Original Research Article

Technical, economic and environmental feasibility for the construction of an interactive solar classroom in Lérida, Tolima; Colombia

ABSTRACT

Currently, the growth in energy demand in all sectors and the excessive use of fossil fuels has generated negative environmental impacts on the environment. Countries in Latin America are committed to increasing their school coverage, with projects that use renewable energy. In the municipality of Lerida, Tolima, Colombia; there is a need to expand school infrastructure in order to provide access to technology and reduce school dropout with the construction of solar classrooms.

Aims: This research aims to evaluate the technical, economic and environmental feasibility for the construction of a classroom with photovoltaic energy system and technology equipment in the municipality of Lérida, Tolima, Colombia.

Study Design: Case study, with quantitative, descriptive and prospective approach

Place and duration of the study: The case study was conducted in the municipality of Lérida, Department of Tolima, 73 kilometers from Ibagué in Colombia; between 2022 and 2023.

Methodology: The methodology consisted in determining the size of a photovoltaic system based on the consumption of the selected equipment, the design and construction of the solar classroom with recyclable materials. Subsequently, the project was financially evaluated based on the social benefits that the project would provide. Finally, the environmental impact was evaluated to determine if the construction of the classroom is technically, financially and environmentally viable.

Results: First, the costs and material for the civil works of the classroom were evaluated and it was determined that it was built with Lego-type plastic wood. Subsequently, the energy demand was determined with the technological equipment, identifying a demand of 2587 kW/hour, at 110V and with 8 hours of daily operation. With these data, the design of the photovoltaic system was carried out to cover the estimated demand, adjusted to the theoretical consumption of the equipment to be installed. With the energy demand, the selection of the number of panels was made, which resulted in 10 panels of 330 W with 5 effective hours of sun, a 3000 W inverter, a 4000 W regulator and 4 batteries of 100 Ah to maintain the energy autonomy of the classroom for 1 day. The photovoltaic system is projected with a useful life of 20 years, with the exception of the batteries, which is only 7 years. The next step was to carry out the cost-benefit analysis that determined the economic viability of the project, with a rate of return on investment of 3.6 years. Likewise, the benefits that the classroom would bring to the community and that are related to the objectives of developing quality education, with affordable energy and modern infrastructure were determined. The economic and social impacts were analyzed, which were positively high by making available technology available to the young people of Lérida that allows reducing the technological gap that generates inequalities and finally the environmental impact was evaluated, which turned out to be of low impact.

Conclusion: Based on the results, it is concluded that the construction of a solar classroom in Lérida, Tolima in Colombia is technically, economically and environmentally feasible.

Keywords: Solar energy, infrastructure for education, innovation, sustainability, economic, financial and environmental feasibility, energy demand.

1. INTRODUCTION

Currently there is a growth in energy demand in all sectors, the excessive use of fossil fuels has generated negative environmental impacts on the environment, however, countries in Latin America are committed to increasing their school coverage, so they require projects with the use of renewable energies.

In Colombia, there is a high potential for renewable energies, so the development of infrastructure projects that contemplate sustainability in the use of renewable resources is very important. "Approximately 78% of the energy consumed today in Colombia comes from fossil sources, while the remaining 22% comes from renewable sources" [1]. The use of renewable energies constitutes a niche opportunity for the economic development of the country.

On the other hand, the municipality of Lérida, Tolima requires the expansion of its educational infrastructure, especially in rural areas, so feasibility studies of renewable sources in educational infrastructure, would increase the capacity of schools in areas where there is no electricity service, solar classrooms being independent of the electricity grid decreases the environmental impacts generated by the transport of energy. It is imperative to grow the educational infrastructure in the municipality as long as this growth is sustainable with renewable energy sources and in compliance with the millennium goals.

The municipality of Lérida, Tolima, has high solar potential for the supply of solar classrooms, also within the development programs of the mayor's office is contemplated budget for the construction of an intelligent classroom. From the business point of view, renewable energy installation projects are carried out in different remote areas of the country, through financing either government or non-profit organizations.

Based on the above and coupled with the fact that in the municipality of Lérida, Tolima has a youth population with high dropout rates at higher levels of education, the expansion of the existing educational infrastructure is proposed, through the construction of solar classrooms that improve access to information technologies, communication and access to the updating of study content with tools that encourage interactivity.

The use of renewable energies with the minimum generation of emissions is within the framework of the energy transformation proposed by the United Nations Framework Convention on Climate Change (UNFCCC) and the manifest of the decrease in dependence on conventional energy sources of the National Development Plan of Colombia 2022-2026 "Colombia, World Power of Life" (PND) [2].

The lack of school infrastructure in rural areas generates the mobilization of the young population to the cities due to lack of access to education in their regions of origin, which hinders access to state-of-the-art technology that allows reducing the technological access gap between rural populations and cities in Colombia.

The present work presents the technical, economic and environmental feasibility of the construction of a solar classroom, for which different phases are presented; In the first, the technical feasibility is determined in which the activities to be carried out for the construction of the classroom are detailed from the point of view of civil construction, later the equipment that is estimated to be used within the classroom is detailed, which allowed to determine the energy needs of the same and with this information determine the capacity of the photovoltaic solar system. Once the previous phase is completed, the monetary investment required for the purchase of equipment and construction of the classroom is determined, which allows the financial evaluation of the project through economic and social indicators, such as the internal rate of return and recovery period of the investment from the social point of view. And finally, the environmental impact assessment that the construction of the classroom and the environmental licensing procedures will have before the Colombian environmental authorities is carried out if required.

Thus, the objective of this research is to determine whether it is technically, economically and environmentally feasible to build an interactive solar classroom in Lérida, Tolima, Colombia?

This research was developed in the context of the transformation of the economy generated by the COVID 19 pandemic, and the military conflict between Russia and Ukraine, which affect the price variability of the equipment contemplated in the classroom.

BACKGROUND

Among the antecedents about the feasibility of solar classrooms are the studies of Alvarado (2020) [3], which determined the feasibility of the installation of self-sustainable schools in northern Mexico (state of Nuevo León), The determination of consumption demand was made with official information and projections of future consumption were made, through statistical modeling. For the evaluation, the number of students, square meters, consumption in kilowatts during the last 10 years was taken into account. The results showed that the recovery of the investment would be less than 5 years, with an internal rate of return greater than 10% with 20 years of useful life of the photovoltaic systems For the selection of the generation equipment of the photovoltaic system, the options available in the Mexican market were evaluated, useful life, installation and maintenance costs, expected inflation in the cost of importing vs. inflation of electricity rates, use of panel in year 0, expected growth in the number of students and the benefits and/or subsidies likely to obtain with the installation of the panels. In conclusion, it was obtained that the installation of photovoltaic systems in the area is viable, as long as the schools have at least 13,228 m^2, with a return on investment time of 7 years.

In Colombia, Valderrama & Montero (2016) [4], determined the technical and economic feasibility of implementing photovoltaic systems in a group of classrooms of the Pedagogical and Technological University of Colombia (UPTC) of Sogamoso. Information regarding renewable energies installed in educational institutions was reviewed and it was concluded that most of the projects are related to the technical and financial dimensioning of solar photovoltaic systems that are viable. Within the legal framework and regulations, it was observed that the conditions in general terms are positive, contributing to the viability of this type of project through tax incentives. A technical study was carried out, where the location of the building and the bioclimatic conditions were evaluated, through the multiannual average of solar radiation and annual irradiation. Subsequently, the selection of the architectural conditions was made, ensuring that they meet the size criteria (sufficient m^2), and that it does not interfere with the activities carried out at the university. Regarding the electrical design, the hours of use per day were evaluated, measurements of the average power and energy during the hours of greatest use were made, and the circuits in which the connections would be made were identified. The energy demand was determined at different times and the study of circuit loads and preceded to the selection of equipment and economic viability, the sizing of solar panels, capacity of the energy storage systems for the hours of maximum demand, design of the battery bank, load regulator, protection systems and selection of the charge controller. With these results, the analysis of the initial return on investment and environmental benefits was obtained. As conclusions it was found that the conditions are favorable with sufficient levels of solar irradiation, with a system outside the electrical grid to guarantee the reliability of the energy supply, the return on investment of the project would be in 13.2 years, with an estimated useful life of 20 years.

For his part, Perdomo (2015) [5] within the framework of the promotion of renewable energies in productive activities under the premise of the great potential of Colombia due to its location in the development of wind and solar projects, conducted an investigation to determine the feasibility of installing a hybrid system (wind and solar) for the generation of energy in the Hobo fish farms, to establish it as a success story to boost economic growth in the area with the least possible environmental impact. They carried out the cost analysis of the implementation of a Microgrid, for which a review of the available and susceptible to import technologies for the generation of wind and solar energy, their different brands, prices and estimated delivery time was carried out. The wind potential was determined with in situ measurement, and through a statistical analysis the wind speed estimates were obtained. Likewise, for solar irradiation, information was obtained from the National Aeronautics and Space Administration (NASA) and the time of solar peak hours was estimated, the number of panels, inverter capacity, converter and number of electrical protection elements to be used were calculated. The energy potential was calculated and energy production was simulated in two scenarios: production with vertical or horizontal wind turbines, and mono- and poly-crystalline photovoltaic solar cells. The energy demand of the fish farm was calculated based on the energy consumption of the equipment used and its time of use under normal production conditions. The economic cost of the system connected to the grid was estimated, both for civil works, mechanical equipment, operating costs, maintenance, and contingency margin of 10%. Projected kW costs for energy consumption over the lifetime of the system were compared. It was concluded that the costs of the photovoltaic generation system are more favorable since they provide the energy demand of the fish farm throughout the year with initial investment cost lower than that of the wind system that would have its maximum in June, while the rest of the year would need help from the energy network, without significant savings, so it was determined that a photovoltaic system should be installed instead of a hybrid one.

For their part, Gómez-Ramírez, Murcia-Murcia and Cabeza-Rojas (2016) [6] evaluated the potentials, antecedents and current perspectives of photovoltaic solar energy in Colombia: concluding that there is the potential to carry out the development of solar energy in an important way given that maintenance costs are low and that the price of solar cells have decreased considerably. According to information from 2015, Colombia had 32% of energy demand in non-interconnected areas, a demand that has not been met. Colombia's solar potential is 4.5 kWh/m^2 on average; however, in 2014 this potential only produced 0.6% of the energy. They also showed that the areas with the greatest potential for solar energy are the Atlantic and Pacific coast region, the Orinoquia and the Central region. The brightness and solar potential in Colombia showed that there are between 4 and 12 hours of sunshine, coupled with the location of Colombia on the equator generates that there are no significant variations in this concept, since the country does not have seasons. In terms of applications, it is observed that solar energy has potential in different sectors: power generation, services, residential, industrial, agricultural, electrification of isolated homes, telecommunications and transport, with the electrification of non-interconnected homes being the most demanded. Finally, they conclude that solar energy would ensure energy supply in non-interconnected areas with lower transmission costs, reducing the demand for kW from fossil sources generating economic benefits.

Finally, Pino (2016) [7], determined the technical-economic feasibility of installing a photo-voltaic solar system connected to the grid in a village in the commune of Rancagua, where the viability of a project that would allow the use of renewable energies in households was estimated, taking advantage of tripartite financing: government, users and private company. Technical, market and economic-financial studies were carried out. The market study identified 310 potential customers, determined the average level of income and expenses, average energy consumption and determined that the economic participation per household would be 20% of the initial investment. The technical study determined the availability of equipment necessary to produce the energy demand taking into account that for participation in the project households will have to switch to LED technology and assume the costs (20% of the total population). It also evaluated household consumption, solar generation system model, generation capacity under the bioclimatic conditions of the place, the needs of equipment, machinery and personnel for installation, operation and maintenance during the 20 years of useful life of the system. The economic and financial study determined the time for the evaluation of the project and estimated the time horizon in 10 years as the minimum to cover the initial investment expenses, the initial investment was determined by the total beneficiaries; the financial study took into account the net cash flows of the project and the internal rate of return. As conclusions it was obtained that the installation is viable, however, some of the homes do not have the minimum number of m^2 for the installation of solar panels. It is also estimated that despite technical and economic feasibility, the perception of potential customers is that the initial cost is very high, so other tax incentives or financing are required to promote this type of project.

2. MATERIALS AND METHODS

DESCRIPTION OF THE STUDY AREA

The study site is the municipality of La Sierra, Lérida, Tolima, in Colombia. Lérida is located on the Magdalena Valley, 78 km from Ibagué and 200 km from the capital of the republic. The municipality of Lérida is geographically located north of the Department of Tolima, 73 kilometers from the capital of Ibagué (Figure 1). With an estimated population of 18 115 inhabitants, of which it is distributed between urban and rural areas, with 98% as rural urban area, and with mainly agricultural economic activities such as rice and sugar cane.

The monthly average radiation at the Ibagué weather station is high levels of radiation all year round, with maximum peaks in the months of July and August above 4800 Wh/m^2. The average sunshine is between 4 to 7 hours, with 6 hours daily in the rainy months, and 7 hours in the dry months. The vegetation cover of the municipality is mostly non-wooded scrub. The climate is mostly hot-dry, with an average total annual rainfall of 1691 mm. The average temperature is 23.2 ºC, with an average maximum temperature between 28 and 30ºC. The relative humidity during the year ranges between 65 and 83%, being higher in the rainy season of the second semester.

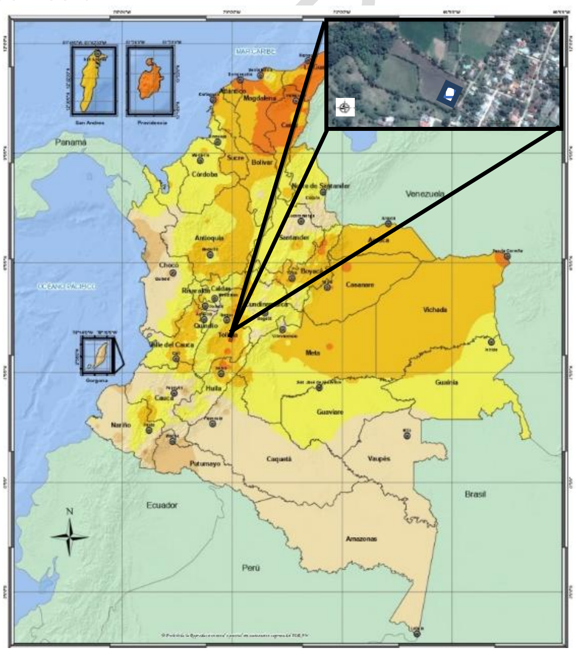

Fig. 1 Location of La Sierra, in the municipality of Lérida, Tolima, Colombia and average solar potential of Colombia [8].

The population of Lérida is mainly engaged in agricultural activities, agricultural production of rice cultivation, a small segment to livestock activity and production of goods. Export is an important activity, which when economic activity declines, unemployment and migration increase, which translates into budgetary insufficiency due to the demand for unsatisfied public services. The natural hazards identified in the Municipality of Lérida are; Mass removal, volcanic, flooding and geological faults.

METHODOLOGY

The present work presents the technical, economic and environmental feasibility of the construction of a solar classroom, for which different phases are presented; In the first, the technical feasibility is determined in which the activities to be carried out for the construction of the classroom are detailed from the point of view of civil construction, later the equipment that is estimated to be used within the classroom is detailed, which allowed to determine the energy needs of the same and with this information determine the capacity of the photovoltaic solar system. Once the previous phase is completed, the economic investment required for the purchase of equipment and construction of the classroom is determined, which allows the financial evaluation of the project through economic and social indicators, such as the internal rate of return and recovery period of the investment from the social point of view. And finally, the environmental impact assessment that the construction of the classroom and the environmental licensing procedures will have before the Colombian environmental authorities is carried out if required.

The methodology used in the first stage consisted of classroom specifications. The activities for the installation of the classroom include the enlistment, leveling and adaptation of the surface where the modular solar classroom will be installed, for which it is necessary to build a reinforced concrete base of 3000 psi (Law 400 of 1997) [9] and thickness of 10 cm, in an area of 70 m^2. The construction of the classroom will be made with lego type plastic wood for the main structure; plastic wood is a product of single-use recycled plastic, which saves time and money in its construction. Being light and modular allows more easily the transport of materials, important given that the installation will be carried out in a rural area. In addition, it has excellent thermal insulation and resistance to environmental conditions.

Next, the calculation of the energy demand in ampere-hours per day was carried out considering a system of constant use, since we want to involve the community in the use of the classroom not only with the development of classes in the school, but also for training to social organizations that require it, The determination of consumption involves the energy consumption of all devices (Video projector, Computer, electronic tablets, air conditioning, LED ceilings, sound system, outlets, modem and Internet signal receiving antenna, interactive board) that will be included in the photovoltaic system, however to size the batteries the maximum estimated energy use is necessary. The sizing of the photovoltaic system was carried out, according to the characteristics of the equipment to be used, taking into account the electrical intensity and performance factor of 0.98, for the determination of the wiring caliber. The capacity of the other equipment is based on the total energy consumption in the estimated hours. With the consumption data per ampere-hour, average daily consumption of the equipment was determined in order to make the correct selection of the number of solar cells, batteries and inverter. As for the determination of voltage and voltage, the highest was taken into account, for the calculation of the inverter, and since all equipment is AC, the system was selected in AC. Since the voltage is greater than 5 kW, the use of 48V batteries is recommended. Subsequently, the peak power was calculated, which is essential for the dimensioning of the load regulator, the inverter, the wiring and the fuses, for this calculation all the AC powers were added, and divided into the voltage, a consumption correction factor of 0.98 was applied by the characteristics of the technology used. Subsequently, we proceeded to the calculation of the batteries, number of photovoltaic modules for which it is necessary to continue with the current and angle of inclination, for this calculation information was taken from the meteorological station of Ibagué because it is the closest to the study area, as observed in the baseline the climate in the project area is usually constant with similar hours of sunshine during the year.

The calculation of batteries for the autonomy of the photovoltaic system was determined by the following formula:

$$Battery\ capacity = \frac{N\ of\ days\ autonomy\ *\ Daily\ consumption}{Maximum\ depth\ of\ discharge}$$

For the determination of the number of panels, the contribution in Watts of the most commercialized panels in Colombia was taken into account, which is 330 Watts. The number of solar panels was determined knowing the individual contribution of each panel and the value of the electrical load in daily A*h, that is, the average daily consumption of the place where the photovoltaic system will be installed; Using the formula:

$$\mathrm{Np} = \frac{(1.4 * \text{Average daily consumption in kWh day})}{(\eta * \text{ Contribution of a panel in kWh day})}$$

Where:
η: is the return of the investor.
1.4 The safety factor of 40%, to cover losses and ensure battery charging after a period of low radiation

For the sizing of the regulator, a protection factor of 25% was taken into account, so the total production value of the panels was taken by 1.25. Also, for the inverter, a safety factor of 1.25 was added for the short-circuit currents of the generator, in order to accommodate the excessive currents due to the increase in irradiation that clouds sometimes produce for short periods of time.

To carry out the cost-benefit analysis of the project, a list of materials, tools and labor necessary for its execution was made, that is, the initial budget of the project. The financial evaluation was carried out prior to the investment, estimating the benefits from the present prices of the opportunity costs of the project. Since the project aims to contribute to the fulfillment of the sustainable development goals, the selected materials will be local, except for cases that do not have production in the country, such as the materials of the photovoltaic installation. To determine the economic viability, an investment budget was determined and the evaluation of rates such as return and recovery of the investment in years.

To determine the flow of benefits at social prices, the benefits associated with the project must be quantified; to make this identification a tree of means and ends was made. For the projection of prices, the value of current inflation in Colombia of 13.12% per year is taken into account (2023), likewise the opportunity cost rate of the investment is taken from the reference banking indicator, this being 11.87% for the purposes of the valuation of the investment in the calculation of the recovery rate of the IRR investment, this value was close to 12%.

After establishing which of the social purposes are financially quantifiable, a cash flow was determined with the social benefits of the project to a scope of 10 years. With the cash flow of the project, the PR (payback period) was calculated from the point of view of social welfare.

For the identification of impacts caused by the development of the activities in the works of the project, first the identification and description of the main activities with relevant impact was carried out, such as: Removal of the vegetal layer, superficial excavations, placement of iron structures, preparation and emptying of concrete, assembly of poles and panels, assembly of wiring, adaptation of regulators, installation of cabinets and batteries, installation of switches, delivery of work, among others. For the identification of environmental aspects, environmental aspects related to water resources, biodiversity, soil and the social component that are directly related to economic activities are taken into account.

The environmental impact assessment (EIA) is essential to develop the Environmental Management Plan (EMP) and represents a critical activity, since it is necessary to know well the activities that generate impacts (negative), the description of the factors, components and attributes affected and especially in the prediction of changes. In this case the identification of environmental impacts was determined on the basis of the analysis of the interaction resulting from the various activities that take place, during and after the operation and their influence on the environment. The assessment of the magnitude of the impact is very important, as it allows adequate planning according to the time and type of measure to be carried out to prevent, mitigate or compensate.

To evaluate environmental impacts, the Matrix methodology was used with the typification and evaluation of impacts proposed by Vicente Conesa-Victoria Fernández, adapted to the needs of this evaluation. These analyses will give us a numerical result, which corresponds to the importance of the impact, and which subsequently indicates the effect generated by the impact, which ranges from moderate to critical.

The parameters evaluated by the methodology proposed by Conesa-Fernández are:

Nature, Extension (*Ex), Intensity (*In), Momentum (*Mo*), Persistence *(Pe*), Reversibility (*Rv*), Recoverability (*Mc*), Accumulation (Ac), Effect (*Ef*), Synergy (*Si*) and Periodicity *(Pr*). In this case the parameters of synergy and periodicity will not be taken into account for the because it can be said that the activities developed do not generate a measurable effect on these parameters.

Once the impacts have been assessed according to the previous classification, each impact is evaluated based on the following formula:

$$I = Nature\,(2In + 2Rv + Mo + Pe + Ac + Ef + Ex + Mc)$$

Finally, all high, medium and low impacts are added together and "percentages" are drawn according to the total impacts identified, in order to identify and classify the project as "high impact projects", "medium impact projects" and "low impact projects".

3. RESULTS AND DISCUSSION

The civil works activities for the installation of the classroom included stages of enlistment, leveling and adaptation of the surface where the modular solar classroom will be installed, later a reinforced concrete base of 3000 psi and 10 cm thick was built, in an area of 70 m^2. The design was carried out under bioclimatic architecture and according to the description of figure 2. The construction of the classroom will be made with lego type plastic wood for the main structure; plastic wood is a product of single-use recycled plastic, which saves time and money in its construction. Being light and modular allows more easily the transport of materials, important given that the installation will be carried out in a rural area. In addition, it has excellent thermal insulation and resistance to environmental conditions.

The calculation of the energy demand in ampere-hours per day was carried out considering a system of constant use and involved the energy consumption of all devices (Video projector, computer, electronic tablets, air conditioning, LED ceilings, sound system, outlets, interactive board, modem and antenna receiving internet signal) that will depend on the photovoltaic system. With the consumption data per ampere-hour, the average daily consumption of the equipment was determined in order to make the correct selection of the number of solar cells, batteries and inverter (Table 1).

Subsequently, the peak power was calculated, which is essential for the dimensioning of the load regulator, the inverter, the wiring and the fuses, for this calculation all the AC powers were added, and divided into the voltage, a consumption correction factor of 0.98 was applied by the characteristics of the technology used. Subsequently, we proceeded to the calculation of the batteries, number of photovoltaic modules (Table 3) for which it is necessary to continue with the current and angle of inclination, for this calculation information was taken from the meteorological station of Ibagué because it is the closest to the study area, as observed in the baseline the climate in the project area is usually constant with similar hours of sunshine during the year.

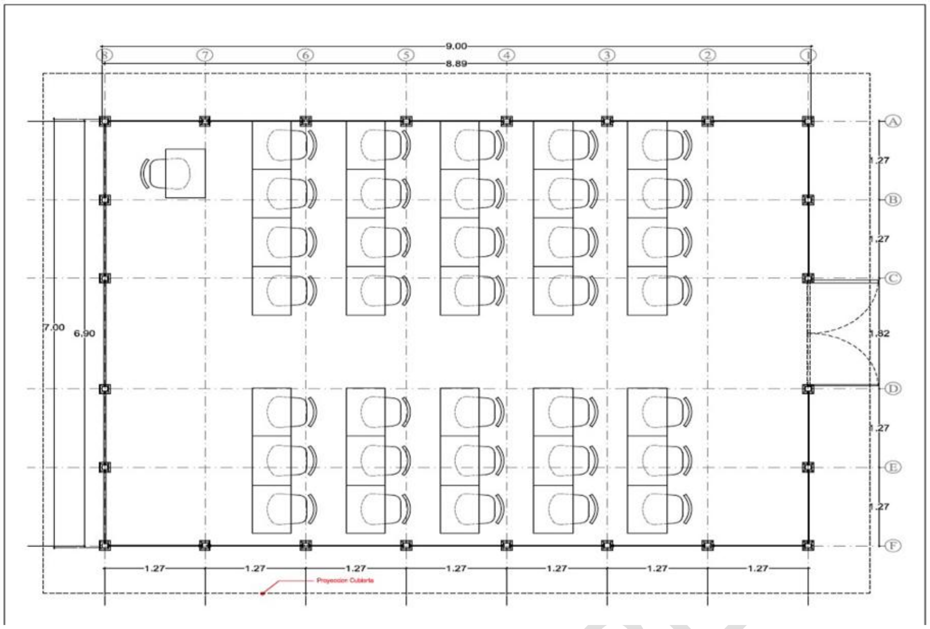

Fig. 2 Solar classroom floor plan view, Lérida, Tolima

Table 1. Calculation of energy demand in ampere-hours per day

Device	Quantity	AC power in W	Voltage	AMP	Hours of use	Weekly cycle	Conversion performance	Nominal voltage	consumption Amp/hour
Video projector	1	330	120	4.5	8	0.86	0.9	48	52.38
Computer	1	65	120	3.25	8	0.86	0.9	48	10.32
Electronic tablet	30	33	120	3.25	3	0.86	0.9	48	1.96
Air conditioning	1	950	120	8.5	4	0.86	0.9	48	75.40
LED ceiling	6	11	120	0.1	4	0.86	0.9	48	0.87
Sound system	1	33	120	4.25	4	0.86	0.9	48	2.62
Outlets	8	120	120		4	0.86	0.9	48	9.52
Interactive dashboard	1	240	120	10.0	4	0.86	0.9	48	19.05
Antenna and modem	1	4	120	2.0	8	0.86	0.9	48	0.716
Total		**1 786.57**		16.5	8	0.86	0.9	48	**172.84**

For the batteries it was taken into account that the voltage is > 5 kW, so it is recommended to use 48V batteries the calculation of the number of batteries was determined as follows:

$$Battery\ capacity = \frac{(N\ of\ days\ autonomy\ *\ Daily\ consumption)}{(Maximum\ depth\ of\ discharge)} = \frac{(1 * 196\ Ah/dia\ )}{0.75} = 261.3\ Ah$$

$$Number\ of\ Batteries = \frac{Battery\ Capacity}{Selected\ Battery\ Capacity} = \frac{261.3\ Ah}{100\ Ah} = 2{,}61 \approx 3\ Batteries$$

The number of panels needed for energy demand would be:

$$\mathrm{Np} = \frac{(1.4 * \text{Average daily consumption in kWh day})}{(\eta *\ \text{Contribution of a panel in kWh day})} = \frac{(1.4 * 2.069)}{(0.9 * 0.330)} = 9.75 \approx 10$$

Charge controllers are estimated within photovoltaic systems to prevent overcharging and excessive discharge of batteries, they also function as controllers, since they detect the voltage of the battery and take measurements according to it. Among the options on the market are temperature compensators in the battery voltage and state of charge. To size the regulator a protection factor of 25% was taken so that the total production value of the panels was taken by 1.25 as follows:

$$Potencia\ de\ regulador = Potencia\ nominal * 1.25 = 2069 * 1.25 = 3103.5\ W\ ajustandolo\ a\ uno\ de\ 4000W$$

To size the inverter, a safety factor of 1.25 was added for the short-circuit currents of the generator, in order to accommodate the excessive currents due to the increase in irradiation that clouds sometimes produce in short periods of time.

$$Potencia\ del\ inversor = Potencia\ nominal * 1.25 = 2069 * 1.25 = 3103.5\ W\ ajustandolo\ a\ uno\ de\ 3000W$$

Table 2 summarizes the equipment that the photovoltaic system will contain.

Table 2. Summary of the equipment to use

Team	Description	Quantity	Power in W
Batteries	Battery array in 48 volts, gel type Capacity 25C, 106 Ah in a usage index of 20 h.	3	4800
Photovoltaic panel	Polycrystalline silicon type IEC 61215:2005, IEC 61730:2004 compliance 25-year efficiency 80%, module efficiency ≥ 16% Maximum power voltage (Vmp) 39V, maximum current power (Imp) 6.98A	9.75 ≈10	330
Regulator	Minimum rated load current 85 Amp Efficiency Max 90%, Rated power 3000W, Voltage PV Max 150V	1	4000
Investor	Input voltage range 38 - 68 Vdc, Maximum efficiency 96%	1	3000

Table 3 below presents the estimated costs of materials and labor for classroom construction in U.S. dollars of equipment, materials, and labor for classroom construction.

Table 3. Costs for solar classroom construction in U.S. dollars en Lérida, Tolima.

Team	Quantity	Price in USD	Total in USD
Batteries	3	204.19	612.57
Photovoltaic panel	10	162.04	1620.42
Investor	1	64.14	64.14
KIT bracket, cable, terminals	1	0.00	523.56
Cement	155	7.85	1217.28
Sand	1.5	49.74	74.61
Gravel	2.5	86.39	215.97
Water	3.78	0.00	0.01
Iron for beam	13	23.87	23.87
Metal structure and plastic wood	1	7039.27	7039.27
Labor	5	184.12	920.58
Video projector	1	2693.98	2693.98
Computer	1	480.63	480.63
Electronic tablets	30	402.09	12062.83
Air conditioning	1	379.32	379.32
LED ceiling	6	4.71	28.26
Sound system	2	167.46	334.92
Dual outlets	8	4.01	32.04
Interactive dashboard	1	41.86	41.86
Furniture	30	41.62	1248.69
Satellite antenna and modem	1	667.54	667.54
	Total		30282.33

Once the total value to be invested is obtained, the source of the resources must be determined, in this case since it is an investment project for the improvement of the quality of education, the investment will be by the Mayor's Office of Lérida, within the allocation of financial resources for development and planning the municipality has a higher item than the estimate of the solar classroom for the improvement of schools in the rural area, so it was determined that the project is economically viable.

In order to establish the cost-benefit analysis, the determination of the cash flow of the quantifiable economic benefits of the project for the expected beneficiaries was carried out, that is, 30 people, under the premise that they are currently high school students who, in order to access technology and systems classes, require moving to other municipalities, with a journey that is made by motorcycle or intermunicipal bus. Additionally, the savings in the payment of electricity service from conventional sources at prices of the company providing the service in the area were taken into account, given the estimate of monthly kW/h required for the operation of the classroom and its equipment. Also, the current value normally paid by community organizations for renting spaces and equipment (projectors and sound) for meetings was taken into account, since the purpose of the classroom extends beyond formal education, this space will be ideal for teaching courses that boost the local economy of arts or crafts.

For the projection of prices, the current inflation in Colombia of 13.12 % per year was taken, and the opportunity cost rate of the investment of the reference banking indicator of 11.87 % for the purposes of the valuation of the investment in the calculation of the recovery rate of the investment TIR, this value approached 12%. It is important to mention that for the financial evaluation of the project, social prices were valued for 10 years, given that the life of the classroom is at least 20 years of the photovoltaic solar system and 35 years of the rest of the infrastructure. It was taken into account a salvage value of the project is 10% since in an estimated time of 5 to 7 years the reinvestment in the batteries of the project will have to be made to continue guaranteeing the independence of the photovoltaic system. Thus, in Table 4 a cash flow was determined with the social benefits of the project the cash flow was made in years, for 10 years.

Table 4. Solar classroom project cash flow in US Dollars, Lérida, Tolima

Year	0	1	2	3	4	5	6	7	8	9	10
Price kWh	0.00	11226.87	12699.84	14366.06	16250.88	18383.00	20794.85	23523.13	26609.37	30100.51	34049.70
Savings in student transfer to another municipality	0.00	109.95	124.37	140.69	159.15	180.03	203.65	230.37	260.59	294.78	333.46
Cost of renting monthly projection equipment for community activities	0.00	2094.24	2369.01	2679.82	3031.41	3429.13	3879.03	4387.96	4963.66	5614.90	6351.57
Gross Social Benefits	0.00	13431.06	15193.22	17186.57	19441.44	21992.16	24877.53	28141.46	31833.62	36010.20	40734.73
Social costs	34824.68	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Initial Investment	30282.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Salvage Value of the project	4542.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Net social flow	-34824.68	13431.06	15193.22	17186.57	19441.44	21992.16	24877.53	28141.46	31833.62	36010.20	40734.73

Once, the cash flow of the project has been obtained, the necessary information is obtained to calculate the PR (investment recovery period) as previously mentioned this financial evaluation is from the point of view of the social welfare generated by the project, which gives us as results that in an approximate period 3 years; therefore, the community could quantify the constant prices, savings in transfers and the cost of renting equipment as the total recovery of the project investment (Table 5).

Table 5. Analysis of internal rate of return indicator and recovery of investment

n	FCL	AC.	PR
0	34824.68	0.00	-34824.68
1	0.00	13431.06	-21393.62
2	0.00	15193.22	-6200.40
3	0.00	17186.57	10986.17
4	0.00	19441.44	30427.61
5	0.00	21992.16	52419.77

To finish Table 6, it shows the summary of the data obtained in the financial analysis; what shows us as a result the cost-benefit return in 3.68 years that is to say 4 years approximately, and an TIR of 50%, being greater than 30% shows us that the project is financially viable.

Table 6. Analysis of the internal rate of return

NPV	USD 90,638.37
DISCOUNT RATE	12%
RBC	3.6
VP BENEFITS	USD 125,463.05
VP COSTS	USD 34,824.68
PAYBACK IN YEARS	3
TIR	49%

The last evaluation was that of environmental impact through the adapted and modified formula of the one presented by Conesa-Fernández [10], the different environmental impacts shown in Table 7 were evaluated. Having the values for each impact, the final classification is categorized in Table 8.

Table 7. Assessment of parameters for EIA

Classification and assessment* of the characteristics of environmental impacts.							
Feature	Characteristic description	Classification and Valuation		Feature	Feature Description	Classification and Valuation	
Nature	Type of impact	Positive	(+)	Effect (Ef)	Cause-and-effect relationship	Indirect	1
		Negative	(-)			Direct	4
Extension (Ex)	Area of influence	Punctual	1	Reversibility(Rv)	Natural recovery of the land	Short term	1
		Partial	4			Medium term	4
		Extensive	8			Irreversible	8
Intensity (In)	Degree of incidence	Casualty	1	Persistence (PE)	Permanence of effect	Fleeting	1
		Stocking	4			Temporary	4
		Loud	8			Permanent	8
Moment (Mo)	Deadline for demonstration	Long term	1	Accumulation (Ac)	Progressive increase	Simple	1
		Medium term	4			Cumulative	4
		Immediate	8				
*. The values were assigned by the author, based on the Conesa-Fernández Methodology				Recoverability (mc)	Recover or rebuild	Immediate	1
						Medium term	4
						Mitigable	8

Table 8 Classification of environmental impacts

Categorization of importance	
Score (-)	**Category**
8 – 24	Slight
25 – 41	Moderate
42 – 56	Significant

Table 9 presents the identification table of the impacts associated with the construction of the solar classroom and its evaluation, and the evaluation matrix of each impact.

Table 9. Environmental Impact Identification Matrix

Component	Soil				Water		Air		Fauna and Flora		Social	
IMPACT / ACTIVITY	Alteration of soil characteristics	Solid waste generation	Debris generation	Alteration of the landscape	Pollution of water sources	Groundwater pollution	Generation of particulate matter	Noise generation	Loss of vegetation cover	Habitat alteration	Generation of environmental awareness	Increase in quality of life
Removal of the Vegetal Layer	X			X					X	X	X	
Surface excavations	X				X		X		X	X		
Placement of structures (Iron)	X											
Concrete Preparation and Casting	X	X	X		X		X					
Assembly of classroom and panels		X		X						X		
Ducting and wiring assembly		X					X					
Installing modules		X										
Installation of inverters		X										
Adaptation of regulators		X										
Installation of cabinets and batteries		X										
Installation of switches												
Tests		X										
Commissioning												
Training and delivery of work											X	X

Once the impacts have been determined, the impact is assessed according to the value assigned to each characteristic, as shown in Table 10.

Table 10 Environmental impact assessment matrix

Environmental impact	**Activity**	**Na**	**Evaluation I= (2In + 2Rv + Mo + Ef + Ex + Pe + Ac + Mc)**
Alteration of soil characteristics	Removal of the vegetal layer	(-)	**32**
	Surface excavations	(-)	**32**
	Placement of structures (Iron)	(-)	**37**
	Preparation and pouring of concrete	(-)	**44**
	Preparation and pouring of concrete	(-)	**29**
	Assembly of classroom and panels	(-)	**26**
	Ducting and wiring assembly	(-)	**20**
Solid waste generation	Installing modules	(-)	**20**
	Installation of inverters	(-)	**20**
	Adaptation of regulators	(-)	**20**
	Installation of cabinets and batteries	(-)	**20**
	Installation of switches	(-)	**20**
Debris generation	Preparation and pouring of concrete	(-)	**20**
	Removal of the vegetal layer	(-)	**22**
Alteration of the landscape	Assembly of classroom and panels	(-)	**22**
Pollution of water sources	Surface excavations	(-)	**19**
	Preparation and pouring of	(-)	**26**

	concrete		
	Preparation and pouring of concrete	(-)	**29**
Generation of particulate matter	Surface excavations	(-)	**29**
	Ducting and wiring assembly	(-)	**20**
Loss of vegetation cover	Removal of the vegetal layer	(-)	**26**
	Surface excavations	(-)	**44**
	Removal of the vegetal layer	(-)	**22**
Habitat alteration	Surface excavations	(-)	**22**
	Assembly of classroom and panels	(-)	**22**
Generation of environmental awareness **	Removal of the vegetal layer	(+)	**58**
	Delivery of work	(+)	**58**
Increase in quality of life**	**Delivery of work**	**(+)**	**58**

With these, results can be made the quantification of environmental impacts. Values rated with less than 21 are considered low impact, identified in green; subsequently, those under 31 are medium impact and yellow, and finally those over 41, are high impact and red, as shown in Table 11.

Table 11 Environmental impact classification matrix

Resource	Environmental impact	Activity	Quantification
Soil	Alteration of soil characteristics (Soil contamination)	Removal of the vegetal layer	32
		Surface excavations	32
		Placement of structures (Iron)	37
		Preparation and pouring of concrete	44
	Solid waste generation	Preparation and pouring of concrete	29
		Assembly of classrooms and panels	26
		Ducting and wiring assembly	20
		Installing modules	20
		Installation of inverters	20
		Adaptation of regulators	20
		Installation of cabinets and batteries	20
		Installation of switches	20
	Debris generation	Preparation and pouring of concrete	20
	Alteration of the landscape	Removal of the vegetal layer	22
		Assembly of classrooms and panels	22
Water	Pollution of water sources	Surface excavations	19
		Preparation and pouring of concrete	26
Air	Generation of particulate matter	Preparation and pouring of concrete	29
		Surface excavations	29
		Ducting and wiring assembly	20
Flora and Fauna	Loss of vegetation cover	Removal of the vegetal layer	26
		Surface excavations	44
	Habitat alteration	Removal of the vegetal layer	22
		Surface excavations	22
		Assembly of classrooms and panels	22

Finally, the most significant environmental impacts were classified by resource (Table 12).

Table 12 Impacts of the establishment of a solar classroom in Lérida, Tolima

Resource	Most significant impacts
Soils	Alteration of soil characteristics
	Solid waste generation
Air	Generation of particulate matter
Flora and Fauna	Loss of vegetation cover

After classifying the impacts according to their importance (by value and color), another table was made where the impacts generated and the activity that generate them are related. For these identifications, the degree of importance of the impact is defined also through a qualitative scale in high, medium and low impact, depending on the magnitude of the damage or deterioration of the environmental element by the execution of the different activities of the project. Finally, the same procedure was carried out as in the previous table, (all high, medium and low impacts are added together and "percentages" are taken according to the total impacts identified), this in order to identify and classify the project as "high impact projects", "medium impact projects" and "low impact projects".

According to the identification of environmental impacts, the project is classified as a *low impact project*, that is, its affectation does not transcend the area of direct influence of the work and that with the implementation of the management measures presented in this Environmental Management Plan, the identified impacts can be prevented, mitigated, controlled or compensated. As can be seen in the impact matrix, the social aspect generates positive impacts due to the increase in the quality of life of users, the generation of environmental education, the availability of energy in non-interconnected areas, the generation of new knowledge, and cultural changes, among others. And among the most significant negative impacts in the construction stage of the project, is the generation of solid waste, emission of particulate matter, the affectation of vegetation and soil.

The results shown here coincide with those of Alvarado (2020) [3], who determined the feasibility of installing self-sustaining schools in northern Mexico (state of Nuevo León). The difference with Alvarado is that the return on investment is 5 years compared to this study that is only 3.6 years; the useful life of the photovoltaic system would be equal to 20 years. They also coincide with the results of Valderrama & Montero (2016) [4], where they determined the technical and economic feasibility of implementing photovoltaic systems in classrooms of the Pedagogical and Technological University of Colombia (UPTC) of Sogamoso, with a return on investment of the project of 13.2 years and useful life of 20 years. On the other hand, Perdomo (2015) [5] concluded that the costs of the photovoltaic generation system are favorable in the fish farm analyzed, which coincides with the present investigation.

For their part, Gómez-Ramírez, Murcia-Murcia and Cabeza-Rojas (2016) [6] evaluated the potentials of photovoltaic solar energy in Colombia and conclude that solar energy would ensure energy supply in non-interconnected areas with lower costs than those of traditional energies, which is corroborated by the results obtained in this research. For his part, Pino (2016) [7], determined the technical-economic feasibility of installing a photovoltaic solar system connected to the grid in a village in the commune of Rancagua, where the viability of a project that would allow the use of renewable energies in homes was estimated, with a useful life of 20 years with a return on investment of 10 years more than double that found in this research.

4. CONCLUSION

Based on those obtained, it is concluded that from the technical point of view the construction of the classroom is viable, since the technological equipment required to cover the energy demand of the classroom is available. As soon as the economic feasibility is determined that the project is within the budgetary range provided in the local economic development plan, so its investment is viable, on the other hand the valuation of social benefits, show that the return on social investment would be in 3 years. On the other hand, in the environmental impact analysis it was observed that the negative impact is considered low, and that no environmental licensing process is required before the environmental authorities, so with specific management plans the project could be carried out without representing significant environmental impacts.

With the above description, it is concluded that the construction of a solar classroom in the rural area of the Municipality of Lérida, Tolima in Colombia is technically, economically and environmentally feasible; It also fulfills the objectives of sustainable development, such as infrastructure innovation, quality education with affordable and non-polluting energy, building sustainable communities and providing young people in Lérida, Tolima, with the available technology with the purpose of reducing the technological gap that generates economic inequalities.

REFERENCES

1. ATN/FM-12825-CO, UPME BID. Integration of non-conventional renewable energies in Colombia. Bogotá: UPME energy mining planning unit 2015.

2. National Development Plan 2022-2026 "Colombia world power of life". 2022- Accessed 07/10/2023.https://colaboracion.dnp.gov.co/CDT/portalDNP/PND-2023/2023-05-05texto con ciliado-PND.pdf

3. Alvarado, R. The use of solar energy for educational institutions in northern Mexico. Monterrey,: Monterrey Institute of Technology and Higher Studies; 2020.

4. Valderrama, D., & Montero, J. Technical-economic feasibility study to implement a photovoltaic generation system in a group of classrooms at the Sogamoso section of the Pedagogical and Technological University of Colombia. Duitama: Pedagogical and Technological University of Colombia; 2016.

5. Perdomo, V. Technical and economic feasibility study for wind and solar photovoltaic generation in the Hobo-Huila area. Pereira Technology University of Pereira; 2015.

6. Gómez Ramírez, J., Murcia Murcia, J. D., & Cabeza Rojas, I. Photovoltaic solar energy in Colombia: potential, background and perspectives. Santo Tomas University, 19; 2017. Retrieved from http://repository.usta.edu.co/handle/ 11634/10312.

7. Pino, R. Technical-economic feasibility study for the installation of an on-grid photovoltaic solar system, in a village in the Rancagua district using tripartite financing. Concepcion: Catholic University of the Holy Conception; 2016.

8. Gomez, O. C. (01, 2014). www.atlas.ideam.gov.co. Retrieved from http://atlas.ideam.gov.co/basefiles/RadiacionSolar01.pdf

9. Law 400 (August 19, 1997). By which standards on Earthquake Resistant Constructions are adopted. THE COLOMBIAN CONGRESS; 1997

10. Conesa Fernández - Vitora, Vicente, Vicente Conesa Ripoll, Luis A. Conesa Ripoll, and María Teresa Estevan Bolea. Methodological guide for environmental impact assessment. 4a. ed. Madrid: Mundi-Press, 2010.