Istraživanja i projektovanja za privredu
ISSN 1451-4117
DOI:10.5937/jaes0-40308
www.engineeringscience.rs

publishing

Journal of Applied Engineering Science
Vol. 21, No. 1, 2023
Original Scientific Paper
Paper number: 21(2023)1, 1071, 275-284

TECHNICAL AND ECONOMIC ANALYSIS OF A PHOTOVOLTAIC SOLAR SYSTEM IN NORTE DE SANTANDER, COLOMBIA

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Solar energy is the most abundant renewable resource on the surface of the earth; where through photovoltaic systems electricity is generated using solar cells that work from the incidence of light. The study's objective is to develop technical and economic analysis for installing a photovoltaic solar system in the municipality of El Zulia, Norte de Santander department, Colombia. For this purpose, different studies on this region's solar radiation are taken as a reference, recorded for nine years, and processed using statistical techniques that suggest photovoltaic energy exploitation. Likewise, the electricity consumption averages were obtained and related to the energy rates currently paid by users in this northern region of Santander. Based on this information, the VENSIM model was analyzed to understand the electric microgeneration process in the Colombian residential sector, and the calculations related to the selection of the inverter, the photovoltaic modules, the photovoltaic generator, and other technical specifications were carried out. Finally, the financial evaluation of the photovoltaic solar system was carried out for 25 years, considering the returns on investment from the tax benefits offered by Law 1715 of 2014 and the savings that microgeneration represents for users. Also, the project proved to have financial viability and a payback period of 4 years.

Keywords: solar energy, photovoltaic system, solar panels, financial viability

1 INTRODUCTION

The Sustainable Development Goals (SDGs) of the United Nations (UN) raise the situation of electricity consumption worldwide, aimed at reducing climate change, promoting economic equality, innovation, and sustainable consumption, but specifically, expanding access to energy in a safe, sustainable and modern way [1, 2]. These objectives establish development guidelines that are relevant in developing countries, as they have rural areas that are geographically isolated and lack energy supply, which has an impact on the persistence of social, economic, and environmental inequality gaps. [3].

However, due to the desire to close these inequality gaps by improving access to electricity for the development of communities [4], and due to the persistent dependence of energy production systems on fossil resources, a significant negative impact has been generated for the environment due to the emission of carbon dioxide into the atmosphere [5]. Currently, the production and use of systems based on renewable sources still do not exceed 20% of world consumption, while, on the other hand, the demand for energy increases as a direct effect of population growth and, therefore, due to industrial development and the production of goods and services [6].

Regarding Colombia, despite the provisions of Law 1715 of 2014 for the use of solar resources in the development of urbanization projects at the municipal level, even this type of renewable system is in the process of being implemented, which is expected to have applicability at the residential, industrial and commercial level. Thus, some studies foresee in the medium term a more efficient scenario of energy self-sufficiency in agricultural and industrial processes [7] to implement solar energy in a proportion of at least 0.6% of the national energy supply [8].

In this context, the implementation of photovoltaic energy systems is presented as a possible option to solve the present and future deficits of energy demand and, precisely, in the municipality of El Zulia, as in other primarily rural regions of Norte de Santander, the quality of life of the communities is limited by the lack of electricity for production processes and domestic consumption in general. The Sustainable Rural Energization Plan of Norte de Santander (SREP-NS) determined the potential of photovoltaic solar energy that the region has and that can be used to electrify urban and rural areas not interconnected so that 100% coverage achieved and to improve the living conditions of the inhabitants. The department of Norte de Santander is located in the northeastern region of Colombia, having a significant solar energy potential where all municipalities have average solar insolation of 3.9 kWh m2 per day, which is higher than the world level. At the same time, 77.5% of the municipalities also have average solar insolation of 4.5 kWh m2 day, which is higher than the national level [8]. This solar potential is not being used adequately by the different areas of the department, within which the municipality of El Zulia is counted (solar potential of 5.3 kWh m2 day), because of the ignorance of this type of technology, as well as the lack of studies that demonstrate the technical and financial viability for its correct implementation.

Some authors have developed studies related to this topic, as is the case of Abul et al. [9], who analyzed the technical and economic viability of solar photovoltaic and thermal systems using exergy analysis. These results revealed that the photovoltaic system is more economically viable than the thermal system without batteries. On the other hand, Cucchiella et al. [10] propose an economic analysis considering different indicators well-known in this subject to generate economic opportunities for different industries. The results show that this system is an alternative to reduce environmental emission with a reduction of 50% from economic sources.

Considering the above, the objective of this work is to carry out a technical and economic evaluation of a photovoltaic solar system in El Zulia, Norte de Santander, Colombia, considering that Colombia was not found an investigation related to this important topic. Therefore, the description of the Municipality of El Zulia is presented as the first measure with data collection through secondary sources to describe the radiation and solar incidence, the current energy demand, and the interconnected national system. On the other hand, the VENSIM model was applied for the general photovoltaic system to identify the system connected to the grid and other calculations for the selection of panels and inverters. Finally, the third part presents the financial simulation and the feasibility analysis regarding the given technical and economic conditions, considering a projection of 25 years of project operation.

2 MATERIALS AND METHODS

2.1 Description of the Municipality of El Zulia, Norte de Santander - Colombia

The municipality of El Zulia belongs to the department of Norte de Santander, which is located in the northeastern region of Colombia, where there are borders with Venezuela to the north and east, while to the south, it connects with the departments of Boyacá and Santander and to the west with Santander and Cesar (See Figure 1) [1]. The Zulia is located 12 km away from the city of Cucuta, the capital of the department, and is characterized by a mainly mountainous relief. The main productive activities are agricultural in regions such as coffee, rice, cocoa, corn, cassava, sugar cane, fishing, and pig farming. Other industrial activities are derived from clay, coal, and sand and in the commerce, services, and transport sectors. The population is estimated at 21,519 inhabitants, of which 57% are in the municipal seat and 43% in rural areas, but in general, 61% of households have between 1 and 4 members, 48% of which are women's and 52%, men's [10].

On the other hand, the municipalities of Norte de Santander have average solar insolation higher than the national level [8]. However, more specifically, recent studies show that the municipality of El Zulia, along with the city of Cucuta (located 12 km from El Zulia), has a significant potential for solar radiation and average insolation of 5,335 kWh m^2 day [11].

Fig. 1. Location of the municipality of El Zulia. Source: Obtained from [12].

According to the results obtained by Contreras [11], the global solar radiation of the city and its surroundings is favorable for photovoltaic energy exploitation. Table 1 shows the calculated insolation and the average monthly solar brightness considering the information collected by the Risaralda station in El Zulia [13].

Table 1. Number of peak solar hours for each month of the year.

Month	(Solar) brightness	Insolation W /m^2/day
January	5.0	3.978,799
February	4.8	4.166,195
March	4.7	4.345,652
April	4.1	4.207,130
May	54	4.491,111

Month	(Solar) brightness	Insolation W /m^2/day
June	5.4	4.394,708
July	6.5	4.738,110
August	6.4	4.822,066
September	6.2	4.784,493
October	5.3	4.352,594
November	4.8	3.962,927
December	4.4	3.720,178

Source: Obtained from [13].

These results indicate that the months with the highest number of peak solar hours are August, followed by September and July, while the least amount is November, December, and January. In this area, variations occur in the midday hours with greater intensity in global solar radiation since it can go from 1000 W m^2 in optimal conditions to values below 200 W m^2 due to elements in the atmosphere. Despite this, during the day, the average radiation is 715,168 W m^2. Based on these figures, the development of studies for the design, dimensioning, and implementation of photovoltaic systems, both autonomous and those connected to the grid, has been recommended [11]. On the other hand, the current use of energy in the municipality of El Zulia, which is part of the interconnected national system, was identified, a service provided by the company Centrales Eléctricas de Norte de Santander CENS, through the monthly consumption table (See Table 2).

Table 2. Monthly energy consumption in the municipality of El Zulia from January to December 2018

Date	Number of Clients	Consumption (Kw / month)
01/01/2018	7,884	2,074,766
01/02/2018	7,857	2,102,603
01/03/2018	7,866	2,164,058
01/04/2018	7,876	2,200,246
01/05/2018	8,013	2,320,047
01/06/2018	8,025	2,282,421
01/07/2018	8,040	2,331,810
01/08/2018	8,195	2,253,987
01/09/2018	8,207	2,415,364
01/10/2018	8,228	2,396,656
01/11/2018	8,242	2,355,011
01/12/2018	8,259	2,378,175

Source: CENS [14].

2.2 Model of the dynamics of the general photovoltaic system in the residential sector

To obtain an overview of the photovoltaic system, the electricity market dynamics were analyzed with the economic components that define prices and demand. Figure 2 describes the feedback situations, taking into account that the electricity price of the conventional grid directly depends on the reserve capacity and margin of the system, which helps to define supply and demand in opposite directions. This margin represents the relationship between demand and installed electricity supply capacity, so its dynamics are inverse. That is, when demand decreases, the price of electricity tends to increase. Thus, when the price increases, the demand falls, generating an increase in the system's margin. The interesting thing is that this dynamic causes the increase in the price of electricity to send signals to stimulate investment in photovoltaic electricity generation, causing the installed capacity to increase in the long term and with this, the reserve margin of the system, which ends up defining what happens when households are more willing to adopt unconventional systems.

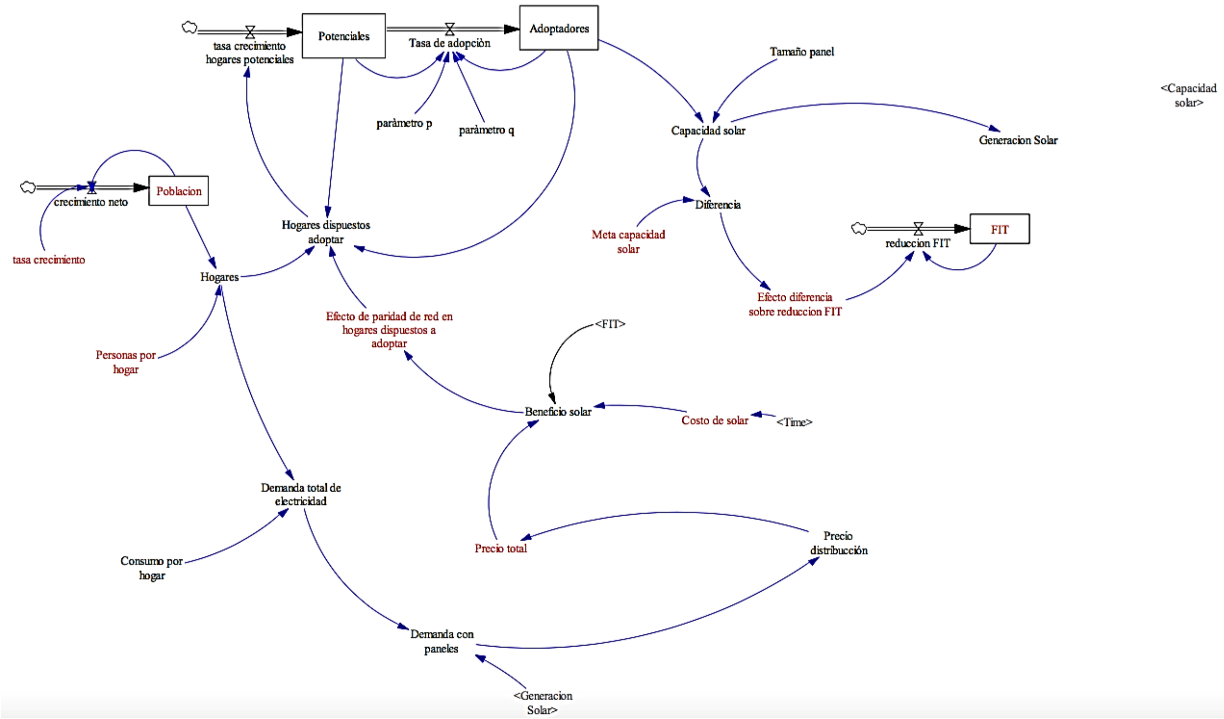
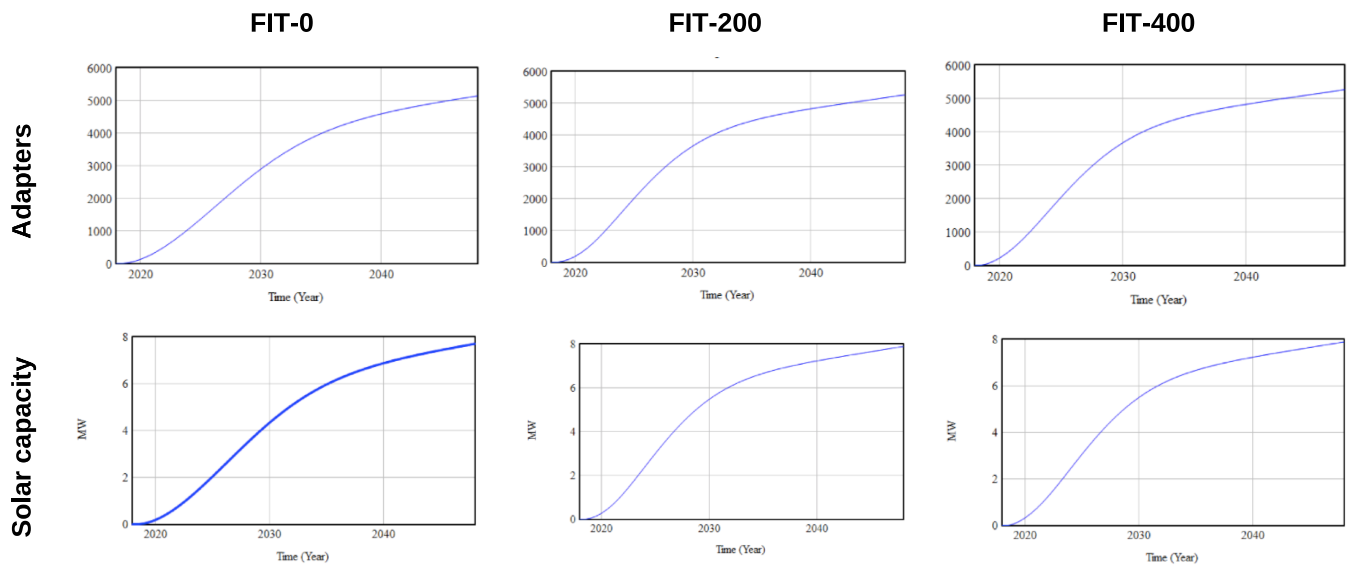


Fig. 2. Dynamic hypothesis of the electric microgeneration process in the Colombian residential sector. Source: Own elaboration

2.3 Technical considerations.

Based on the dynamics of Figure 2 on the electricity market in photovoltaic systems, the model that explains what happens when households become micro-generators of energy, based on situations such as the growth of households, adopters, the solar capacity, solar generation, and reduction of Feed-In Tariff (FIT). An effect is generated in the price of electricity from the alteration of two demand variables. On the one hand, there is the variable related to the demand for the network (growth rate of potential households) and the variable of the use of renewable technologies by residential consumers. Therefore, it is observed that the increase in population growth directly impacts the number of households and those willing to adopt unconventional systems.

The intrinsic increase in household electricity demand stimulates photovoltaic solar generation with an effect on the purchase of panels, reducing distribution costs and, consequently, the total investment price. In addition to the above, it must be taken into account that the time factor in any investment expects to receive benefits, which materialize through the FIT and other tax inventories that can be used for renewable energy sources, generating that in the long term a network parity effect is achieved in households willing to adopt. In this way, the population growth rate directly affects the adopters (it defines the adoption rate), who, depending on the solar capacity and the technical specifications of the panels, define the photovoltaic generation capacity based on the goals established by regulators and the different effect of the reduction of the FIT. The result is a benefit perceived by microgeneration that stimulates the decrease in prices, but later this same decrease in rates discourages the perceived benefit of microgeneration, causing the number of microgeneration homes to be reduced until a balance is reached between the variables.



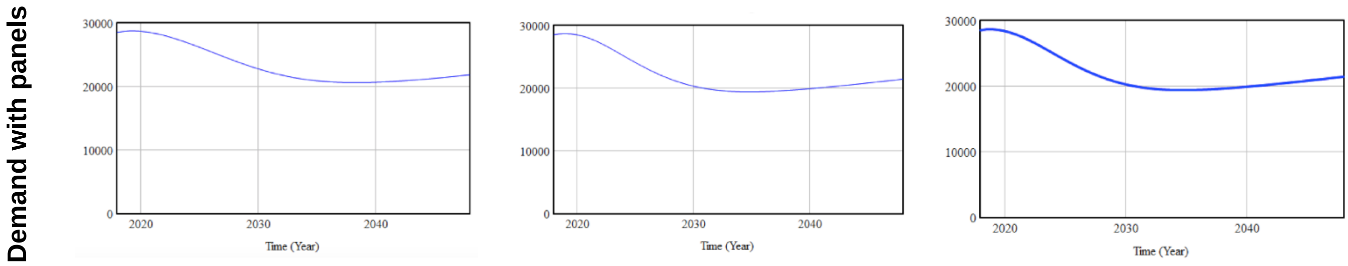


Fig. 3. Simulations in VENSIM for the FIT 0, 200 and 400 scenarios in the dynamics of the electric microgeneration process in the residential sector. Source: Own Elaboration

2.3.1 Adapters

Figure 3 highlights the notable variation of the adapters at the beginning of the project period in the three simulations carried out for FIT of 0, 200, and 400, but as the time variable advances, the difference tends to disappear, mainly between the FIT 200 and 400. In this sense, for the year 2020, different behavior is observed in the data of each calculation (FIT 0: 123.9 adapters; FIT 200: 181.6 adapters; FIT 400: 218.0 adapters), for the year 2030, there are already fewer differences between FIT 200 and 400 (FIT 0: 2,891.8 adapters; FIT 200: 3,652.7 adapters; FIT 400: 3,669.8 adapters), but at the end of the project period for the year 2043 the figures tend to be more homogeneous (FIT 0: 4,823.7 adapters; FIT 200: 4,993.0 adapters; FIT 400: 4,993.4 adapters), due to the reduction in the potential demand of households willing to use the power generation system.

2.3.2 Solar capacity

In Figure 3, it is possible to relate a behavior of the solar capacity similar to that presented with the adopters, observing differences at the beginning of the project period in the three simulations with a FIT of 0, 200, and 400, but with time the difference is noticeably reduced between FIT 200 and 400. Therefore, for 2020 there are differences in the data for each FIT (FIT 0: 0.185 MW; FIT 200: 0.272 MW; FIT 400: 0.327 MW), but in 2030 the differences are smaller between FIT 200 and 400 (FIT 0: 4.33 MW; FIT 200: 5.47 MW; FIT 400: 5.50 MW), but for the year 2043, the three data are similar to each other (FIT 0: 7.23 MW; FIT 200: 7.48 MW; FIT 400: 7.49 MW), whose situation responds to a reduction in the demand of the potential consumption of energy generated by the photovoltaic solar system.

2.3.3 Demand with panels

The dynamics of the demand for panels differs somewhat from the two previous factors, taking into account that at the beginning of the project, the FIT 0 does not differ much from the FIT 200 and 400 but later, the demand in the FIT 0 is slightly higher than the other two, although at the end of the project the gaps are again reduced. In Figure 3, these calculations are observed, where clearly, for the year 2020, there are no important differences in the data of each scenario (FIT 0: 28,711 panels; FIT 200: 28,524 panels; FIT 400: 28,406 panels), but already for the year In 2030 the differences are more marked between FIT 0 with 200 and 400 (FIT 0: 22,797 panels; FIT 200: 20,332 panels; FIT 400: 20,276 panels), however, in 2043 the three data returned to normalize among themselves (FIT 0: 20,992 panels; FIT 200: 20,443 panels; FIT 400: 20,442 panels), being a situation related to the same reduction in the potential demand for adapters.

In other words, the grid parity effect presents negative feedback between the variables of micro-generator homes and the homes that could potentially install solar photovoltaic systems, and that tends to increase as the general population increases. This situation describes a particular behavior in which the increase in potential micro-generator homes generates an increase in micro-generator homes that effectively install photovoltaic solar systems, which causes a decrease in the group of potential homes. From the above, it is understood that the growth rate of the potentials stimulates the perceived benefit, and more and more homes will be installed installing photovoltaic solar systems because of the benefit of micro-generating. Simultaneously, the pressure on the increase of the technological learning curves is observed, taking into account the economic stimulus by the energy generated with solar panels. This dynamic means that the increase in the number of microgenerator homes encourages the installation of photovoltaic panels and the reduction of material and equipment costs, which also makes the perceived benefit of microgeneration greater.

3 RESULTS AND DISCUSSIONS

3.1 Calculation of the Photovoltaic System

To carry out the technical and economic evaluation of a photovoltaic solar system in the municipality of El Zulia, a system connected to the grid is taken into account, which is the product of the development of technologies for the use of renewable energy sources in the country. Since 2009, the CREG Energy Regulation Commission determined the importance of the future use of smart grids and distributed generation, which included using solar energy to supply demand for the year [15]. Other more specific recommendations included the sale of surplus self-generators, dual metering, and differential rates, as well as the development of pilot plans in housing complexes and residential areas. [16]. Subsequently, Law 697 of 2001 was established to encourage the rational use of energy and promote alternative energy use. By 2014, the outlook for this type of self-generating system connected to the grid was already clearer, since Law 1715 of 2014 was enacted, which established the regulation to integrate non-conventional renewable energies with the Sistema Energético Nacional (SIN) [17].

3.1.1 Equations for panels and inverters

Photovoltaic solar energy generation systems require defining the load of the system and its structural elements [15]. To dimension the photovoltaic system, the energy demand method is used to establish the parameters of the technical dimensioning and the project's cost. For this reason, table 2 shows the average monthly demand for the previous year, where a load of 2,272,930.91667 kWh-month is observed and which is taken as a reference to calculate the required power of the photovoltaic modules that a home must have. in the municipality of El Zulia.

$$\mathrm{PGFV} = \frac{\mathrm{Ei}}{\mathrm{HSS}} \times \mathrm{N} \times \mathrm{PR} = 18\ \mathrm{MWh} \qquad (1)$$

Where: PGFV, It is the power that must be obtained from the photovoltaic generator (This value allows calculating the power that the photovoltaic modules should produce in total to supply the average monthly consumption of the historical record), Ei is the energy consumed monthly (kWh-month) 2'272,930.91667, HSS is the standard hours of sunshine in the area (for this case 6), N is the number of days in which the energy E is consumed (30 days), and PR is the performance factor of the system (0.7).

3.1.2 Inverter

According to Eq. 1, the power that the photovoltaic generator must deliver is 18,039 MW, corresponding to the power that must be obtained at the inverter output. From this data, the availability of the inverter in the market is reviewed, the most convenient one is selected, and the parameters to obtain the power are identified (input power and maximum MPP point). According to the average demand, the sizing of the system is estimated with an Inverter SE4K 4,000 VA SolarEdge Three-phase Grid Connection that requires a maximum input power of 6.2 kW and the maximum MPP power point is 250 to 480 V (see Table 3).

Table 3. Electrical parameters Inverter SE4K 4000VA SolarEdge Three-phase grid connection

<table>
<tr><th>Output</th><th>Unit</th><th>SE-4K</th><th>SE-5K</th><th>SE-7K</th><th>SE-8K</th><th>SE-9K</th><th>SE-10K</th><th>SE-12.5K</th></tr>
<tr><td>Rated AC power</td><td>VA</td><td rowspan="2">4,000</td><td rowspan="2">5,000</td><td rowspan="2">7,000</td><td rowspan="2">8,000</td><td rowspan="2">9,000</td><td rowspan="2">10,000</td><td rowspan="2">12,500</td></tr>
<tr><td>Max AC power</td><td>VA</td></tr>
<tr><td>AC output line connections</td><td>-</td><td colspan="7">3 phase, 4 wire / PE (L1-L2-L3-N), TN and TT</td></tr>
<tr><td>AC output voltage</td><td>Vas</td><td colspan="7">380/220 – 400/230</td></tr>
<tr><td>AC output voltage range</td><td>Vas</td><td colspan="7">184-264.5</td></tr>
<tr><td>AC frequency</td><td>Hz</td><td colspan="7">50/60 ± 5</td></tr>
<tr><td>Max. Continuous output current</td><td>A</td><td rowspan="2">6.5</td><td rowspan="2">8.0</td><td rowspan="2">11.5</td><td rowspan="2">13.0</td><td rowspan="2">14.5</td><td rowspan="2">16.0</td><td rowspan="2">20.0</td></tr>
<tr><td>Max. Continuous overcurrent protection</td><td>A</td></tr>
<tr><td>Residual current detector</td><td>mA</td><td colspan="7">300/30</td></tr>
<tr><td>Grid supported (3 phase)</td><td>-</td><td colspan="7">3/N/PE (WYE with neutral)</td></tr>
<tr><td>Inrush current AC</td><td>Aac (rms)/(ms)</td><td colspan="7">3/20</td></tr>
<tr><td>Max. Output fault current</td><td>A</td><td colspan="7">33</td></tr>
<tr><td>Power factor range</td><td>-</td><td colspan="7">1 (Adjustable from ± 0.9</td></tr>
</table>

Source: Solar Edge [18].

3.1.3 Photovoltaic modules

When defining the power of the inverter input, the power required at the output of the photovoltaic modules is established; this value indicates the number of panels that must be installed to obtain the calculated 18 MW. Thus, a FE 180M photovoltaic module is selected for the project, which offers a power of 370 W, a maximum voltage of 40.1 V, and the device's maximum current of 9.23 A (see Table 4).

Table 4. Mono crystalline solar panel technical information

ESPSC type	Unit	Details					
Power class	W	300	330	340	350	360	370
Max. Power voltage (Vmpp)* at STC **	V	37	37.95	38.5	39.1	39.6	40.1
Max. Power current (Impp) at STC	A	8.1	8.7	8.84	8.96	9.1	9.23
Open circuit voltage (Voc) at STC	V	44.8	45.75	46.4	47.1	47.7	48.3
Short circuit current (Isc) at STC	A	8.7	9.3	9.45	9.6	9.8	9.95
Efficiency module	%	15.4	17.0	17.5	18.0	18.5	19.0

Source: Solar Technology [19]. Note that: * MPP, is the maximum power point, ** STC (standard test conditions) at 1000 W / m^2, 25 ºC and AM equal to 1.5, and *** normal operating cell temperature.

3.1.4 Photovoltaic generator

In general, the photovoltaic system must have 56,373 370 W panels to obtain a power of 18 MW. According to the number of 56,373 panels calculated, the configuration is carried out in series to add the voltage or in parallel in the case of adding current to obtain an output voltage (Vmp) according to the range of the maximum MPP power point of the inverter. Furthermore, as it is a system connected to the grid, a general panel with a PCC coupling point is used to connect with the photovoltaic system and install the current protections and the respective energy meters.

3.2 Simulation of the Financial and Environmental Assessment

3.2.1 Financial projections

An evaluation of the project's profitability was carried out to install and start a photovoltaic solar system in the municipality of El Zulia. The main evaluation criteria, such as the investment value, the system's monthly production, the estimated value of the electricity service bill, and the annual savings [20], are presented in Table 5. The initial investment requires a 10% addition for year 10 for battery replacement and system maintenance.

Table 5. Scenario for the evaluation of the photovoltaic solar system

Concept	Value in COP
Investment costs Colombian pesos	$24’390,000.000
Monthly production of the solar system kWh	$243,000
Total power to install in Kw	$18,000
Price of kWh paid in energy bill	$523
Annual savings with a solar system	$1’525,068.000
A historical annual increase in energy price	10%
Inflation value	Not Applicable
Capital Cost Rate (WACC)	4.3%

Source: Own Elaboration

The annual savings of the project were calculated, based on $ 1,525,068,000 as a product of self-generation of energy and a historical annual increase of 10% is applied for 25 years. The tax benefit offered by Law 1715 of 2014 was considered with a 40% tax that can be deducted by whoever invests for a maximum term of 5 years, corresponding to $ 1,951,200,000 annually (see Figure 4). When deducting from the total investment the benefits for annual savings in the payment of the service plus the tax benefits, profits of COP 132,912,953,236 are obtained, which brought to net present value with a discount rate of 4.3% represents COP 81,469,778,052 to current prices. Figure 4 shows that the accumulated cash flow has a behavior with greater growth than the base cash flow. Thus, it is shown that the project is financially viable. This result indicates that the investment recovery period is four years.

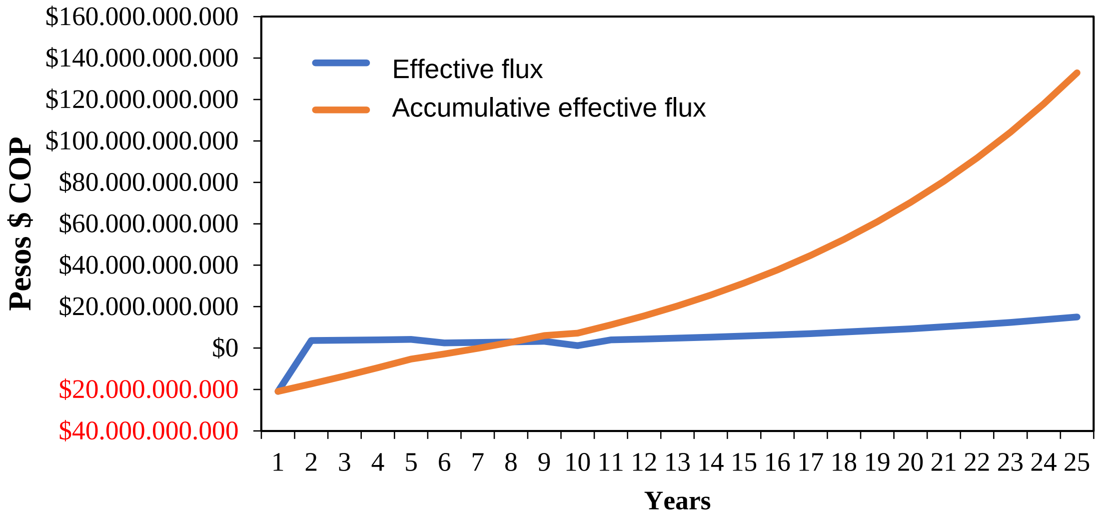


Fig. 4. Financial projection of the photovoltaic solar system. Source: Own Elaboration

3.2.2 Projections in reducing CO_2 emissions

The electrical energy consumption (kWh) recorded in the municipality of El Zulia was taken every month for one year, from January to December 2018 (Table 2), from which the carbon footprint was calculated using equation 2, taken from [21]:

$$HC = \text{Consumption} \times \text{Emission factor} \quad (2)$$

Where: the consumption is the kWh of each period, and the emission factor is 0.367 kg CO_2 eq / kWh for Colombian electricity generation [22]. From the calculations carried out and Figure 5, it was estimated that the carbon footprint reduction of the photovoltaic solar system in replacement of conventional electric energy is 10,009,978 kg CO_2 eq / kWh each year, that is, 250,249 Ton CO_2 eq / kWh for the 25 years of the project. The curve of emissions avoided each month is presented in figure 5, considering the monthly variability of energy consumption (kWh per month), which is repeated for each year of operation of the proposed system.

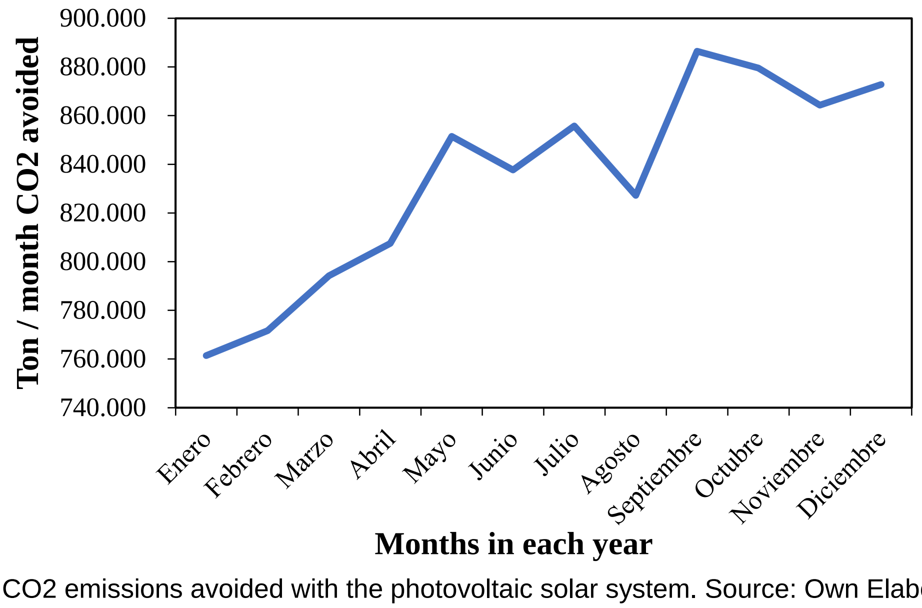


Fig. 5. CO2 emissions avoided with the photovoltaic solar system. Source: Own Elaboration

On the other hand, there was evidence of the increase in the demand for electricity that characterizes the world today, which requires studies to determine the technical and financial viability of installing systems based on renewable energy sources for residential uses. In this sense, the case of the municipality of El Zulia is taken, located in the Department of Norte de Santander, whose population is located both in the urban and rural areas of the territory and that requires improving access to energy networks safe and sustainable [1]. However, among the current shortcomings of the municipality, the population persists in the use of energy sources based on firewood and coal, considering that the value of kWh is high for the lower strata of levels 1 and 2, as well as the lack of projects that offer viable and profitable energy alternatives, mainly at the rural level where the main production facilities of the municipality are located.

4 CONCLUSIONS

The solar potential that characterizes the municipality of El Zulia is higher than the world average and the national average, making it a location with optimal conditions for installing the photovoltaic solar energy system that meets the needs of the population and mainly household consumption and small agricultural production units that characterize the region. Furthermore, the high rates of solar radiation received in the municipality of El Zulia allowed the dimensioning of an efficient and low-cost photovoltaic solar system that takes advantage of the number of peak hours and responds to the average demand of households.

The technical characteristics of the photovoltaic system were under the high solar potential available and allowed to maintain a relatively low level of investment costs, which was crucial for determining that the project has financial viability with a projection of 25 of operation. The investment recovery is in approximately four years, thus finding an energy reduction of 50% as has been reported by other authors in this area of research. It is estimated that the relationship between annual savings and the value paid by homes for electricity service will stimulate the perceived benefit, and they will be willing to install photovoltaic solar systems for microgeneration, making the project manager discount the cost of the initial investment through the cash flow accumulated during the 25 years of operation of the system.

A long-term limitation for implementing the research project is the constant increase in materials due to the rise in the dollar and the changing energy market that, in the case of Colombia, the materials must be exported from abroad.

At an environmental level, the development of the project in the municipality of El Zulia in Colombia offers a positive impact represented by 10,009,978 kg CO_2 eq / kWh that is avoided each year, which adds up to 250,249 Ton CO_2 eq / kWh for the 25 years of operation of the residential photovoltaic solar power generation project.

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Paper submitted: 30.09.2022.

Paper accepted: 23.10.2022.