Periodicals of Engineering and Natural Sciences
Vol. 11, No. 1, February 2023, pp.74-90
ISSN 2303-4521
Case Study

Technical-economic evaluation of a portable solar machine of potential use in pumping systems and water purification, through the use of photovoltaic solar technology for non-interconnected areas in Colombia

Diego Armando Cartagena Calderón[1], Brayan Eduardo Tarazona Romero[1], Arly Dario Rincón Quintero[1], Camilo Leonardo Sandoval Rodriguez[1], Omar Lengerke Perez[1], Gianina Garrido Silva[2]
[1] Faculty of Natural Sciences and Engineering, Unidades Tecnológicas de Santander, Colombia
[2] Electronic Engineering Program, Universidad Santo Tomás Sede Bogotá, Colombia.

ABSTRACT

The purpose of this article is to present the dimensioning of a portable, autonomous solar machine, of potential utility in pumping systems and water purification, through the use of photovoltaic solar technology and innovation to an unsatisfied basic need, such as service drinking water, in areas of the country, where there are inconveniences for access to drinking water and electricity service. The solar machine is innovative, modular, portable, easy to transport and install, sustainable and environmentally friendly, with zero greenhouse gas emissions as it is powered by photovoltaic technology. The solar machine is innovative, modular, portable, easy to transport and install, sustainable and environmentally friendly, with zero greenhouse gas emissions as it is powered by photovoltaic technology and does not use batteries. This portable solar machine substantially reduces the cost of investment, operation and maintenance, by using photovoltaic solar panels and working with direct current, eliminating the use of the conventional electrical power network, inverters, for its operation and can be dimensioned for water. surface water from rivers or reservoirs to the reservoir or pond, the same as for groundwater from wells, for the supply of drinking water, through the improvement, disinfection and sterilization of drinking water, to improve the quality of life of rural communities and secondly measure for use in the agricultural sector, for irrigation, domestic use, livestock (livestock pasture) and other services, for the rural development of the regions in Colombia.

Keywords: Conventional Filtration, Ultraviolet Light, Water pumping system, Off-Grid connection photovoltaic solar system, Non-Interconnected Zones in Colombia.

Corresponding Author:
Diego Armando Cartagena Calderón
Faculty of Natural Sciences and Engineering
Unidades Tecnológicas de Santander
Calle de los Estudiantes #9-82 Ciudadela Real de Minas-Bucaramanga-680005, Colombia
E-mail: dacartagena@correo.uts.edu.co

1. Introduction

The Political Constitution of Colombia establishes as one of the main purposes of the activity of the State, the solution of unsatisfied basic needs, among which is access to drinking water service, which is essential for human life [1]. The adequate supply of quality water for human consumption is necessary to avoid cases of morbidity due to diseases such as cholera and diarrhoea. In Colombia it is evident that, although there is legislation on water resources in the national territory, many of the aqueducts established outside urban areas have been built by the inhabitants themselves through tube systems connected to a water source, without any kind of treatment or purification [2]. In Latin American countries there are coverage limitations for the provision of drinking water service and despite the fact that large sums of money are invested in technologies and structures to expand the service [3], good quality is not necessarily guaranteed, since not all solutions are in accordance with the needs or conditions of each population. [4].

Addressing scarcity, guaranteeing service provision and water quality, is undoubtedly one of the greatest challenges facing the world's population in the coming years. This problem is especially serious in those regions where, in addition to the limited water supply, there is a lack of electricity to pump, distribute or transport the water, pointing out, furthermore, that in the Non-Interconnected Zones a local energization solution is required, which offers a constant and reliable service, and whose generation costs are affordable to the population.

In fact, unsafe water is the leading cause of diarrhea with an 88% annual contribution, causing 842 thousand deaths, mainly among children under 5 years of age [4]. Thus, access to drinking water, especially in rural regions, has become a political priority in many countries, which is why, at the meeting of world leaders at the United Nations headquarters, to adapt the sustainable development goals or objectives world, it was established that all people have universal and equitable access to drinking water, at an affordable price for all, by the year 2030.

In Colombia, 29% of the population lives in the countryside and 48% does not have access to a supply network. Of the remaining 52%, among those who do have water, only 12% have safe liquid for human consumption [2]. In Colombia, according to studies carried out by the Ministry of the Environment and presented in its report on water resources in the country's drinking water treatment systems, it was found that, although 53.4% of the communities have water coverage, only 11.8% can be guaranteed the quality of this supply. The situation of these communities is difficult since they do not have the economic resources to pay for a good water service; This is observed in the report delivered by the Ministry of the Environment where many Colombian rural communities in the eastern plains, the upper Guajira, and areas of the Pacific coast, which due to their geographical conditions are far from treatment networks and it is necessary transport drinking water long distances, or by necessity the available resource must be used with inappropriate treatment methods. Potability projects must be designed to be sustainable and technically and economically feasible. From the point of view of electricity supply, currently in Non-Interconnected Zones (ZNI)[5], there are inconveniences for access to drinking water and water for general use. The ZNI are located in places that are difficult to access, at long distances from urban centers; they lack physical infrastructure and do not have appropriate access roads [6]. They are areas of high ecological importance; they are characterized by their wealth of natural resources and great biodiversity; we find there most of the reserves and natural parks of the country. Public services are scarce and deficient; they lack basic services such as energy, water supply and sewerage, and have difficulties in accessing education, health, drinking water and communication. Faced with this situation, an innovative solution is proposed, with the dimensioning of a solar machine, which presents sustainable technological alternatives, technically and economically viable [7] [8]according to the needs of each community and/or region in the non-interconnected areas of Colombia [6] [9] [10] [11] all integrated inside a cabinet, to pump [12] and purify water [8]using solar photovoltaic technology [13] [14] and the use of filtration and purification technologies [2] using UV rays [15], easily transported, to improve the quality of life of rural communities and secondly for use in the agricultural sector, for irrigation, domestic use, livestock (livestock pasture) and other services, for the rural development of the regions in Colombia.

2. Methodology of design

The research methodology, which was developed, for the dimensioning of the solar machine is quantitative, based on stages, which have the following activities implicit:

2.1 Stage 1. Analysis

2.1.1 Preliminary conditions

Location: Municipality of Sipí – Chocó. (ZNI)
Type of User: Domestic - Single Family Home.
Regime of Use: daily.
Installation Location:
Latitude: 4.651667°
Length: -76.643889°
Temperature: twenty-eight Average degrees centigrade
Climate: Its lands are distributed in the hot, temperate and cold thermal floors.
Height: 50 m above sea level.
Location of the portable solar machine:

The portable solar machine will be located in an area or land of 5 m^2; 4 m^2 for the cabinet and solar panels suspended on a structure 2 meters or 4 meters from the floor, without shadows or any object or tree that casts a shadow on the solar panels and 1 m^2 for the location of the equipment or water purification system.

The portable solar machine has the sizing of the conductor caliber, for connection from the AC protection to the inverter output up to 6 meters for connection to the distribution board of the house, through an underground connection. In the event that this distance is greater than that indicated, the supplier must be consulted to recalculate the conductor and validate the voltage regulation of the installation.

The materials and equipment used for the portable solar machine must be certified under the RETIE Standard.

The family unit will be trained in the use, connection, maintenance, safety standards, electrical risks of the solar machine, as well as in the selected water purification equipment or system.

2.1.2 Solar radiation analysis [5]

Determine the solar radiation in the municipality of Sipí - Choco.

According to the measurements made by the IDEAM Institute of Hydrology, Meteorology and Environmental Studies in the Atlas of Solar Radiation in Colombia 2014 in Colombia, the average radiation is 5.3 Kw/day. For its part, in the area such as the Department of Chocó, on average it is 3.5 kW/day; and for the municipality of Sipi, Choco, on average, it is 4.0 to 4.5 kWh/m^2, as shown in figure 1.

2.2 Stage 2. Dimensioning, selection of equipment for the off-grid solar photovoltaic system

2.2.1 Ampere-hour method

2.2.1.1 Maximum number of days of autonomy

The maximum number of days of autonomy (N), foreseen for the installation based on the climatological characteristics of the area and the application or final use of the critical domestic installation, plus experience and economic limitations, was estimated at 3.5 days. N= 3.5 days.

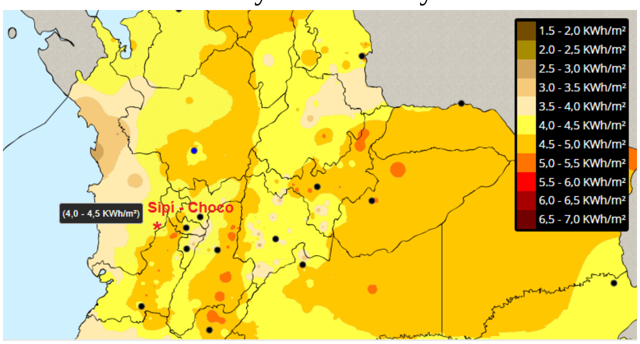

Figure 1. Map of solar radiation in the municipality of Sipi - Choco- Colombia.
Source: IDEAM Institute of Hydrology, Meteorology and Environmental Studies in the Atlas of Solar Radiation in Colombia 2014

2.2.1.2 Maximum allowable depth of discharge for the battery (PD)

The maximum allowable depth of discharge for the battery (PD), was determined from both the type of battery used, as well as the number of charge and discharge cycles assumed by the installation and the cost of the system.

Battery Type: Lead-acid

Technology: VRLA Valve Regulated Lead Acid battery

Battery: GEL

Advantages: In gel batteries, the electrolyte is gelled when silicon dioxide is added, allowing it to increase its useful life because it prevents gassing, guaranteeing more charge and discharge cycles.

Maximum allowable discharge for the GEL battery: 80%.

2.2.1.3 Rated installation voltage

In general, voltages of 12 V are recommended for powers less than 1.5 kW, 24 or 48 V for powers between 1.5 and 5 kW, and 48 or 120 V for powers greater than 5 kW. [6].

For the portable solar machine, the nominal voltage of the installation is 24 V.

2.2.1.4 Estimated daily consumption (Wh/day) for loads in D.C.

Table 1. Types of loads in D.C with their daily consumption (Wh/day) (Source: Author's elaboration)

Type of load in D.C	**Rated Power in W**	**Typical daily operating time (hours/day)**	**Daily consumption (Wh/day)**
Motor pump SHURflo, 24 VDC 13.6 litres/minute.	144 W	0,5	72
Conventional Refrigerator 246 Lt. Energy Efficiency A.	17,1 kWh/mes	24	570
Saving Bulb Type Led 7 W (4 Units)	28 W	5	140
TV	60 W	3	180
Other loads	100 W	3	300
Power Mix 2 Speed Blender	550 W	0,25	137,5
Total cargas DC			1,3995 kWh/día

2.2.1.5 Daily energy demand value (Wh/day)

The necessary energy (L) is calculated taking into account the efficiencies of the different subsystems and the losses. [6]. Thus:

$$L = \frac{L_{CC}}{\eta_g} + \frac{L_{Ca}}{\eta_g \, \eta_{inv}} \qquad (1)$$

Where:

L_{CC}= is the daily charge in direct current

L_{Ca} = is the daily charge in alternating current = 0 kWh/día

n_g = is the charge-discharge efficiency of the battery

n_{inv} = is the average daily efficiency of the inverter

n_g = The charge-discharge efficiency of the battery is estimated at 95%

n_{inv} = An estimated 97% average daily efficiency of the inverter

$$L = \frac{1{,}3995\ kWh/día}{0{,}95*0{,}97} = 1518{,}72\ Wh/día$$

Daily energy demand (*Wh/día*) = 1518.72 *Wh/día* = 1.51872 *kWh/día*

2.2.1.6 Inclination angle and orientation of the solar panels

For autonomous installations with constant annual consumption, as is the case of the installations of the portable solar machine, in the period of time and/or month of less solar radiation, the optimal inclination is [6]:

$$\beta_{opt} = \varphi + 10 \qquad (2)$$

$$\beta_{opt} = 4.652° + 10$$

$$\beta_{opt} = 14.652° \text{ para efectos prácticos } 15°$$

The angle of inclination of the solar panels for the portable solar machine is 15° and they must be in a South direction, placing the portable solar machine strategically in an open area of 5 m^2 without shadows, trees and/or objects that establish shade in the solar panels.

2.2.1.7 HSP (peak solar hours) of the most critical month

For the dimensioning of peak solar hours (HSP), we will analyze the data corresponding to the most unfavorable situation (<<worst month>>), in order to guarantee autonomy in the worst situation. We proceed to consult the PVGIS software; photovoltaic geographical information system, Radiation database: PVGIS-NSRD; placing the latitude and longitude coordinates, to obtain and analyze the monthly global irradiation data for the year 2005-2015.

To simplify the calculations, we proceed to consider the constant consumption throughout the year, in order to determine the HSP of the most critical month at the best inclination [6]. In our case, it is the month of February with Global irradiation of 3.658214286 kWh/m^2 at the optimum angle of 15° at medium temperature.

$$HPS = \frac{dayli\ Irradiation}{Constant\ \ Irradiation} \qquad (3)$$

$$HPS = \frac{3650\ Wh/m^2}{1000\ Wh/m^2} = 3{,}65 \text{ h}$$

2.2.1.7 Sizing, selection, connection and number of solar panels in the installation

2.2.1.7.1 Selection of the solar panel for the portable solar machine

We select a solar panel with half-cell or split cell technology, based on the decision of its advantages, cost/benefit and that by delivering more power per square meter, fewer panels are required to generate the same power, this means longer installation times. speeds and the need for fewer components, such as brackets and wiring, which reduces overall costs, for the portable solar machine.

Technical characteristics of the selected solar panel:
Power: 375 Wp Polycrystalline. Canadian Solar.
Technology: 144 Half-cell or split cell (half-cell).
Opt. Operating Voltage (Vmp): 40,2 V
Opt. Operating Current (Imp): 9,34 A
Open Circuit Voltage (Voc): 47,6 V
Short Circuit Current (Isc): 9,91 A
Module Efficiency: 18,9 %

Figure 2. Polycrystalline solar panel 375 Wp; 144 Half-cell or split cell (half-cell). Canadian Solar brand.
Source: Solartex Energy Company for Colombia.

The size of the field of panels, or peak power of the installation, is calculated taking into account the available solar radiation. The HSP value for the worst month is used. With this value and taking into account the peak watts of a panel, the necessary number of panels is calculated, according to the expression. [6].

$$\textit{Number of photovoltaic modules} = \frac{L}{W_p \; X \; HSP_{\alpha,\beta} \; X \; F_S \; X \; PR} \quad (4)$$

Where:

L is the actual daily energy needed.
Wp are the peak watts of the photovoltaic module used in the installation.
$HSP_{\alpha,\beta}$ They are the hours of peak sun incident on the plane of the panels (β is angle of inclination on the horizontal and α the orientation with respect to the south).
Fs is the shading factor or shading loss coefficient (0 is equal to 100% losses: 1 equals 0% shadow loss).
PR is global.
loss factor or performance ratio = 0,72

$$\text{Number of photovoltaic modules} = \frac{1.51872 \; kWh/día}{375 \; w \; x \; 3{,}65 \; x1x0{,}72} = 1{,}54$$

Number of photovoltaic modules= 1,53 ≅ 2 panels.

Given the voltage of the solar panels to be implemented, a connection of the 2 solar panels will be made in parallel. In this way, the peak power of the photovoltaic generator or portable solar machine will be 375 W x 2 = 750 Wp.

2.2.1.7.2 Sizing structure for solar panels

Figure 3. Post support for 2 solar panels 375 Wp
Source: Solartex Energy Company for Colombia.

Post Support MV915 SUNFER for Solar Panels
- 2 photovoltaic modules
- Recommended installation: post mount
- Profiles: Aluminum EN AW 600 5. T6
- Screws: Stainless Steel
- Hot galvanized steel
- Measurements: 1650 x 1000 mm
- Post included
- Regulable de 0º hasta 15º
- Horizontal layout of modules.

2.2.1.7.3 Charge regulator sizing

In order to guarantee the continuous operation of the installation, between the bank of accumulators and the field of panels, on the one hand, and the load, on the other, the regulating equipment is dimensioned and installed, whose mission is to protect the accumulators, in order to lengthen its life, and ensure the proper functioning of the installation.

To calculate the regulator, we must know what the maximum current provided by the photovoltaic generator will be. The intensity of the regulator I_R (A), will be:

$$I_R > 1{,}2 \times NP \times I_{sc} \quad (5)$$

Where:

Np = number of solar panels
Isc= Short circuit current of each panel.
According to the technical characteristics of the selected solar panel, the short circuit current (Isc) of each panel is 9.91 A, substituting in formula 5 to find the intensity of the regulator, we have:

$$I_R > 1{,}2 \times 2 \times 9{,}91$$
$$I_R > 23{,}784\ A$$

Also, the maximum current that the consumptions can demand must be considered, since the regulator must be prepared so that this current circulates through it (Isc max.), using the following formula:

$$I_R > 1{,}2 \times I_{CCmáx} \qquad (6)$$

Where:

$$I_{CCmáx} = \frac{P_{CCmáx} + \frac{P_{inv}}{\eta_{inv}}}{V_{CC}} \qquad (7)$$

$P_{ccmáx}$ is the maximum power demanded by direct current loads
P_{inv} is the rated power of the inverter= 0 W
ηinv is the return on the investor
V_{cc} is the voltage level used for the DC circuit.

Estimated daily consumption (Wh/day) for loads in DC, the data is replaced in formula 7, to find the $I_{ccmáx}$:

$$I_{CCmáx} = \frac{1.51872\ kWh/día}{24} = 66{,}13 \text{ A}$$

Substituting the result of the $IDC_{máx}$ in formula 6:

$$I_R > 1{,}2\ x\ 66{,}13$$

$$I_R > 80\ A$$

We select a charge regulator from of 85 A.

Figure 4. Regulador de carga SmartSolar MPPT 150/85-TR VE. Can Victron
Source: Solartex Energy Company for Colombia.

2.2.1.7.4 Sizing of the accumulator or battery of the installation

The design of the necessary accumulation for the correct operation will basically depend on the capacity of the designed battery bank. The necessary capacity of the portable solar machine will be a function of the daily energy needed, the autonomy, the depth of discharge and the voltage required by the installation:

$$C\ (Ah) = \frac{Consumption\left(\frac{Wh}{days}\right)\times\ Autonomy\ days(days)}{Battery\ Voltaje\times\ discharge\ depth} \quad (8)$$

Maximum number of autonomy days: 3,5 días
Battery discharge depth: 80%
Nominal installation voltage: 24 V

$$C\ (Ah) = \frac{1518{,}72\ w \times\ 3{,}5}{24\ v\ \times\ 0.8}$$

$C\ (Ah)$ = 276,85 Ah

An accumulator is selected: 300 Ah

Figure 5. $Battery$ technology Gel 12 V- 300 Ah Tensite
Source: Solartex Energy Company for Colombia.

to comply with the nominal voltage of the 24 V installation, two (2) batteries with Gel technology will be connected; 12 V – 300 Ah in series.

2.2.1.7.5 Maneuvering and protection devices

2.2.1.7.5.1 DC protection sizing

2.2.1.7.5.1.1 Fuses

The main function of the fuses will be to protect the system from overcurrents by opening the filament that is inside the system, preventing the excess current from continuing its path. The fuses that are part of the photovoltaic system are designed to work in direct current and must be acts for both polarities, formula 9 is used for their selection.

$$I_{fusible} = (1{,}25 \times NP \times Isc)\ x1.25 \quad (9)$$
$$I_{fusible} = (1{,}25 \times 2 \times 9{,}91)\ x1.25$$
$$I_{fusible} = 30{,}96\ A$$

In the DC connection box (parallel connection of the panels), a fuse type protection will be placed, with a breaking capacity of 40 A. A molded case type magneto-thermal automatic switch can also be used, which acts in a similar to the fuse, interrupting the operation of the circuit when an over-current occurs, with the advantage that it can be reset manually, without the need to change it.

2.2.1.7.5.2 Grounding system sizing

In the site where the solar machine will be implemented, the respective grounding system of the installation must be designed, built and certified according to the RETIE and NTC 2050 standards. According to current regulations, the resistance for a residential installation must be less than 20 Ω. The frames of the photovoltaic modules, the metallic structure and all those metallic masses present belonging to the solar installation will be grounded.

2.2.1.7.5.3 Selection of conductors for D.C.

To select the direct current conductor, formula 10 and the technical characteristics of the selected panel must be applied:

$$S= \frac{2PL}{\gamma eU} \qquad (10)$$

Power: 375 Wp polycrystalline
Vmp: 40,2 V; Imp: 9,34 A; Voc: 47,6 V; Isc: 9,91 A

P= is the power (W)
L= length (m)
e= Tension fall (V)
U is the line voltage (V)
ɤ is the conductivity (m / Ω mm^2).

The installation is made up of a branch of 2 panels connected in parallel, so the voltage of the branch will be: 40.2 V, the intensity of the branch will be 9.34 A and the power of the branch will be 40.2 V x 9.34 A x 2 panels = 750.936 W. In this way, the necessary section for the branches will be:

$$S= \frac{2X750{,}936\, W\, x\, 1m}{44\, x\, (0{,}015x40{,}2V) x\, 40{,}2V}$$

$$S= 1{,}408\ mm^2$$

A normalized section of S= 1.5 mm^2 is taken as reference.

Identifying the section according to the UNE 20460-5-523:2004 standard, in table 52-B1; the reference installation method is identified: B (Insulated conductor in a conduit) where it indicates that for an XLPE insulation (90° C) and two conductors, column 10 of table A.52-1 BIS should be consulted, in which, taking 1.5 mm^2 as the normalized section, the conductor supports a maximum current of 20 A, a value higher than the intensity of the branch set at 9.34 A and the short-circuit current of the branch at: 9.91 A. what we choose the section of 1.5 mm^2

According to the calculated cross section, the next commercial gauge is 14 AWG XLPE 90° C with 2.08 mm2 Halogen free, resistant to abrasion, heat and humidity when referenced in table B.310.15 of the Colombian Technical Standard 2050, it can be seen that the capacity of the cable is 25 A for 90° C, complying with the maximum current capacity of the connection of the two panels in parallel in the installation.

2.2.2 Single line diagram

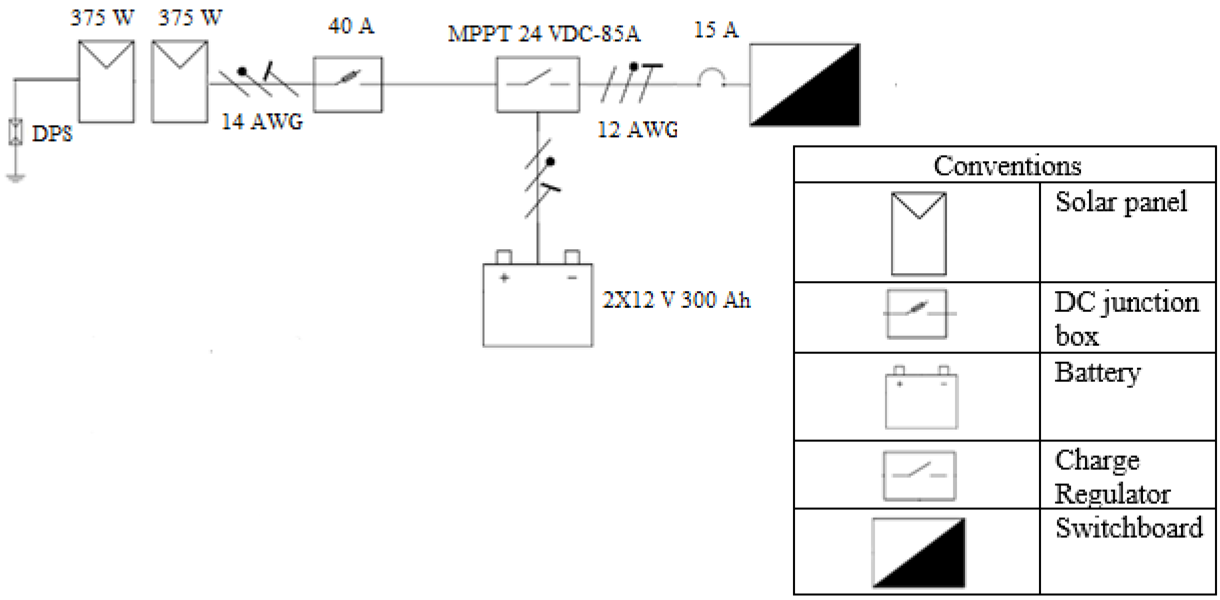

Figure 6 Single Line Diagram solar machine
Source: Author's elaboration

2.2.3 Dimensioning cabinet equipment photovoltaic solar system and pumping system.

Metal cabinet Width 2000 mm x Length 1500 mm x Depth 0.6 mm
Fully welded structure built in BWG No. 18 sheet metal.
Welded side panels, roof and floor. Doors and accessories made of BWG No. 16 sheet metal.
Modules adjustable in depth continuously. Labyrinthine door closure. Weatherstrips on the door of the self-adhesive rubber type. Half turn lock with key.

2.3 Stage 3 dimensioning, selection of equipment for the water pumping, filtration and potabilization system.

2.3.1 Sizing, selection of equipment for the pumping system

We selected two units of the SHURFLO model 2088-514-145 household pressure pump for 24-volt battery power and continuous operation. Capable of supplying a continuous flow rate of 13.6 litres/minute.

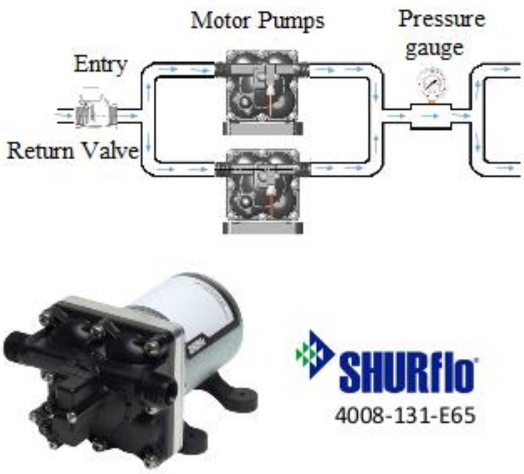

Figure 7 SHURFLO domestic pressure pump model 4008-131-E65
Fuente: Data sheet SHURFLO

2.3.2 Sizing conventional filtering system [2]

To guarantee the water filtration process, for the solar machine, the conventional filtering technique will be used, through sand and activated carbon filters. Sand filters consist of beds of fine sand one meter thick on a bed of gravel 30 cm high and a drainage system. We will use activated carbon filters to remove bad odors, flavors or unpleasant color from water, volatile organic compounds, pesticides and even radon. Activated carbon has a large surface area and therefore a high capacity for adsorption of compounds, which remain adhered to its surface. These filters are cheap, easy to maintain and operate, so their use is very common. It should be noted that these filters must receive frequent and periodic maintenance to avoid obstruction of the pipes.

Figure 8. Sand and active carbon filtration
Source: Author's elaboration

2.3.3 Disinfection and sterilization of water [2] [15]

To guarantee the water disinfection and sterilization process, ultraviolet radiation lamps will be used, because ultraviolet light destroys viruses and bacteria, in addition to providing a simple operation and maintenance method, it is useful with short contact times and does not generate toxic waste or by-products.

Figure 9. Disinfection and sterilization of water
Source: Catalog Homecenter-Colombia

The technical characteristics of the select ultraviolet lamp are:

Bulb power: 6 W
Bulb working time: 9000 Hours
Flow rate: 0.5 GPM (0.1 m^3/h)
Working pressure: 8 BAR (116PSI)

2.4 Stage 4: Budget

Net cost in euros of the photovoltaic solar system and the pumping system.

Table 2 lists each of the elements, materials, and equipment for the portable solar machine, taking into account manufacturing labor, consumable material such as screws, among others, and the usefulness of the entire system.

Table 2 Budget in € solar machine and pumping system
Source: Author's elaboration

Item	Equipment and/or Material	amount	Unit value	Total cost
1	Panel photovoltaic - Canadian *Solar*. 375 Wp	2	115,09 €	230,18 €
2	Regulator SmartSolar MPPT 150/85-TR VE. Can Victron	1	668,53 €	668,53 €
3	Battery Technology Gel 12 V- 300 Ah	2	350 €	700 €
4	2 Motor Pum Shurflo 24V 13.6 l/min	1	252,08 €	252,08 €
5	Conductor gauge 14 AWG	3m	0,22 €	0,66 €
6	MC4 Female and Male Connectors Kit	1	15 €	15€
7	Structure metallic	1	130,00 €	130 €
8	Cabinet Solar system, Pumping system	1	250 €	250 €
9	DC Protection Kit	1	80 €	80 €
10	Grounding System Kit	1	38 €	38 €
11	Filtration system + UV lamp	1	300 €	300 €
12	Logo PLC + Solenoid valve + Pressure Sensors	1	245 €	245 €
			Total value Equipment and/or Materials	2909,45 €
			Workforce	436,41 €
			Utility 15%	444,6675 €
			annual maintenance 0,5%	14,54 €
			Total	3805,0675 €

2.5 Stage 5: Net present value of the investment (VAN) and the internal rate of return (TIR)

For the analysis of the net present value of the investment (VAN) and the internal rate of return (TIR), the following considerations will be taken into account, for the photovoltaic solar system and the pumping system, since, for the filtration system and purification, there are no exact data on the costs of the aqueduct service and the costs per m3 of each family unit in the non-interconnected area. This is why only the VPN and the TIR of the photovoltaic solar system and the pumping system will be analyzed:

The general rule indicates that the useful life of a solar panel is 25 years. However, with proper maintenance, a solar panel can last for thirty years or more. Of course, its power will decrease after twenty years due to the degradation of its photovoltaic cells.

For our analysis we will take a time horizon of 25 years.

Interest rate: 10%
Production in kWh / year: 545.8932 kWh / year.
Energy sale price: €0.29/kWh (we assume an increase of 6% per year)
Source: SUI. SSPD-DTGE calculations.
Maintenance expenses: €14.69/year (we assume an increase of 1% per year)
Annual staff costs: €81.54/year. Source: Colombian minimum daily wage.
Contribution of the members of the family unit: €4,000.
Payment time: 8 years.

Table 3 shows the results for the VPN and the TIR, for the photovoltaic solar system and the pumping system:

Table 3 VAN value and the TIR of the photovoltaic solar system and the pumping system.

VAN	1789,06 €
TIR	2 %
Payback (Years)	4

The solar photovoltaic system and the pumping system of the portable solar machine is viable, because the NPV is positive, with an IRR of 2%, showing that the project is profitable. According to the pack back analyzed at 4 years it will begin to generate profits or recover the investment.

3. Conclusions

3.1 General scheme of the portable solar machine

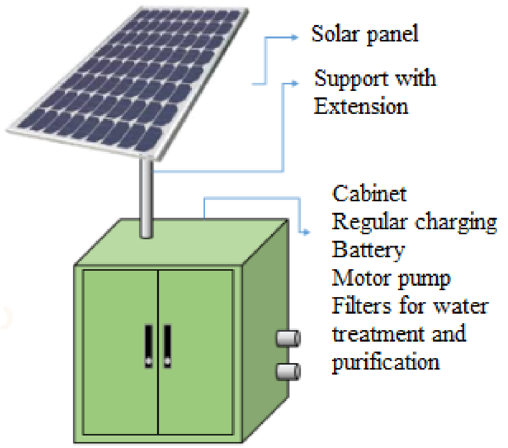

Figure 10. General scheme of the portable solar machine
Source: Author's elaboration

3.2 General equipment distribution diagram of photovoltaic solar system and portable solar machine pumping system.

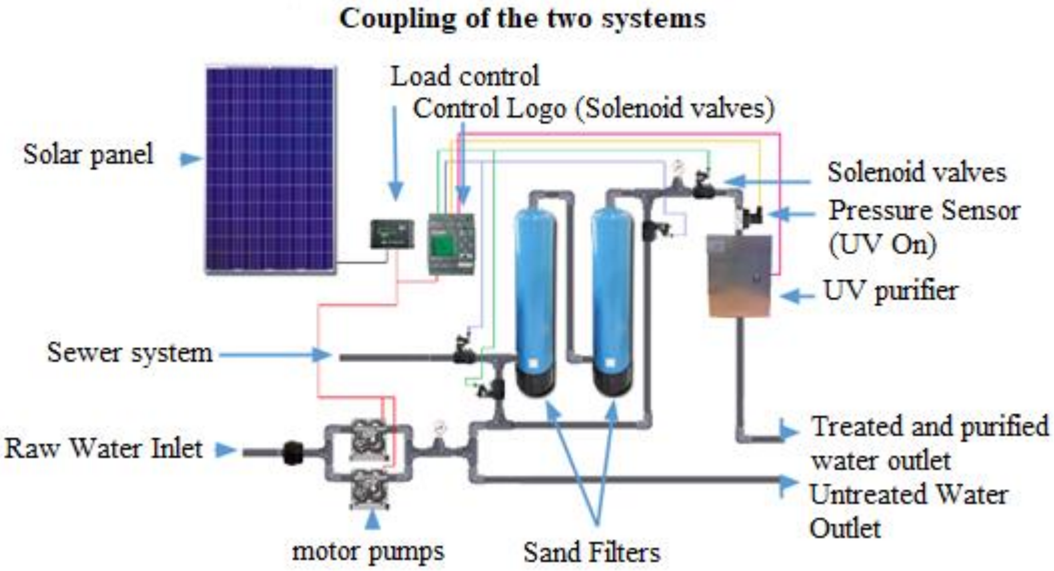

Figure 11. General scheme of equipment distribution photovoltaic solar system and pumping system of the portable solar machine
Source: Author's elaboration

3.3 General scheme of the pumping, filtration and water purification system

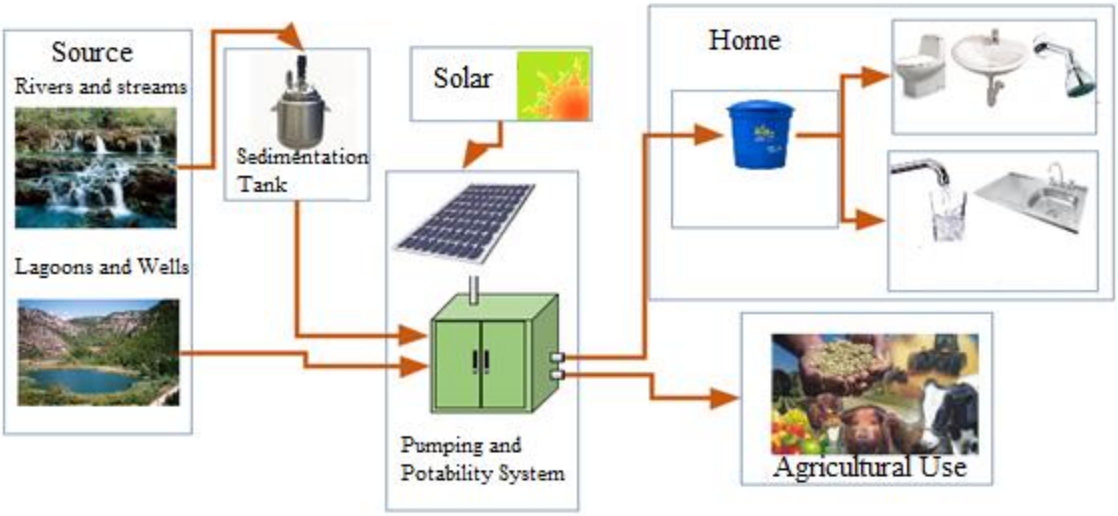

Figure 12. General scheme of the pumping and water purification system

3.4 Components of the portable solar machine, Off-Grid connection:

- Polycrystalline technology photovoltaic solar panels.
- Power: 375Wp. Brand: Canadian Solar.
- A charge regulator.
- SmartSolar MPPT 150/85-TR VE. Can Brand: Victron
- Protections of D.C
- Grounding system kit.
- Electrical conductors according to RETIE regulations.
- MC4 Male connectors.
- MC4 Female connectors.

- High efficiency motorized pump running on direct current. SHURFLO domestic pressure pump 24 VDC - 13.6 liters/minute continuously.
- Sand and activated carbon filtration system
- 6 W ultraviolet lamp
- Metal cabinet.

The dimensioning of the portable solar machine is designed using sustainable and renewable technology, substantially reducing the cost of investment, operation and maintenance by using photovoltaic solar panels, charge regulator, batteries, without the use of the inverter, in addition to working with current continues the pumping system for surface water and/or groundwater from wells, supplying drinking water, through the conventional filtration system and ultraviolet light disinfection, compared to other technologies and/or commercial products.

The dimensioning of the portable solar machine is a unique design, all integrated within a cabinet, designed to be compact, resistant to the atmospheric environment, easy to transport, with a support for a photovoltaic generator with a different degree of inclination, compared to others. technologies and/or designs established in the market.

The methodology applied for the sizing of the portable solar machine establishes a procedure as a basis for future designs or sizing for the development of rural communities in the regions in the Non-Interconnected Zones in Colombia (ZNI).

The analysis of the VAN and the TIR, for the portable solar machine, is an attractive, profitable investment project for the family unit of the Non-Interconnected Zones (ZNI), and the Colombian state is required to invest and promote, To a great extent, the massive use of renewable energies at low cost or zero costs for each of the municipalities of the ZNI, or more investments are made with research to demonstrate innovative, sustainable and sustainable projects, for the development of rural communities and the development of the country.

The sizing of the portable solar machine will allow, with its application and implementation, timely attention to the needs of Electric Power and drinking water consumption in any territory of the Colombian national order and especially to those communities that have suffered an atmospheric catastrophe such as a tsunami, floods , hurricanes, cyclones, typhoons, tornadoes, avalanches, since it allows their displacement and installation in areas of difficult access, while humanitarian aid arrives, giving a relief of comfort and hope, while the services and quality of life of affected families.

Declaration of competing interest

The authors declare that they have no known financial or non-financial competing interests in any material discussed in this paper.

Funding information

No funding was received from any financial organization to conduct this research.

References

[1] M. Belén, O. Giupponi, and M. C. Paz, "The Implementation of the Human Right to Water in Argentina and Colombia La justiciabilidad del derecho humano al agua en Argentina y Colombia," Anuario Mexicano de Derecho Internacional, pp. 323–352, Sep. 2015, doi: https://doi.org/10.1016/j.amdi.2014.09.006.

[2] C. Forero, J. Ernesto, H. Zuluaga, and D. Andrés, "POTABILIZAR AGUA CON ENERGÍA SOLAR, UNA ALTERNATIVA PARA LAS COMUNIDADES MÁS ALEJADAS DE LOS CENTROS URBANOS," Trilogia Ciencia Tecnologia Sociedad , vol. 4, no. 6, pp. 121–132, May 2012, [Online]. Available: https://www.redalyc.org/articulo.oa?id=534366879005

[3] M. S. Faure, J. Ducci, M. Altamira, and A. Perroni, "Agua Potable, Saneamiento y los Objetivos de Desarrollo del Milenio en América," Jun. 2013. Accessed: Apr. 08, 2022. [Online]. Available: https://publications.iadb.org/publications/spanish/document/Agua-potable-saneamiento-y-los-Objetivos-de-Desarrollo-del-Milenio-en-Am%C3%A9rica-Latina-y-el-Caribe.pdf

[4] A. I. Schafer, G. Hughes, and B. S. Richards, "Renewable energy powered membrane technology: A leapfrog approach to rural water treatment in developing countries?," Renewable and Sustainable Energy Reviews, vol. 40, pp. 542–556, Dec. 2014, doi: https://doi.org/10.1016/j.rser.2014.07.164.

[5] R. A. López et al., "Solar PV generation in Colombia - A qualitative and quantitative approach to analyze the potential of solar energy market _ Elsevier Enhanced Reader," Renewable Energy , vol. 148, pp. 1266–1279, Apr. 2020, doi: https://doi.org/10.1016/j.renene.2019.10.066.

[6] B. L. Miravet-Sánchez et al., "Solar photovoltaic technology in isolated rural communities in Latin America and the Caribbean," Energy Reports, vol. 8, pp. 1238–1248, Nov. 2022, doi: 10.1016/j.egyr.2021.12.052.

[7] J. D. Ortiz, "Viabilidad técnico-económica de un sistema fotovoltaico de pequeña escala," Revista Visión Electronica, vol. 7, pp. 1–15, Jun. 2013, doi: https://doi.org/10.14483/22484728.3858.

[8] J. L. Lugo and E. R. Lugo, "Beneficios socio ambientales por potabilización del agua en los pueblos palafíticos de la ciénaga grande de Santa Marta-Colombia," Revista U.D.C.A Actualidad & Divulgación Científica, vol. 21, no. 1, Jun. 2018, doi: 10.31910/rudca.v21.n1.2018.685.

[9] S. Hoyos, C. J. Franco, and I. Dyner, "Integración de fuentes no convencionales de energía renovable al mercado eléctrico y su impacto sobre el precio," Ingeniería y Ciencia, vol. 13, no. 26, pp. 115–146, Nov. 2017, doi: 10.17230/ingciencia.13.26.5.

[10] N. A. G. Barrera, D. C. P. González, F. Mesa, and A. J. Aristizábal, "Procedure for the practical and economic integration of solar PV energy in the city of Bogotá," Energy Reports, vol. 7, pp. 163–180, Nov. 2021, doi: 10.1016/j.egyr.2021.08.091.

[11] F. Almeshqab and T. S. Ustun, “Lessons learned from rural electrification initiatives in developing countries: Insights for technical, social, financial and public policy aspects,” Renewable and Sustainable Energy Reviews, vol. 102, pp. 35–53, Mar. 2019.
[12] D. M. Rodríguez-Macías and A. M. Vélez-Quiroz, “Estudio de Factibilidad de un Sistema de Bombeo sin Cobertura Eléctrica en el Sector Hoja Blanca del Cantón Flavio Alfaro,” REVISTA CIENTIFICA-DOMINIO DE LAS CIENCIAS, vol. 7, pp. 527–540, 2021, doi: 10.23857/dc.v7i6.2347.
[13] R. K. Akikura, R. Saidur, H. W. Ping, and K. R. Ullaha, “Comparative study of stand-alone and hybrid solar energy systems suitable for off-grid rural electrification: A review,” Renewable and Sustainable Energy Reviews, vol. 27, pp. 738–752, Nov. 2013.
[14] D. O. Akinyele and R. K. Rayudu, “Strategy for developing energy systems for remote communities: Insights to best practices and sustainability,” Sustainable Energy Technologies and Assessments, vol. 16, pp. 106–127, Aug. 2016.
[15] Rossel Bernedo Luis Jhordan, Rossel Bernedo Luis Alberth, Ferro Mayhua Félix Pompeyo, Ferro Gonzales Ana Lucia, and Zapana Quispe Ronal Reynaldo, “Radiación ultravioleta-c para desinfección bacteriana (coliformes totales y termotolerantes) en el tratamiento de agua potable,” Revista de Investigaciones Altoandinas, vol. 22, pp. 68–77, Dec. 2020, doi: 10.18271/ria.2020.537.