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Design of a Photovoltaic System to Cover the Energy Demand of a Home in the Rocafuerte Canton, Manabí Province

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Keywords

distributed generation;
MPPT technology;
photovoltaic system;
interconnected grid;
solar irradiation;

Abstract

In the present work, a photovoltaic system connected to the network and integrated into a house in the Rocafuerte canton, province of Manabí, is designed. For its development, the computer tool for sizing photovoltaic systems PVsyst was used, with which the annual production of electrical energy for the 8.8 kWp system was determined, losses were also analyzed due to the main factors such as shading, wiring, power electronics, photovoltaic array, angle of inclination, temperature and by the irradiance of the sun. In addition, the main parameters of the installed system provided data for planning electricity consumption. The results showed that the electrical energy generated can cover 84% of the demand of the house, in infrequent conditions, but with a projection to cover the entire demand in the months of less consumption. Which constitutes an alternative for the generation and obtaining of energy, taking advantage of available spaces in the houses.

Contents

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1 Introduction

The systems interconnected to the network are becoming more and more accepted by the users of the distribution network, due to the fact that they acquire great benefits, with an affordable investment. The problem focuses on the high rates by the distributor and the migration to renewable energy sources through which the energy system passes, because of this, users seek other alternatives to get out of the conventional. The indiscriminate use of fossil fuels and the electrical energy produced by industrial processes are the main contributors to global warming, due to CO_2 emissions (Salazar-Peralta et al., 2016). Ecuador, due to its geographical location and the characteristics of receiving hours and intensity of the sun, is a territory considered one of the most suitable countries for the generation of photovoltaic solar energy (Sánchez, 2015). Over the years, solar infrastructures reduce their acquisition cost, due to this in Ecuador it is necessary to make readjustments to the legal framework that encourages the installation of small photovoltaic solar projects (Muñoz et al., 2018), whether for entrepreneurship or self-sufficiency.

Due to the great demand of new users implementing this technology, governments manage regulations, such is the case of Ecuador with its Distributed Generation Regulatory Framework for self-supply of regulated electricity consumers (2021). According to (Mejia et al., 2009), distributed generation focuses on using small power plants near consumption centers. The main objective of this work is to size a photovoltaic system interconnected to the network to reduce the tariff demand of each month in a home in the Rocafuerte canton. In addition, as a specific objective, it is intended to analyze the behavior of the same system, as well as its losses and the energy injected into the network. The results obtained will be projected based on the design proposed in PVsyst, having the same capacity of the software to carry out simulations with precise meteorological data and characteristics of the equipment, which intervene in the environment, with which the sustainability of the localities under the conditions is achieved. premises of sustainable local development. (Mieles-Mieles et al., 2021).

2 Materials and Methods

Case study

The population that I study focuses on a house, located in the province of Manabí, Rocafuerte canton, which is a single-story block and concrete, whose location is shown in figure 1, in the red box. The dimensions of the roof are 13.1x6.6 m, with a total area of 86.46 m^2.

Figure 1. Aerial view of the house
Source: (PVsyst7.1, 2022)

The roof surface is gabled with a slope angle of 10.38°. The house is located at the latitude of -0.92 to the south and the longitude of -80.45 to the west, with an altitude of 20 meters.

Grid connected photovoltaic systems

Unlike other photovoltaic systems such as independent ones, those connected to the network do not have batteries for energy accumulation, since they are designed to supply energy to the network. These systems constitute a distributed generation solution, with the basic purpose of saving the consumption of electricity generated with other more expensive and polluting sources of the environment. (Rodríguez, & Vázquez, 2018). Grid-connected Photovoltaic Generation systems have three main components; the energy generating element (solar panels), a DC to AC transformer (inverter) and a measurement device that can measure injected energy and consumed energy (bidirectional meter). In addition to these elements, there are also the DC and AC protection systems and the respective conductors (Tawalbeh et al., 2021; Mejia et al., 2014; Alsema & Nieuwlaar, 2000).

Software Pvsyst

The (Pvsyst,2022) computer tool in its version 7.2, is a software package for PC that deals with the study, analysis, and dimensioning of complete photovoltaic systems (Webgeneve, 2022). PvSyst has a complete set of tools, including preliminary design and project design and simulation, with three options: grid-connected, isolated and pumping systems Garcia, 2015). The preliminary design is a resizing of a project, where monthly values are quickly evaluated, using few characteristics or general parameters of the system. In project design and simulation, it is already for detailed system designs using detailed hourly simulations with all requested parameters and features. In addition, PVsyst has meteorological and component databases, having a wide variety of elements to work with. It also has the option to add elements in case you need data that the program does not have in its database (Hernández et al., 2012; Santosa & Yusuf, 2017; Veliz et al., 2021).

User needs

For the implementation of a PV system connected to the network, the respective load study was carried out, in this way it was possible to dimension the project.

Table 1
Load study

Housing Load Study						
Items	Appliances	Quantity	Pn(W)	CI (W)	Ffun (H)	CIR (Wh)
1	router	1	18	18	24	432
2	sewing machine	1	400	400	0,5	200
3	pc	1	120	120	14	1680
4	led balcony spotlight	1	40	40	2	80
5	TV	1	140	140	12	1680
6	griddle	1	1500	1500	0,0357	53,55
7	led spotlight rooms	2	8	16	9	144
8	room fluorecene spotlight	1	42	42	6	252
9	fourth fluorescence bulb	1	20	20	8	160
10	refrigerator	1	121,1	121,1	24	2906,4
11	washer	1	750	750	2	1500
12	radio	1	24	24	3	72
13	Freezer	1	125	125	24	3000
14	extractor	1	400	400	0,5	200
15	blender	1	600	600	1	600
16	freezer	1	110	110	24	2640
17	freezer	2	170	340	24	8160
18	freezer	1	165	165	24	3960
19	ice cream machine	1	2500	2500	5	12500
20	ps4	1	100	100	0,02	2
21	wii	1	45	45	0,03	1,35
22	washing machine engine	1	700	700	1	700
23	TV	1	130	130	7	910
24	room led spotlights 4	2	8	16	7	112
25	balcony spotlights 2	2	8	16	14	224
26	balcony spotlight 3	1	40	40	12	480
27	workshop spotlights	2	40	80	5	400
28	kitchen spotlight	2	8	16	8	128
29	chargers	2	7,5	15	5	75
30	bathroom spotlight	1	50	50	2	100
31	pc	1	120	120	7	840
	Total	38	8509,6	8759,1	275,0857	44192,3

Where:
Pn(W) → Rated power
CI(W) → Installed Load
Ffun(h) → Operating factor
CIR(Wh) → Referential Installed Load

Table 1 shows the hourly power used by the dwelling in one day, this being a daily average, since these values may change slightly from one day to the next. In one day, the house consumes around 44,192.3 Wh, which is equivalent to 44.19 kWh, being a value quite close to the average described by (CONOLEC, 2013) in its master plan for electrification 2013-2022 II, study and demand management, where it is indicated that the average consumption in homes at the national level is greater than 50kWh per day.

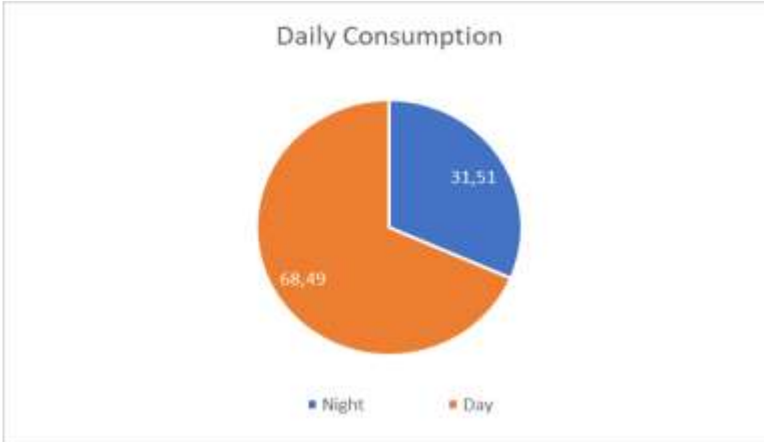

Figure 2. Percentage of daily consumption

In Figure 2, the highest percentage of consumption occurs during the daytime, with 68.49% of consumption, this value being almost three quarters of household consumption. This is beneficial for the grid-connected photovoltaic system, since the highest energy consumption is occurring during the time of solar radiation. At night, 31.51% is consumed.

Geographical Site
Rocafuerte
Ecuador

Situation

Latitude	-0.92 °S
Longitude	-80.45 °W
Altitude	20 m
Time zone	UTC-5

Monthly Meteo Values

Source Meteonorm 7.3, Sat=100%

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year	
Horizontal global	4.75	5.56	5.96	5.68	5.19	4.61	4.30	4.87	5.44	5.22	4.68	5.03	5.10	kWh/m²/day
Horizontal diffuse	2.41	2.76	2.66	2.50	2.32	2.62	2.52	2.86	2.79	2.75	2.53	2.56	2.61	kWh/m²/day
Extraterrestrial	10.17	10.48	10.53	10.16	9.58	9.20	9.31	9.82	10.31	10.43	10.22	10.02	10.01	kWh/m²/day
Clearness Index	0.467	0.530	0.566	0.559	0.542	0.501	0.462	0.496	0.528	0.500	0.458	0.502	0.510	ratio
Ambient Temper.	25.7	25.8	26.0	25.4	25.2	23.7	23.8	23.6	23.1	23.7	23.7	24.9	24.6	°C
Wind Velocity	3.0	2.3	2.3	2.5	3.1	3.6	3.8	3.9	4.0	4.1	4.0	3.8	3.4	m/s

Figure 3. Monthly mapping
Source: PVsyst 7.2.

Figure 3 shows the monthly mapping values, the data source is Meteonorm 7.3, the geographical data of the location of the PV design, its latitude, longitude and altitude, as well as significant parameters for the study and dimensioning of the PV design, are shown. systems, such as the global horizontal solar irradiation or the hours of sunshine in the months of the whole year, in the month of March the highest value of hours of sunshine is shown and in June the lowest, the annual average of this value is equivalent at 5.1 kWh/m^2/day, one of the best values for the use of solar energy through photovoltaic systems, it also shows the diffuse horizontal solar irradiation, extraterrestrial irradiation, the brightness index, the ambient temperature and the speed of the wind. The nominal power of the solar panels is measured in Watt peak (Wp) and is calculated with equation 1.

$$Power\ of\ Panels\ to\ Install\ = \frac{Total\ Daily\ Power}{Global\ Horizontal\ Solar\ Radiation} \quad (1)$$

Where:

$$Power\ of\ Panels\ to\ Install\ = \frac{44912.3}{5.1} = 8806.333Wp$$

Which is equivalent to 8.8 kWp, according to the Distributed Generation Regulatory Framework for self-supply of regulated electricity consumers (2021). Systems for regulated self-consumption meet the following characteristics: the dimensioned system must have a nominal power of less than 1MW; it has to connect synchronously to the networks of the distribution system; focuses on renewable energy resources and uses any technology for generating electrical energy with or without energy storage. The designed system meets these requirements and since the total power demand of the home is less than 1MW, day and night demand can be covered. The PVsyst program allows you to size a system connected to the grid by the area available for the project or by the nominal power of the photovoltaic system (García & Álvarez, 2014).

3 Results and Discussions

Figure 3 shows the block diagram of the simulated 8.8 kWp interconnected PV system. Mainly made up of 3 parts: the PV modules, the power electronics or conversion system, and the user's connections to the electrical grid.

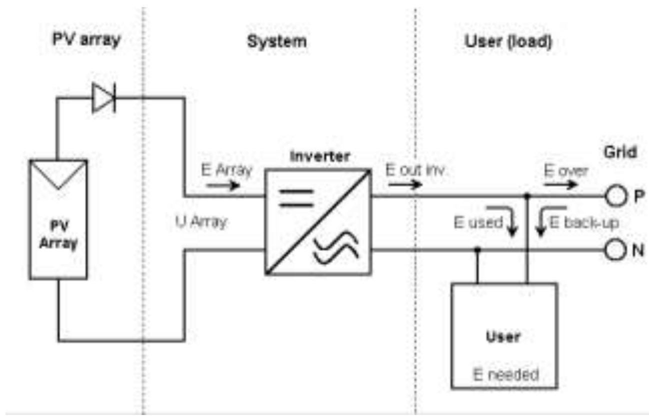

Figure 4. Simplified scheme

Table 2 details a summary of the sizing of the system, with a total of 20 Hanwha Q Cells 425 Wp Q Peak Duo L-G8-425 monocrystalline solar panels. These will be connected in two chains of 11 modules in series, a Fronius Primo inverter of 8.2kW between 80-800 V of three phases with 2 MPPT, an occupation area of 47m2, this being less than the area of the house.

Table 2
System summary

Number of modules	22
Module area	47 m^2
Number of investors	1
Rated photovoltaic power	9.4 kWp
Maximum photovoltaic power	9.0 kW CC
Rated AC Power	8.2 kW CA
Rated Power Ratio	1.140

The possibility of installing the photovoltaic modules on the roof of the house and the losses of 0.1% due to some trees located on the right were taken into account. The neighboring house and nearby wiring did not hinder the incident radiation on the solar panels (Ghadami et al., 2021; Parvez et al., 2016; Krauter & Rüther, 2004).

Figure 5 shows a graph of the solar path of the Canton Rocafuerte, which details the path that the sun takes throughout the year, the path is symmetrical with respect to the line of Ecuador since the canton is located at -0.922 ° latitude, which represents that the hours of sunlight are almost the same in the year, the losses due to shading are observed, which appear before 8 am, the evolution of the daily solar trajectories shows that the greatest losses occur between the months of February to October, but globally they are very small in the year.

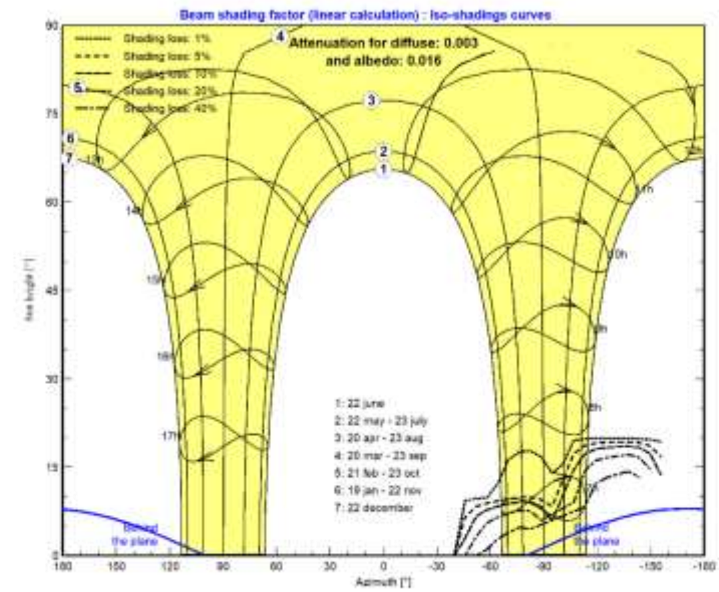

Figure 5. Solar path and shading factor

The incident energy per month is shown in figure 6, where it can be seen that the month with the highest solar incidence is March, in which the greatest generation of energy will be produced by the system, in the same way the months of April and September have high utilization of solar resource. On the other hand, the month with the least solar incidence is november, this being the lowest in energy production.

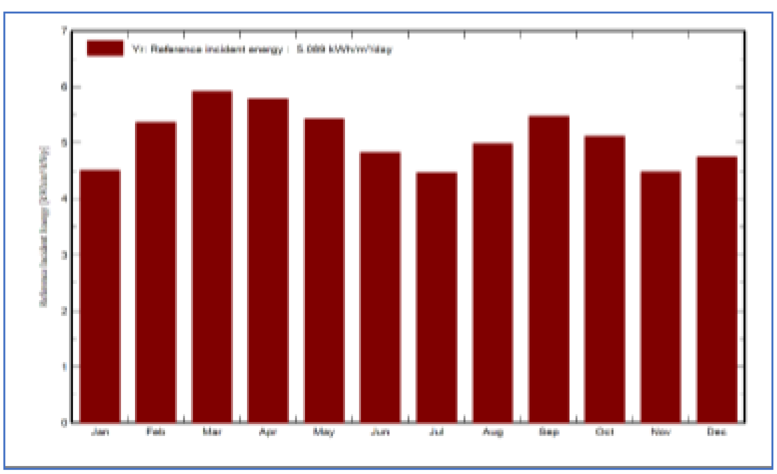

Figure 6. Incident energy per month

Figure 7 shows the normalized productions, note that the useful energy produced If found at the inverter output shows a daily annual average of 4.24 kWh/kWp/day, equivalent to 83.2%, note also that the months with the highest production of useful energy are March, april and September, and those with the lowest production are January, jJuly and november.

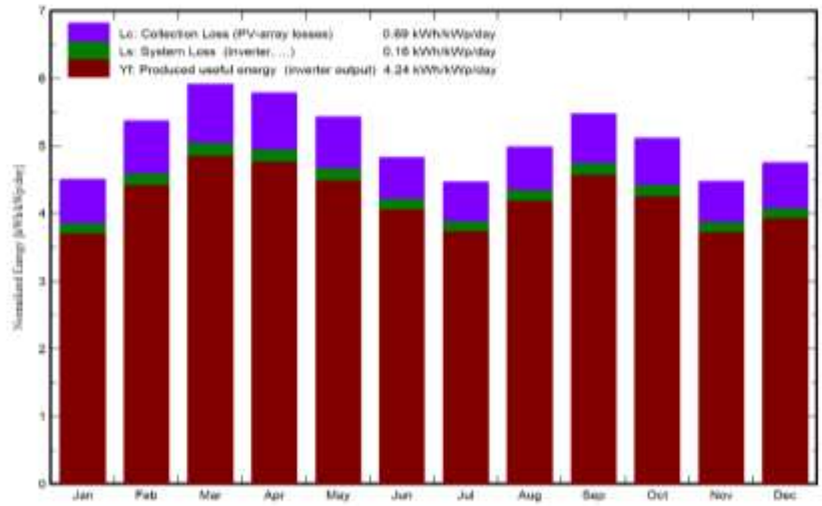

Figure 7. Normalized productions (per kWp installed): Nominal power 9.35 kWp

The losses of the PV set Lc, are 13.6%, about 0.69 kWh/kWp/day and the loss of the system Ls, which is the energy necessary for the operation of the inverter, is 3.2%, which would be equivalent to 0.16kWh /kWp/day. Figure 7 shows the performance ratio, which is the relationship between the useful energy generated by the system and the theoretically available energy, this being an annual average value of 0.832, and maintaining little variability during the months.

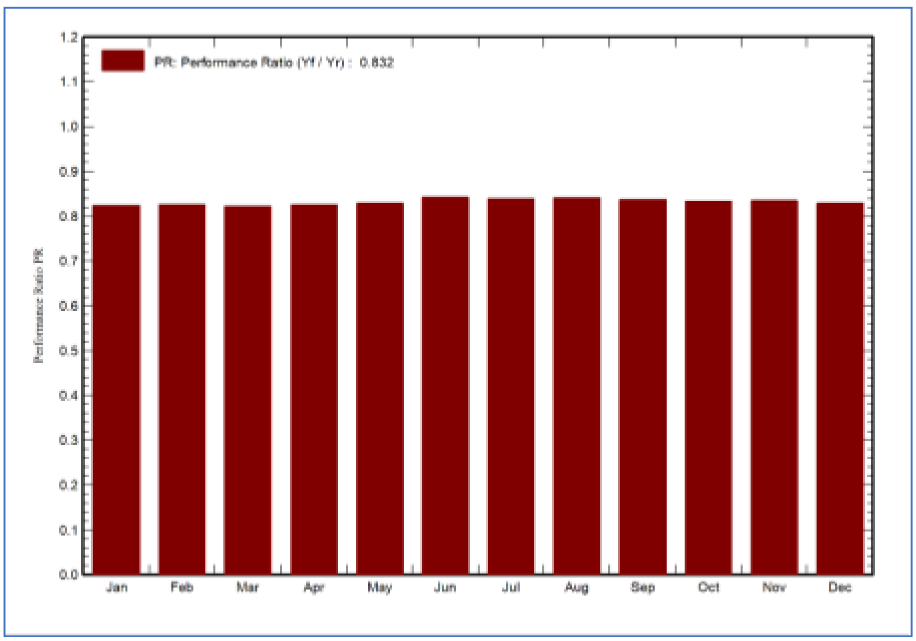

Figure 8. Performance Ratio

Table 3 shows the main values of the simulation results for one year. The month where the greatest use of solar irradiation occurs is in March, with a global horizontal irradiation of 5.96 kWh/m^2/day, obtaining in this month an energy injected into the network of 1,411 MWh, and the least significant value It is given in the month of November with just 1,049 MWh of energy injected into the network. Annually, the system injects 14,456 MWh into the network, with a global horizontal irradiation of 4.68 kWh/m²/day.

Table 3
Balance sheets and main results

	GlobHor kWh/m²/day	DiffHor kWh/m²/day	T_Amb °C	GlobInc kWh/m²/day	GlobEff kWh/m²/day	Earray kWh	E_Grid kWh	PR Performance
January	4.75	2.41	25.71	4.51	4.51	1120	1077	0.825
February	5.56	2.76	25.78	5.37	5.23	1206	1162	0.827
March	5.96	2.66	26.03	5.92	5.78	1464	1411	0.823
April	5.68	2.50	25.42	5.79	5.67	1391	1340	0.825
May	5.19	2.32	25.24	5.43	5.31	1356	1306	0.830
June	4.61	2.62	23.69	4.83	4.71	1185	1142	0.843
July	4.30	2.52	23.80	4.46	4.35	1129	1088	0.840
August	4.87	2.86	23.60	4.98	4.87	1262	1217	0.842
September	5.44	2.79	23.08	5.48	5.35	1334	1286	0.837
October	5.22	2.75	23.73	5.12	4.99	1285	1237	0.834
November	4.68	2.53	23.74	4.48	4.34	1090	1049	0.835
December	5.03	2.56	24.93	4.60	4.60	1186	1142	0.829
Year	5.10	2.61	24.56	60.97	59.71	15007	14456	0.832

Where:
GlobHor→Horizontal global irradiation
DiffHor→Horizontal diffuse irradiation
T_Amb→Ambient Temperature
GlobInc→Global incident receiving plane
GlobEff→Effective Global Irradiance, correction for tilt angle modification and shading
EArray→Effective energy at the output of the array
E_Grid→Energy injected into the grid PR→Performance Ratio

The results reflected in table 3 allow establishing monthly energetic plans, these favors when planning the consumption that is planned in the home during the month, trying to remain in these values for the maximum use of the system (Osorio Laurencio & Montero Laurencio, 2016). The system losses are shown in figure 9, very well detailed, starting from global horizontal irradiation, up to the energy injected into the network. In the first block the optical losses in the solar collection are shown, these are equivalent to 2.8%, the loss of the incident irradiation on the receptor plane is given by not having an angle of inclination defined by the latitude of the place, considering this loss of the 0.3%, the loss due to close shading detailed in Figure 6 is also shown, this being a value of 0.1%, and the losses due to the global tilt angle modification factor (IAM) of 2.4 %, this is due to the positioning of the home.

The conversion of solar irradiation to electrical energy has an efficiency in standard test conditions (STC) of 19.84%. The PV array generates a nominal energy of 16932 kWh, starting from this nominal energy, the second block of figure 9 is found, this is divided into the losses of the PV array 11.6% and the losses of the MPP array of the inverter 3, 7%, these are due to the operation of the inverter. The highest value of reduction in system performance is due to the PV array, with the main factor being temperature, with a loss percentage of 0.35% per degree Celsius. The operating losses of the PV array are relatively high, at 8.6%. A 0.8% gain was obtained for module quality (Chao, et al., 2008; Makrides et al., 2010; Li et al., 2016).

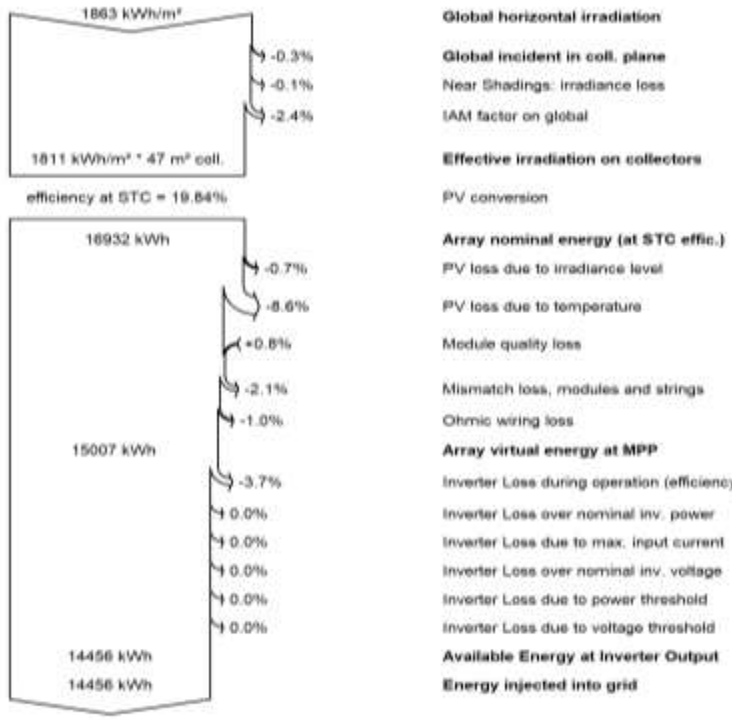

Figure 9. Loss diagram

In total, a loss of 18.1% is obtained, having as energy injected into the network a value of 14,456 kWh per year, which represents 83.2% of the energy consumed in the home annually.

Economic evaluation and carbon balance

System costs are divided into 2, installation cost and operation cost. The values of the equipment were obtained from the (Solaris-Shop, 2022), PV system store, an American industry, the other costs, such as studies, installation, insurance, bank charges in case of loans and taxes, are approximate values for Ecuador. The total value of the installation cost is USD 11,038.72, this being also the depreciable asset. The cost of operation are the annual operating values of the system, in which are grouped: maintenance, insurance and bank charges. Likewise, these values are approximations to the Equator. The cost of this section is USD 565.18 per year, taking into account annual inflation of 1.5%. The summary of the system can be seen in table 4, highlighting the main values, the cost of installation, operation, the energy produced by the system and the cost of the energy produced, which is equivalent to 0.073 USD/kWh, about approximate 7 pennies. dollar per kWh.

Table 4
System summary

System Overview	
Total, cost of installation	11038.72 USD
Operating cost (incl. inflation 1.50%/year)	565.18 USD/year
Produced Energy	14.5 MWh/year
Cost of Energy Produced (LCOE)	0.073 USD/kWh

The main aspects of the financial analysis begin in the simulation period, where the useful life of the technology is indicated, this being 25 years, taking into account a possible start of operation of the system in 2023. In the variation of income over time, inflation, the aging of the system and the discount rate, corresponds to 3.50% per year. One of the points to highlight in this section is amortization, which gives us a amortization period of 15 years. Another important point is the sale of electricity, the PVsyst program, we simulated the system to be able to sell the energy generated to the public network, but, in Ecuador, due to the fact that the system is for self-supply and due to the Regulatory Framework for Generation Distributed for self-supply of regulated consumers of electrical energy (ARCERNNR, 2021), users of these systems will not be able to sell energy to the network, the energy balance is made through the difference of the energy obtained from the network and the energy injected by the PV system is tell:

$$Total\ Energy = Energy\ taken\ from\ the\ grid - Energy\ injected\ into\ the\ grid \quad (2)$$

In the event that the $Total\ Energy \leq 0$, the distributor invoiced the user 0, and if on the contrary the $Total\ Energy > 0$, the distributor invoiced the difference. If the system injects more energy into the network than it consumes in a month, the absolute value of equation 2 will remain as a credit in favor of the user, which can be used in the months where the PV system does not cover all the household energy needs. This credit value can only be used within a range of 24 months, after which it resets to 0. Due to this, the value of kWh was established at 10 pennies of dollar, approximate price in the province of Manabí, thus ensuring that the return-on-investment data is reliable. The return on investment is shown in table 5, where a recovery period of approximately 14 years is shown, time when it is expected to pay the minimum value in the distributor's rate. The net present value is equivalent to the energy savings in the 25 years of operation of the system, being a value of 5556.74 USD.

Table 5
Return on investment

Return of investment	
Payback period	13.9 years
Net Present Value (NPV)	5556.74 USD
Return on investment (ROI)	50.3%
Dividends paid	1843.93 USD

Figure 10 shows the data obtained by the Carbon Balance tool included in PVsyst 7.2. In this section, it is possible to estimate the savings in CO_2 emissions expected for the photovoltaic installation. The basis of these calculations is the so-called Life Cycle Emissions (LCE), which represent the CO_2 emissions associated with a certain component or amount of energy (Webgeneve, 2022). The graph in Figure 12 shows the CO_2 emissions saved over a 30-year period of 109 tons of CO_2. These values are estimated from the International Energy Agency (IEA, 2013) data source for Ecuador.

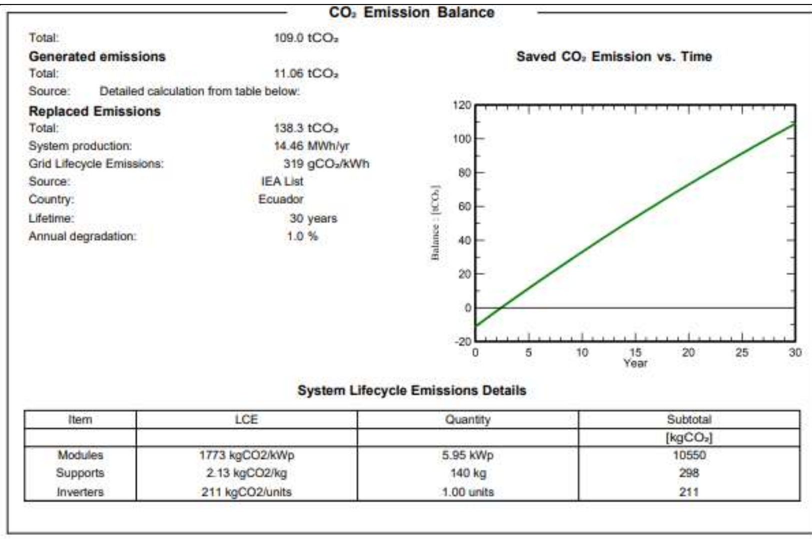

Figure 10. Balance of CO_2 emissions

4 Conclusion

The energy injected into the network can easily cover the total demand of the home, this is because it is not consumed in the same way every day, but the photovoltaic system does generate constant energy. The system covers a large part of the energy demand, generating savings in the monthly rate. The ease and friendliness of the PVsyst software made it possible to determine in detail the energy performance dimensioned for this study, carefully manipulating each process variable to obtain the most accurate values possible. However, it is necessary to consider the uncertainty of the project, since in the end it is a simulation, it is quite close to reality, but the atmospheric conditions can vary very easily.

The large PVsyst database allows not only to have a meteorological source, by having several options the effectiveness of the data can be confirmed, an example is the case of temperature, a very important value when determining the efficiency of the PV modules. As the temperature on the coast rises on summer days, where the system is supposed to have better efficiency, the opposite occurs due to the effect of loss of PV power due to temperature rise. Having the technical data sheets of the inverters and solar panels available for the installation ensures more reliable results. Taking advantage of this technology on the roofs of houses helps in considerable energy savings, obtaining visible results in the medium and long term.

Acknowledgments
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