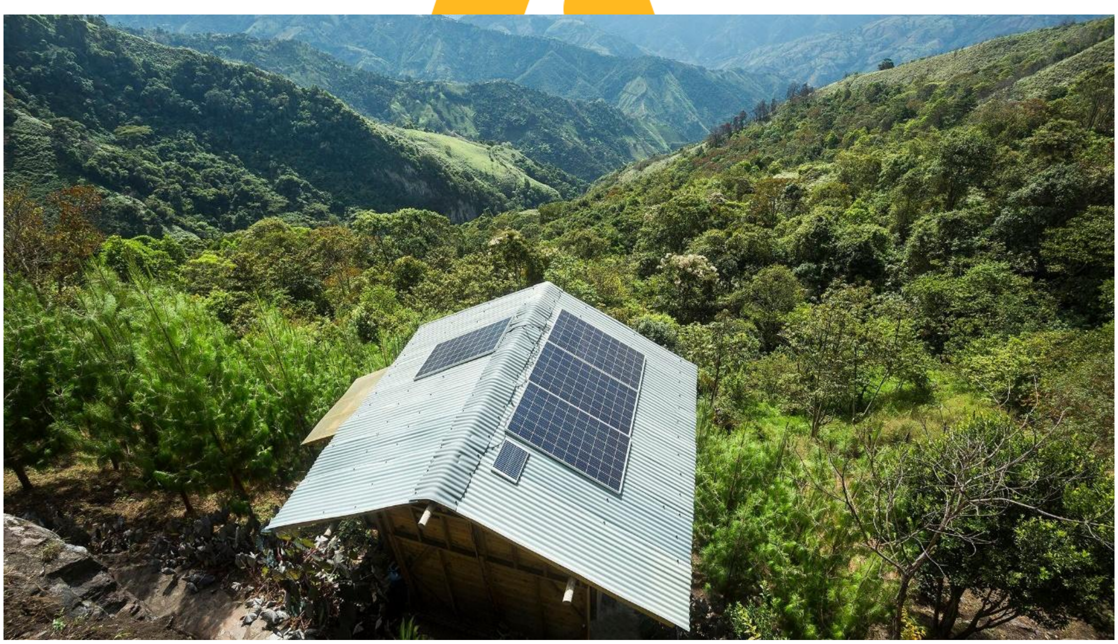
Detailed description of the selected alternative

The generation per residential unit is defined as an optimal solution according to the analysis of alternatives because it allows significant cost savings in the implementation of the photovoltaic system and this type of system requires a smaller area for its implementation per residential unit compared to the area that should be occupied by the centralized generation and the assembly of networks within the area, including transformers and infrastructure required to be able to distribute all the energy generated through this option, which significantly increases the investment that must be carried out, so this design model of centralized generation is discarded and the generation per residential unit is chosen. Additionally, this type of design greatly facilitates issues related to maintenance and cleaning of the equipment. Based on all the aspects

The above mentioned and for the accessibility and ease of implementation and operation of the generation system, this alternative was selected.

Cálculos por unidad residencial			
	Día (kWh/día)	kWh/mes	**kWh/año**
Ed	7005,00	21015	2521,80
W a instalar	1556,67	46700	560,4
Paneles	3		
Batería CAPA	730		

The number of panels and batteries required for the implementation of the photovoltaic system per household is identified, which allows sizing the design of the system taking into account the advantages and disadvantages mentioned above. With this, the prototype of the system that will be implemented in the residential units is made.



8. Engineering specifications for the solution and sizing of components.

The capacity of the equipment was determined through the initial energy demand of the residential units of the Mokaná reservation:

Demanda unidad residencial			
	Día (kWh/día)	**kWh/mes**	**kWh/año**
Ed	7005.00	21015	2521,80
W a instalar	1556.67	46700	560,4
Paneles	3		
Batería CAPACIDAD NOMINAL (Ah)	730		

Based on the customer's demand, the capacity of the equipment to be implemented is determined. The panel capacity was determined according to its efficiency.

ELECTRICAL DATA (STC)

Peak Power Watts-P_{MAX} (Wp)*	480	485	490	495	500	505
Power Output Tolerance-P_{MAX} (W)	0/+5					
Maximum Power Voltage-V_{MPP} (V)	42.0	42.2	42.4	42.6	42.8	43.0
Maximum Power Current-I_{MPP} (A)	11.42	11.49	11.56	11.63	11.69	11.75
Open Circuit Voltage-V_{OC} (V)	50.8	51.1	51.3	51.5	51.7	51.9
Short Circuit Current-I_{SC} (A)	11.99	12.07	12.14	12.21	12.28	12.35
Module Efficiency η_m (%)	20.1	20.3	20.5	20.7	20.9	21.1

STC: Irradiance 1000W/m², Cell Temperature 25°C, Air Mass AM1.5.
*Measuring tolerance: ±3%.

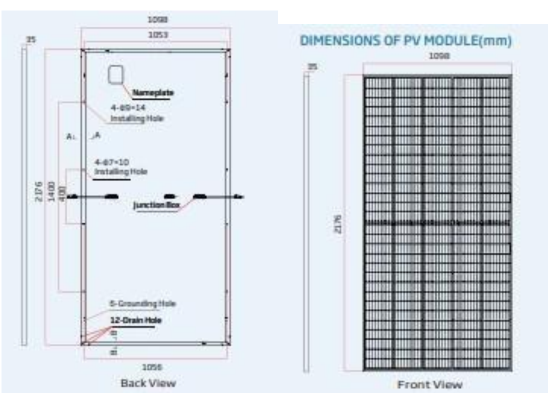
ELECTRICAL DATA (STC)

Peak Power Watts-P_{MAX} (Wp)*	480	485	490	495	500	505
Power Output Tolerance-P_{MAX} (W)	0/+5					
Maximum Power Voltage-V_{MPP} (V)	42.0	42.2	42.4	42.6	42.8	43.0
Maximum Power Current-I_{MPP} (A)	11.42	11.49	11.56	11.63	11.69	11.75
Open Circuit Voltage-V_{OC} (V)	50.8	51.1	51.3	51.5	51.7	51.9
Short Circuit Current-I_{SC} (A)	11.99	12.07	12.14	12.21	12.28	12.35
Module Efficiency η_m (%)	20.1	20.3	20.5	20.7	20.9	21.1

STC: Irradiance 1000W/m², Cell Temperature 25°C, Air Mass AM1.5.
*Measuring tolerance: ±3%.

MECHANICAL DATA

Solar Cells	Monocrystalline
Cell Orientation	150 cells
Module Dimensions	2176 ×1098× 35 mm
Weight	26.3 kg
Glass	3.2 mm High Transmission, AR Coated Heat Strengthened Glass
Encapsulant Material	EVA
Backsheet	White
Frame	35 mm Anodized Aluminium Alloy
J-Box	IP 68 rated
Cables	Photovoltaic Technology Cable 4.0mm² Portrait: N 280mm/P 280mm Landscape: N 1400 mm /P 1400 mm
Connector	TS4



CONTROLADOR SOLAR SAT MPPT

SAT GSC F12 24 30

- Capacidad de las Baterías: 38 Ah ~ 800 Ah
- Eficiencia Max:>98%
- Voltaje Nominal: 12V / 24V 24V / 48V

ESPECIFICACIONES TÉCNICAS*

DESCRIPCIÓN	ESPECIFICACIONES
REFERENCIA	SAT GSC F12 24 30
PANTALLA	LCD + LED
VOLTAJE NOMINAL	12V / 24V 24V / 48V
CORRIENTE MAXIMA DE RECARGA	10 / 20 / 30 / 40 / 50 / 60 A
MAXIMA CORRIENTE DE CARGA	10 / 20 / 30 / 40 / 50 / 60 A
MAXIMA POTENCIA DEL PANEL SOLAR	12V- 120 / 240 / 360 / 480 / 600 / 720W 24V- 240 / 480 / 720 / 960 / 1200 / 1440W 48V- 480 / 960 / 1440 / 1920 / 2400 / 2880W
CAPACIDAD DE LA BATERIA	38 Ah - 800 Ah
EFICIENCIA MAXIMA	> 98%
MAX VOLTAGE DE ENTRADA PV	F1224 (12 V: 0 - 30V: 24V: 0 - 60V); F2448 (24V: 0 - 48V: 48V:0 - 96V)
VOLTAGE DE OPERACIÓN OPTIMO (Vmp)	12 V: 15 - 22V: 24V:29V-38V:48V:58V - 72V
VOLTAJE DE CARGA ECUALIZADO	12 V: 14.6 V ± 1%; 24 V: 29.2 V ± 1%; 48 V: 58.4 V ± 1%
VOLTAGE DE CARGA FLOTANTE	12 V: 14,4 V ± 1%; 24 V: 28,8 V ± 1%; 48 V: 57,6 V ± 1%
PROTECCION DE SOBRECARGA	12 V: 14.7 V ± 1%; 24 V: 29.4 V ± 1%; 48 V: 58.8 V ± 1%
VOLTAGE PLEGABLE DE CARGA	12 V: 13.2 V ± 1%; 24 V: 26.4 V ± 1%; 48 V: 52.8 V ± 1%
ALARMA DE BAJO VOLTAGE	12 V: 11,2 V ± 1%; 24 V: 22,4 V ± 1%; 48 V: 44,8 V ± 1%
PROTECCION DE SOBREDESCARGA	12 V: 10.8 V ± 0.3 V; 24 V: 21.6 V ± 0.3 V; 48 V: 43.2 V ± 0.4 V
VOLTAJE DE ESTRELLA DE RESTAURACIÓN DE SOBRECARGA	12 V: 13.2 V ± 0.3 V; 24 V: 26.4 V ± 0.3 V; 48 V: 52.8 V ± 0.4 V
SOBRECARGA / PROTECCION CONTRA CORTO CIRCUITO	110% para 255 s; 125% para 60 s; 150% para 10 s / AUTO-APAGADO SI HAY CORTO CIRCUITO
PROTECCION INVERSION DE POLARIDAD DEL PANEL	DISPONIBLE
COMUNICACIONES (OPCIONAL)	RS232 / CONTACTOS EN SECO
TEMPERATURA DE OPERACIÓN	(-20°C - 45°C)
TEMPERATURA DE ALAMACENAMIENTO	(-25°C - 85°C)
ALTITUD MAXIMA	1000 ma la potencia nominal (reducción del 1% por cada 100 m adicionales); Max. 4000 m
HUMEDAD REALTIVA	0- 95% NO CONDENSADO
HUMEDAD DE ALMACENAMIENTO	< 85%
INSTALLACIÓN	Montaje vertical en un muro
DIEMNSIONES	164 × 168 × 100 (F1224 - 40 / 50 / 60M& F2448 - 30 / 40 / 50 / 60 M)
PESO NETO	2.05 Kg
PESO BRUTO	2,25 Kg

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Model	IP1000-12	IP1000-22	IP1000-11	IP1000-21	IP1500-12	IP1500-22	IP1500-11	IP1500-21
Technical Specification								
Rated Input Voltage	12VDC	24VDC	12VDC	24VDC	12VDC	24VDC	12VDC	24VDC
Input Voltage Range	10.8 ~ 16VDC	21.6 ~ 32VDC	10.8 ~ 16VDC	21.6 ~ 32VDC	10.8 ~ 16VDC	21.6 ~ 32VDC	10.8 ~ 16VDC	21.6 ~ 32VDC
Input Surge Voltage	<20VDC	<40VDC	<20VDC	<44VDC	<20VDC	<40VDC	<20VDC	<40VDC
Output Voltage	220VAC / 230VAC (± 5%)		110VAC / 120VAC (± 3%)		220VAC (± 5%) 230VAC (-7% ~ + 5%)		110VAC (± 3%) 120VAC (-7% ~ + 3%)	
Output Frequency	50/60±0.1Hz							
Output Continuous Power	800W				1200W			
Output Power 15 min.	1000W				1500W			
Surge power	1600W				2400W			
Power factor	0.2-1(VA lower than output continuous power)							
Output Wave	Pure sine wave							
Distortion THD	THD≤3%①		THD≤5%①		THD≤3%①		THD≤5%①	
Max. Efficiency	94.5%		92.5%		93%	94%	93%	94%
No-load Current	<0.8A	<0.5A	<0.8A	<0.5A	<1.0A	<0.6A	<1.0A	<0.6A
USB Output Port②	5VDC/Max.1A							
RS485 Com. Port②	5VDC / 200mA							
Binding Post	Φ10mm							
Overall Dimension (㎜)	298.3 × 231.5 × 98.5	284.7 × 231.5 × 98.5	298.3 × 231.5 × 98.5	284.7 × 231.5 × 98.5	326.12×231.5 ×98.5	284.7×231.5 ×98.5	326.12×231.5 ×98.5	284.7×231.5 ×98.5
Mounting Dimension	183 × 220 mm	163 × 219.5mm	183 × 220 mm	163 × 219.5mm	208 × 220 mm	163 × 219.5mm	208 × 220 mm	163 × 219.5mm
Mounting Hole Size	Φ5.5mm							
Net Weight	3.9 kg	3.6 kg	3.9 kg	3.6 kg	4.6 kg	3.9 kg	4.6 kg	3.9 kg

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2. Technical data (Reference temperature 20 °C)

Type U_e V/cell	C_{1h} Ah 1.67	C_{10h} Ah 1.80	C_{20h} Ah 1.80	C_{72h} Ah 1.80	C_{100h} Ah 1.80	C_{120h} Ah 1.80	C_{240h} Ah 1.80	R_i 1) mΩ	I_k 2) kA	Length (L) mm	Width (W) mm	Height (H) mm	Weight kg
2 PVV 140	71	121	134	153	157	158	165	1.65	1.30	105	208	420	12.4
3 PVV 210	107	182	202	229	236	238	247	1.15	1.86	105	208	420	17.1
4 PVV 280	143	243	268	306	314	318	331	0.89	2.40	105	208	420	19.4
5 PVV 350	179	304	336	383	393	397	412	0.73	2.91	126	208	420	23.3
6 PVV 420	215	364	404	460	472	477	496	0.63	3.39	147	208	420	27.4
5 PVV 550	254	447	506	570	583	589	609	0.68	3.14	126	208	535	31.4
6 PVV 660	302	529	598	671	686	693	715	0.58	3.64	147	208	535	36.9
7 PVV 770	350	610	688	770	788	795	820	0.52	4.12	168	208	535	42.4
6 PVV 900	417	729	834	943	968	978	1,012	0.46	4.63	147	208	710	49.5
7 PVV 1050	492	858	980	1,116	1,140	1,154	1,195	0.36	5.81	215	193	710	60.4
8 PVV 1200	559	970	1,106	1,252	1,280	1,296	1,344	0.32	6.54	215	193	710	67.3
9 PVV 1350	616	1,090	1,252	1,418	1,450	1,464	1,524	0.34	6.29	215	235	710	75.5
10 PVV 1500	691	1,200	1,382	1,562	1,600	1,620	1,675	0.28	7.50	215	235	710	82.5
11 PVV 1650	748	1,320	1,512	1,713	1,750	1,764	1,836	0.28	7.56	215	277	710	90.8
12 PVV 1800	822	1,440	1,644	1,857	1,900	1,920	1,989	0.24	8.63	215	277	710	97.7

Design	Sistema Individual
DC Nameplate	1.52 kW
AC Nameplate	1.14 kW (1.33 DC/AC)

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Design	Sistema Individual
Module DC Nameplate	1.52 kW
Inverter AC Nameplate	1.14 kW Load Ratio: 1.33
Annual Production	2.170 MWh
Performance Ratio	78.0%
kWh/kWp	1,432.4
Weather Dataset	TMY, 10km Grid, meteonorm (meteonorm)

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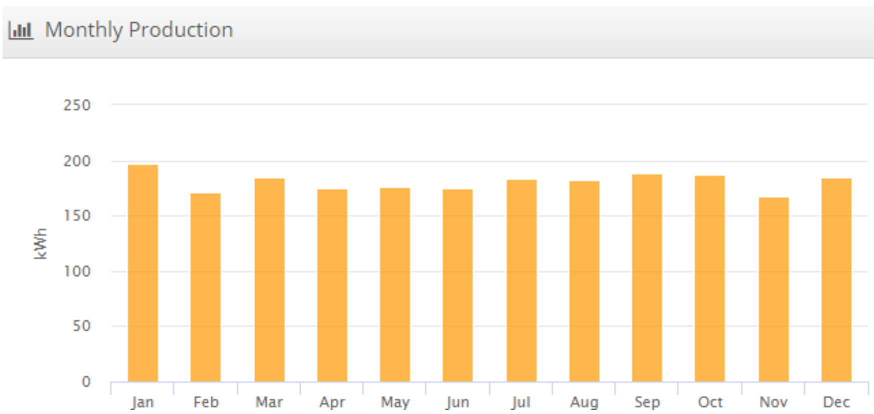

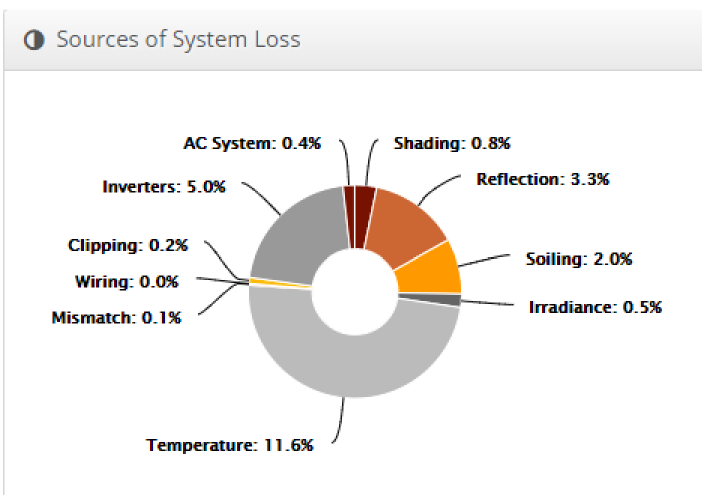

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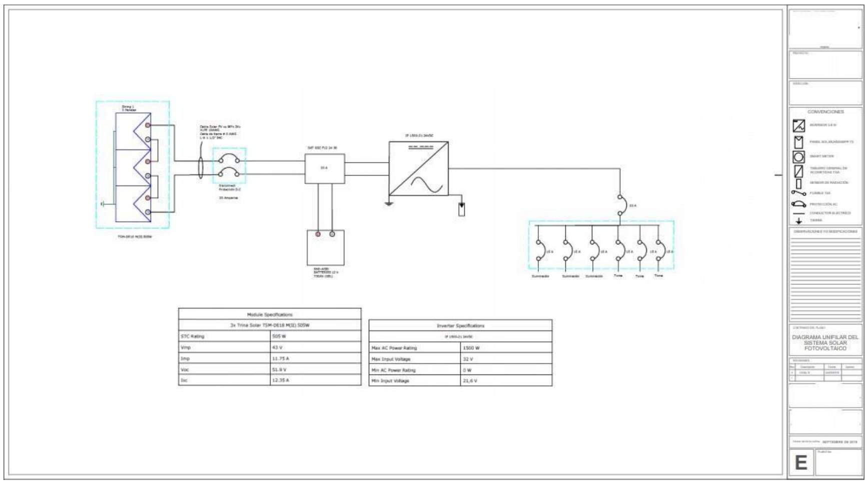

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9. Design cost analysis

Make an analysis of the costs that would be incurred for the development and implementation of the proposed solution.

AVERAGE PRICES			
TEAM	CASA	COST OF STAND-ALONE SYSTEM (29 HOUSES)	CENTRALIZED SYSTEM COST
PANEL	$ 623,333.33	$ 72,306,666.67	$ 66,073,333.33
CONTROLLER	$ 503,442.67	$ 14,599,837.33	$ 14,599,837.33
BATTERY	$ 8,160,804.00	$ 236,663,316.00	$ 236,663,316.00
INVESTOR	$ 708,970.67	$ 20,560,149.33	$ 20,560,149.33
CABLE	$ 110,000.00	$ 1,320,000.00	
Total	$ 10,106,550.67	$ 345,449,969.33	$ 337,896,636.00

Table 12. Average costs of the options for each equipment per alternative.
Source: Own elaboration.

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10. Prototyping or conceptual design

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11. Conclusions and recommendations

Taking into account the background, needs, geographic location and challenges in the project area, such as poor accessibility, lack of basic services, lack of qualified personnel and rudimentary infrastructure, and after analyzing the technical and social aspects of the area, it was decided to choose the option of installing generation systems per residential unit, since this system provides better results in the operation and maintenance of the system, In addition, the cost of implementing this type of system is lower than centralized generation, since this would require the renovation of the electrical infrastructure in the area, such as wiring, poles and transformers, in addition to the area to be occupied for the execution of the civil works and assembly of the system.

On the other hand, the implementation of generation per residential unit facilitates the assembly of systems, operation and maintenance, since they are more compact and more practical, and additionally, this type of generation system per residential unit provides greater reliability to the users of the area, since in the event of a failure or damage to the equipment, it would only affect the residential unit involved and not the entire population.

It should be noted that the optimal functioning and durability of the system depends entirely on its maintenance, operation and care. It is recommended that training be provided to the inhabitants of the area so that they themselves are charge of these tasks.

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12. References

Note: List the authors and sources referenced throughout the document. Please generate the table of references automatically through MS-Word.

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