SOCIAL, ENVIRONMENTAL AND TECHNO-ECONOMIC IMPACT OF RURAL ELECTRIFICATION ISOLATED WITH PHOTOVOLTAIC SYSTEMS

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ABSTRACT

Objective: To analyze the social, environmental, and techno-economic impact of rural electrification through the implementation of photovoltaic systems in isolated communities, in order to improve the quality of life of the inhabitants and promote sustainable development.

Theoretical Framework: Successful cases of off-grid rural electrification with photovoltaic solar energy in Latin America for the economic and social development of isolated communities are reviewed. The drivers and limitations of this technology in Latin America, the cost of energy and the contribution to local development are analyzed to promote its adoption and sustainability.

Method: A qualitative documentary method is used to study the social, environmental and techno-economic impact of rural electrification with photovoltaic systems in rural and marginal communities in Latin America, focusing on the case study of the community of Masa 2 in the Gulf of Guayaquil. Aspects such as the adoption of solar systems, implementation costs, benefits for the inhabitants and the need for a management plan to guarantee the sustainability of the systems are evaluated.

Results and Discussion: The results of the study show that isolated electrification with photovoltaic systems in the case study has had a positive impact on the development of the quality of life of the inhabitants, allowing access to basic services such as electricity and telecommunications and providing the possibility of receiving virtual classes and entertainment, among other benefits. The need for policies that promote the adoption of photovoltaic technology is emphasized, as well as the importance of considering technical, economic and social aspects to ensure the successful implementation of rural electrification.

Research Implications: The paper discusses the importance of implementing photovoltaic systems with management plans, in addition to the positive impact on the quality of life of the inhabitants, economic savings and access to basic services and improving educational opportunities.

Originality/Value: The multidisciplinary approach in addressing the social, environmental and techno-economic impact of implementing photovoltaic systems in isolated communities. The study also analyzes the benefits of rural electrification in terms of local development, access to basic services and improvement of the quality of life of the villagers, highlighting the horizontal analysis of the state of losses or gains.

Keywords: Local Development, Photovoltaic, Economy, Clean Energy.

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IMPACTO SOCIAL, AMBIENTAL E TECNO-ECONÔMICO DA RURAL ISOLADA COM SISTEMAS FOTOVOLTAICOS

RESUMO

Objetivo: Analisar o impacto social, ambiental e tecnoeconômico da eletrificação rural por meio da implementação de sistemas fotovoltaicos em comunidades isoladas, com o objetivo de melhorar a qualidade de vida dos habitantes e promover o desenvolvimento sustentável.

Referencial Teórico: São analisados casos bem-sucedidos de eletrificação rural fora da rede com energia solar fotovoltaica na América Latina para o desenvolvimento econômico e social de comunidades isoladas. Os motivadores e as limitações dessa tecnologia na América Latina, o custo da energia e a contribuição para o desenvolvimento local são analisados para promover sua adoção e sustentabilidade.

Método: Um método documental qualitativo é usado para estudar o impacto social, ambiental e tecnoeconômico da eletrificação rural com sistemas fotovoltaicos em comunidades rurais na América Latina, com foco no estudo de caso da comunidade de Masa 2 no Golfo de Guayaquil. São avaliados aspectos como a adoção de sistemas solares, os custos de implementação, os benefícios para os habitantes e a necessidade de um plano de gerenciamento para garantir a sustentabilidade dos sistemas.

Resultados e Discussão: Os resultados do estudo mostram que a eletrificação isolada com sistemas fotovoltaicos teve um impacto positivo no desenvolvimento da qualidade de vida dos habitantes, permitindo o acesso a serviços básicos, como eletricidade e telecomunicações, e proporcionando a possibilidade de receber aulas virtuais e entretenimento, entre outros benefícios. Enfatiza-se a necessidade de políticas que promovam a adoção da tecnologia fotovoltaica, bem como a importância de considerar aspectos técnicos, econômicos e sociais para garantir a implementação bem-sucedida da eletrificação rural.

Implicações da Pesquisa: O artigo discute a importância da implementação de sistemas fotovoltaicos com planos de gerenciamento, além do impacto positivo na qualidade de vida dos habitantes, economia econômica e acesso a serviços básicos e melhoria das oportunidades educacionais.

Originalidade/Valor: A abordagem multidisciplinar ao tratar do impacto social, ambiental e tecnoeconômico da implementação de sistemas fotovoltaicos em comunidades isoladas. O estudo também analisa os benefícios da eletrificação rural em termos de desenvolvimento local, acesso a serviços básicos e melhoria da qualidade de vida dos moradores, destacando a análise horizontal do estado de perdas ou ganhos.

Palavras-chave: Desenvolvimento Local, Energia Fotovoltaica, Economia, Energia Limpa.

IMPACTO SOCIAL, AMBIENTAL Y TECNO-ECONÓMICO DE LA ELECTRIFICACIÓN RURAL AISLADO CON SISTEMAS FOTOVOLTAICOS

RESUMEN

Objetivo: Analizar el impacto social, ambiental y tecnoeconómico de la electrificación rural mediante la implementación de sistemas fotovoltaicos en comunidades aisladas, con la finalidad de mejorar la calidad de vida de los habitantes promoviendo el desarrollo sostenible.

Marco Teórico: Se revisan los casos de éxitos de electrificación rural sin conexión a la red con energía solar fotovoltaica en Latinoamérica para el desarrollo económico y social de comunidades aisladas. Se analizan los impulsores y limitaciones de esta tecnología en América Latina, el costo de la energía y la contribución al desarrollo local para promover su adopción y sostenibilidad.

Método: El método utilizado es cualitativo documental, se estudia el impacto social, ambiental y tecnoeconómico de la electrificación rural con sistemas fotovoltaicos en comunidades rurales y marginales en Latinoamérica, centrándose en el caso de estudio de la comunidad de Masa 2 en el Golfo de Guayaquil. Se evalúa los aspectos como la adopción de sistemas solares, costos de implementación, beneficios para los habitantes y la necesidad de un plan de gestión para garantizar la sostenibilidad de los sistemas.
Resultados y Discusión: Los resultados del estudio muestran que la electrificación aislada con sistemas fotovoltaicos en el caso de estudio ha tenido un impacto positivo en el desarrollo de la calidad de vida de los habitantes, permitiendo el acceso a servicios básicos como la electricidad y telecomunicaciones brindado la posibilidad de recibir clases virtuales y entretenimiento, entre otros beneficios. Se enfatiza la necesidad de políticas que impulsen la adopción de la tecnología fotovoltaica, así como la importancia de considerar aspectos técnicos, económicos y sociales para asegurar el éxito de la implementación de electrificación rural.

Implicaciones de la Investigación: En el documento se discute la importancia de la implementación de sistemas fotovoltaicos con planes de gestión, además del impacto positivo en la calidad de vida de los habitantes, ahorro económico y el acceso a servicios básicos y mejorando oportunidades educativas.

Originalidad/Valor: El enfoque multidisciplinario al abordar el impacto social, ambiental y tecnoeconómico de la implementación de sistemas fotovoltaicos en comunidades aisladas. El estudio también analiza los beneficios de la electrificación rural en términos de desarrollo local, acceso a servicios básicos y mejora de la calidad de vida de los pobladores, destacando el análisis horizontal del estado de pérdidas o ganancias.

Palabras clave: Desarrollo Local, Fotovoltaica, Economía, Energía Limpia.

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1 INTRODUCTION

The main challenge presented by developing countries and especially in Latin America is universal access to electrification, so in 2015 the United Nations assembly agreed that to achieve a fairer, equitable and sustainable society it is necessary to adopt a new agenda called Sustainable Development Goals (SDGs). It includes 17 specific points by 2030, Goal 7 seeks to ensure access to affordable energy for all inhabitants, taking into account security, sustainability and modernity.

Despite the promising increase in rural electrification in poor countries in recent years, there are still many places without electrification, especially in isolated places, which is why access, sustainability of projects to electrify from clean and renewable sources is indispensable. Ecuador, a country in South America with a high rural population in 2020, became a world reference because 99% of the population has access to electricity, this is due to the inauguration of several generation plants, especially hydroelectric generators, electricity distribution systems and the electrification program “Fondo de Electrificación Rural y Urbano Marginal” (FERUM) promoted in seeking to improve the quality of life of the inhabitants of marginal and rural urban sectors. (Energy – Sustainable Development, s.f.) (Sheik et al., 2016; Syahri et al., 2022)

The lack of electrification in rural areas causes inequalities in society, poverty and no development, to this is added the abandonment of their homes in search of better days in the big cities transferring the inconveniences and being easy prey of land traffickers in marginal
areas. The authorities and universities with programs to link with society in recent years have significantly promoted the implementation of small residential photovoltaic systems where by harnessing the energy of the sun they can meet the basic energy needs of the home avoiding the use of generators that use fossil fuels being a valid and non-polluting alternative. On the other hand, the use of fossil resources such as oil is not sustainable over time because of the volatile market price, the scarcity of the primary source and first of all environmental pollution. (Hussein et al., 2017)

Wassei and Adaramola (2021) examined the factors and impacts driving rural electrification powered by photovoltaic (PV) systems in the Republic of Ethiopia, for the study took 605 rural households, of which 137 had photovoltaic solar power. For the data analysis used linear regressions and econometric analysis, among the findings they mentioned that the use of systems in rural areas is growing significantly, electrified households can save the consumption of 43.68 L of fuel and avoid the emission of 107 kg of CO2 annually. Reducing the use of kerosene in household electrification saves between $65 and $75 per year. The researchers conclude that renewable energy facilities provide energy for 3 to 5 hours a day, improving quality of life, and can even generate income for micro-businesses.

Electrification through the use of residential photovoltaic systems seeks to generate electricity to households living in remote areas of difficult access, geographically isolated, especially for the inhabitants of islands or forests in the jungle of South America, the implementation of this type of projects improves the quality of life of the inhabitants, the safety of users, refrigerated conservation of medicines and access to information and entertainment technologies, on the other hand they find the problem that many of the projects do not work properly during the life time that have been planned due to several reasons that are addressed by researchers, among the main ones is not to have a maintenance plan, misuse of the system by the population and increase the capacity of the load with respect to the original design.

The authors (Gómez-Hernández et al., 2023) carry out a study where they analyze the different budgetary restrictions for the expansion of rural electrification, therefore, projects must be prioritized to define the order of implementation. The procedure has to consider the order of the stakeholders, the economic, technical and especially the social criteria, maximizing the positive impact of the inhabitants ensures sustainability throughout the project. In the study of the state of the art of rural electrification economic bias is found in most independent systems for each community, researchers present a multicriteria decision procedure where they define a hierarchical order of electrification of communities based on technical and social criteria. It begins with the social diagnosis of the community, the situation of the socioeconomic context
of the communities and the renewable resources of the locality is evaluated. Seven technical criteria and seven social criteria are considered for the design and evaluation of the renewable energy system. The results are complemented by the analysis of the sensitivity for decision making when implementing the system.

In Latin America and the Caribbean, Miravet et al. discuss the main advantages in the energy substitution of fossil fuels such as kerosene by photovoltaic systems with the change avoid greenhouse gas emissions improving the health of the inhabitants and reduce CO2 emissions, review the increasing use of small-scale photovoltaic systems in Latin American countries where positive changes are noted in terms of the development of the quality of life of users, have improved physical and mental health. The researchers conducted surveys where they collected 216 data on electrified homes with photovoltaic systems in 9 communities, the information collected indicates the reduction of CO2 when ceasing to use fossil fuels, such as in the reduction in the consumption of firewood by 2,123 t/year and the use of kerosene with 40.80 t/year. The results of the work are encouraging, and could be improved if countries in Latin America and the Caribbean had strict laws and regulations on the use of these new technologies and the integration of photovoltaic energy in isolated communities, social policies and financial aid would further boost rural electrification. (Miravet-Sánchez et al., 2022)

Much of the information reviewed indicates that the use of this type of system has improved the standard of living of households and especially of women by being able to provide them with certain activities of the household, by ceasing to use fuel generators the noise in the sector has decreased markedly and the economy of the household has improved by ceasing to buy however an evaluation in the social, technical, environmental and econometric has not been carried out rigorously. The document is divided into the introduction, the second section deals with the success cases of rural electrification, section three refers to the case study in the Masa 2 community in the Gulf of Guayaquil to finish in section four analyzes the results obtained.

2 OBJECTIVES

To know the social, environmental and techno-economic impact of isolated rural electrification with photovoltaic systems through the use of specialized software and field surveys.
3 RURAL ELECTRIFICATION WITH SOLAR PHOTOVOLTAIC ENERGY IN LATIN AMERICA

The definitive solution for the inhabitants of isolated places is electrification through the implementation of photovoltaic systems, below, some of the projects developed in Latin America are mentioned:

Solar photovoltaic technology is not new in South America, in Brazil it starts the first projects since the year 1950 due to the favorable meteorological characteristics such as the high level of solar irradiation and high purity quartz reserves for the production of silicon photovoltaic cells, in 1970 German universities started scientific collaborations with local universities, with which a significant number of groups started research in the field of solar photovoltaic energy. In 1980 the industrial manufacture of solar panels with imported cells was inaugurated, then the cells were developed locally by Heliodinamica. In 1994, funding was obtained for programs of the federal and state government for this type of alternative energy, among the main programs is the Energy Development of the States and Municipalities (PRODEEM), managed by the Ministry of Energy of Brazil in 1994, in 2000 the Ministry of Energy offered six international tenders for the acquisition of new technology for the 26 Brazilian federal states in the Northeast and North regions of the country. The operation of the installed systems passed to the utilities within the “Light for All” program in 2006, in 2011 and 2013 the first 1 MWp photovoltaic plants were inaugurated (Ferreira et al., 2018).

Colombia is another of the region’s leading countries, where the Ministry of Government implemented five major projects to electrify 174 families with solar photovoltaic panels in seven communities in the municipality of San Onofre. The projects were financed with an investment of $3,541 million Colombian pesos, the financing comes from the Allocation for Peace of the General System of Royalties. Through this program and the Ministry of Mines and Energy have been able to finance, since 2018 and to date more than 70 electrical energy projects, benefiting about 27 thousand families (specifically, 26,870) the total investment is about 516 billion pesos. On the other hand, 363 families from the Sucre sector have benefited from the installation of photovoltaic solar panels in their homes.

In the Dominican Republic, the National Energy Commission (CNE) donated isolated photovoltaic energy systems to be implemented in the basic education schools of La Laguna and Rosa La Piedra located in the Elías Piña province, near the border with Haiti. The project benefits 270 students, 164 belong to the school La Laguna while the rest to the school Rosa La Piedra. In the first school, the system is made up of 12 photovoltaic modules of 445 Wp each,
the photovoltaic generator is 5.3 kWp, the installed inverter is 3 kW; for the battery bank 16 units of 12 V, 800 Ah type maintenance-free gel are used. For the Rosa de la Piedra school, the solar system is made up of 8 photovoltaic modules with a power of 445 Wp, the installed power is 3.5 kWp, the inverter is similar to the previous case with 3 kW while the storage system is made up of 12 batteries of 12 V, 600 Ah, maintenance-free gel type. The total cost of the two projects is approximately $33,000 (Rural Communities Away from The Electric Grid Achieve Access to Electricity In Mexico, 2021).

**Figure 1**

*Photovoltaic system implemented in a rural school.*

The latest World Bank reports estimate that in Mexico there are about 3.5 million people who do not have electricity, 60% of them are located in indigenous communities in the interior of the country. The Mexican state predicts that as a result of population growth in the next decade the number of people without access to electricity would increase by about 20%, so it becomes state policy to seek viable, reliable and short-term solutions, for this reason the PSIE is created with the objective of proposing rural electrification strategies and measures under the supervision of the Secretariat of Energy (SENER) and with the support of the World Bank. The short-term results are encouraging, a total of 2235 households in 40 rural communities are electrified, the installed power is 2357 kilowatts of photovoltaics, an important point is the reduction of the emission of 139 000 tons of CO2, not to mention the social and educational improvement, being able to access online educational resources and health infrastructure from isolated places (World Bank, n.d.)

Some Latin American governments have called companies to bid for the implementation of solar systems, Chile launches the solar homes program through the Ministry of Energy of Chile and the Energy Sustainability Agency (AgenciaSE) where it calls for the application for
the purchase and aggregate implementation of low power photovoltaic solar systems with grid connection for a total of 654 projects in twenty communes throughout the country, which are distributed in Arica, the High Hospice, Antofagasta, Iquique, Calama, Copiapó, la Vallenar, Coquimbo, La Serena, Curicó, Linares, the Maule region, Chillán, Temuco, Valdivia, La Unión, Puerto Montt Osorno, Coyhaique and south in Punta Arenas.

While Peru is bidding for 21 rural electrification projects with photovoltaic mini-grids for an investment of 355 million soles ($87.8 million), the projects would benefit 91,000 people from 977 locations across the country. The projects are part of the National Rural Electrification Plan that seeks to serve low-income per capita villages in the regions of Ancash, Apurímac, Ayacucho, Cajamarca, Cusco, Huánuco, Junín, La Libertad, Loreto, Piura, San Martín and Ucayali. With this, it is expected to reach the target set to electrify 96% of the population by 2023 and that, by the year 2026, universal energy access would be achieved in rural areas throughout the country, achieving one of the UN Sustainable Development Goals (SDGs) of which Peru is a part.

**4 PHOTOVOLTAIC SOLUTION FOR ELECTRIFICATION**

4.1 COMMUNITY OF MASA 2

The implementation project was carried out in the Gulf of Guayaquil in the community of Masa 2, which is 40 minutes from the Caraguay pier by river transport at coordinates -2.36, -79.85. The place is made up of 17 houses with the same number of families, the houses are built mostly of wood and on pillars because they are next to the Guayas River and when the tide rises or in the rainy season they suffer from flooding as shown in Figure 2.

The inhabitants lack basic services such as electricity and piped and potable water, 4 of the 17 houses have fuel generators that work from 6:00 p.m. to 9:00 p.m., the other houses provide energy at a cost of a dollar a day, the place being away from the city has complications in the acquisition of fuel.
Figure 2

Panoramic view of the mass community 2.

Through visits to the sector and the collection of information about the homes of the commune of Masa 2, the following consumption data and devices used by the families were obtained. The community had serious telephone communication problems, only received signal at a certain time, this is increased by not having internet signal and not being able to use communication applications such as whatsapp, messenger, telegram, etc.

The community receives about 12 hours of sunshine a day, so the energy potential of the sun is high at the implementation site, the daily average consumption is 7.94 kWh/m²/month as shown in Figure 3, the community is composed of 17 homes, the wind speed has an average of 2 m/s for this reason it is not viable to install wind turbines since it needs a speed of 12m/s to reach nominal power.

Figure 3

Consumption curve per dwelling mass 2.

There are high expectations for improving small-scale wind turbine technology in the coming years, especially vertical-type wind turbines for residential-type power generation.
4.2 PHOTOVOLTAIC GENERATOR

The model of the solar panel to be used is monocrystalline type JKM405M-72H, it is commercially available, the technical characteristics are the following: maximum power of 405 W under standard conditions; the efficiency is 20.13 percent; the open circuit voltage (Voc) is 49.4 V, the maximum voltage is 40.42 V; the short circuit current (Isc) is 10.69 A, while the maximum current reaches 10.02 A; The panel size is (mm) is 2008×1002×30 mm; the capital cost is US$ 187.64/40 5 Wp; replacement cost is the same; $10 cost is proposed for operation and maintenance is low because it has no moving parts, the manufacturer determines a 25-year service life.

The estimation of the hourly energy production of the solar panel can be calculated using equation 1, in kWh $E_{PV}$(Lata-García et al., 2019)

\[
E_{PV}(T) = (N_{PV} \times V_{PV}(t) \times I_{PV}(t) \times \Delta t)/1000 \quad (1)
\]

Where:

are the number, voltage and current of the photovoltaic solar panel. $N_{PV}, V_{PV}, I_{PV}$

4.3 CHARGE CONTROLLER

The energy generated by the solar panel has to be treated to store it in batteries or use it directly in the charge, the device commissioned or delivered to modify the voltage values and control the status of the battery is the charge controller, currently there are components with novel technology that intelligently manages the generation of the solar panel to reach the maximum charge in the battery in a shorter time. The equipment to be used is from the manufacturer Victron type MPPT 75/15, a photovoltaic power of up to 440 W can be connected in 24VDC.

4.4 BATTERY BANKS

Being an isolated system, the battery bank is the device that stores backup energy during certain hours of the day or when charging requires it. It has two loading and unloading processes, the first occurs when the generation generated by the solar panel is greater than the
demand for electrical energy per hour that the user needs, the state of the load can be calculated by means of the equation, 2 while for the discharge state equation 3 is used. ("Technical and economic analysis of different configurations of autonomous hybrid renewable energy systems: a case study", 2016)

\[
SOC(t) = SOC(t - 1) + \frac{E_{bat}(t) \times \eta_{bat}}{P_{bat}} \times 100
\]  

\[
SOC(t) = SOC(t - 1) + \frac{E_{bat}(t) \times \eta_{dbat}}{P_{bat}} \times 100
\]

The equation considers for a given time the state of the equipment charge, the battery power (kWh), the performance of the equipment, at the time of charging and discharging the battery power. In the case of lithium batteries, the state of charge is different, however, implementation in isolated places is complicated by the initial cost of the element despite achieving a lower energy cost and a longer service life.

Items that are distributed locally with the manufacturer's power Ritar with a capacity of 100 Ah to 12 V, the battery type is maintenance-free AGM. Due to the characteristics of this type of batteries, it is defined as a rechargeable accumulator, it is sealed and belongs to the family of lead acid, because its manufacture does not require maintenance or ventilation.

4.5 INVERSER OFFLINE.

Most of the household appliances owned by the house work in alternating current, for this reason it is necessary to convert the direct current of the battery bank into alternating current, the component commissioned is the inverter without connection to the grid for this purpose is used from the manufacturer Victron energy 24/250, 120V, the peak power is 400W with an efficiency of 88%.

To calculate the power generated by the photovoltaic panel, it is done using equation 4, where the battery power plus the power from the solar panel to the inverter and the performance of the equipment intervene in reverse.

\[
P_{inv,load} = (P_{batinv} + P_{reninv}) \times \eta_{inv}
\]
4.6 COST OF COMPONENTS USED IN THE SYSTEM

In the document has been explained the technical and modeling characteristics of each of the components used in the installation, the dimensioning of the system for housing was done in the PvSyst software that is specialized in indicating the elements to be used, the system is composed of a 405 W single crystalline photovoltaic panel at a cost of $187.64, two batteries of 12 V 100 Ah connected in series to get a 24 V system at a cost of $467.64, a MPPT charge controller of 75/15 at a cost of $150.17, an inverter of 250 VA to 24V Cost of $205.79, in addition to all consumables for the internal installation of the home, the total cost of the implementation is $1171.24.

5 RESULTS

5.1 TECHNICAL AND ECONOMIC DIMENSION

Currently there are several software for the sizing and optimization of hybrid renewable energy systems, among the main ones is HOMER (Homer, 2017), each one offers advantages over its competitors, because it will take advantage of a single generation source, the dimensioning and economic study is carried out in PVsyst, while the emissions analysis in HOMER (Sinha & Chandel, 2014) (Version 6.67, 2018) (Juan et al., 2019).

To meet the energy needs of the house the renewable energy system consists of a 405 W solar panel, a charge controller from 15A, 75V to 24VDC, 2 batteries from 12 V, 100Ah and an isolated inverter from 24VDC/120VAC of 250VA, the operating scheme is shown in Figure 4, where the only component that is generator and storage is the battery bank made up of two units.

Figure 4

Scheme of the photovoltaic system implemented
The photovoltaic panel will generate 535 kWh/year of which 296 kWh/year will be used, to take advantage of the excess energy the use of the load must be analyzed, the cost of the installation is 1663.05 dollars, the maintenance cost is 10 dollars annually because the system has no moving parts. The leveled cost of energy is 0.258 USD/kWh, in the next 25 years it is not possible to recover the investment, however, the purpose of the project is not the economic part but the social part for the development of the community.

The main energy results of the system are a production of 1320 kWh/kWp/year, the yield ratio is 0.467, the normalized production reaches 2 kWh/kWp/day, the panel losses are 2.06 kWh/kWp/day while the system losses are 0.21 kWh/kWp/day. To know the reduction of greenhouse gas emissions was performed a simulation where the only power source of the load is a diesel generator of 0.22 kW, the cost of energy is 0.549 USD/kWh, the emission of carbon dioxide is 631 kg/year, carbon monoxide is 3.98 kg/year, unburned hydrocarbons is 0.173 kg/year, particulate matter is 0.0241 kg/year and sulfur dioxide is 1.54 kg/year, these values are per house.

5.2 CONTRIBUTION TO LOCAL DEVELOPMENT

In the literature it is referred that electrification is the fundamental pillar for the development of isolated communities with the generation of income to be able to work in hours where artificial light is needed, to know and understand the extent of the benefits of the implementation of solar energy for households the Lowing Coe method is used.

All users in the mass 2 community are requested to describe in order of priority the benefits they have obtained with the implementation of the photovoltaic system on a scale of 1 to 5, where 1 is the most important, the information has been obtained based on surveys after 6 months of implementation and operation of the photovoltaic solar system. The benefits established in the survey were based on a meeting with the communal board and then socialized with 68 people from 17 families who were benefited, the calculated weighted average score is shown in the figure below.
According to the average score ranking presented, the best benefit is access to virtual post-pandemic classes, once the photovoltaic systems have been implemented, 3 of the 17 families contracted the internet service and share the signal with neighbors, the equipment is fed 24 hours a day, with them students can receive virtual classes and be able to investigate on the web to complete academic training.

The second benefit in importance for the inhabitants of the isolated community is access to entertainment, in the design of the charge the operation of the television is 5 hours with which they can see the news in the three editions, football matches, novels etc., while those who have access to the internet can connect to social networks and communicate without worrying about the download of the cell phone by battery backup of the system, in this locality they do not have mobile phone coverage.

The third benefit, in order of priority, is fuel economy and energy payment. In the community two gasoline generators were turned on from 6:30 p.m. to 9:30 p.m., each family was charged a value of $25 per month for three hours of energy per day at night, with the implementation of the system each family does not make the payment of the aforementioned value equivalent to a not negligible contribution to the domestic economy, also the noise pollution of the operation of the generator set is avoided. The environmental issue stops polluting by not emitting greenhouse gases by consuming two gallons of gasoline a day.

The fourth benefit in order of priority for users is the lighting in the early hours of the morning to prepare to go out to work on fishing at 5 in the morning and travel the approximately 50 m path from the houses to the canoes, in this journey they have met snakes that put at risk the safety of fishermen.
The fifth benefit is the night lighting, the dimensioning of the system considers the use of 5 LED bulbs of 9 W for 6 hours therefore during the night hours students can reinforce academic activities.

As a last benefit in order of priority for users is to charge the cell phone and the radio, however, this point is interesting because in visits to other communities the most requested requirement by the inhabitants is to be able to charge the cell phones to communicate.

5.3 STATEMENT OF PROFIT OR LOSS

A horizontal analysis of the state of losses or gains of the Comuna Masa 2, which is constituted by seventeen households, was visualized a difference of income (sales by catching fish) and annual expenses (education, food, purchase of fuel) before and after implementation of the photovoltaic systems. The Commune had an increase of 35% of the income due to the start-up of new ventures such as grocery store, fast food sales, etc. and a decrease of 9% of the expenses due to the non-purchase of fuel resulted in an increase of 201% of the profit, this thanks to the fact that households no longer incurred the expense that requires the use of the electric generator based on diesel which were the purchase of diesel, the transfer to buy diesel and the repair of the generator. In addition, this economic saving allowed him to have a basic service which is Internet access which gives him connectivity with the outside or create new sources of income apart from fishing as the creation of ventures such as the sale of meals and small shops.

Table 1

Results status by horizontal analysis

<table>
<thead>
<tr>
<th>Horizontal Analysis</th>
<th>Before Photovoltaic Systems</th>
<th>After Photovoltaic Systems</th>
<th>Absolute variation</th>
<th>Estimated Variation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Revenue</strong></td>
<td>$106,080.00</td>
<td>$106,080.00</td>
<td>$0.00</td>
<td>0%</td>
</tr>
<tr>
<td>Other Income</td>
<td>$0.00</td>
<td>$36,720.00</td>
<td>$36,720.00</td>
<td>100%</td>
</tr>
<tr>
<td><strong>Total Revenue</strong></td>
<td>$106,080.00</td>
<td>$142,800.00</td>
<td>$36,720.00</td>
<td>35%</td>
</tr>
<tr>
<td><strong>Expenditures</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Education</td>
<td>$1,020.00</td>
<td>$1,020.00</td>
<td>$0.00</td>
<td>0%</td>
</tr>
<tr>
<td>Feeding</td>
<td>$61,200.00</td>
<td>$61,200.00</td>
<td>$0.00</td>
<td>0%</td>
</tr>
<tr>
<td>Diesel</td>
<td>$6,324.00</td>
<td>$0.00</td>
<td>-$6,324.00</td>
<td>-100%</td>
</tr>
<tr>
<td>Health</td>
<td>$10,200.00</td>
<td>$10,200.00</td>
<td>$0.00</td>
<td>0%</td>
</tr>
<tr>
<td>Internet</td>
<td>$0.00</td>
<td>$476.00</td>
<td>$476.00</td>
<td>100%</td>
</tr>
<tr>
<td>Generator Repair</td>
<td>$1,360.00</td>
<td>$0.00</td>
<td>-$1,360.00</td>
<td>-100%</td>
</tr>
<tr>
<td><strong>Other Expenditures</strong></td>
<td>$4,080.00</td>
<td>$4,080.00</td>
<td>$0.00</td>
<td>0%</td>
</tr>
<tr>
<td><strong>Total Expenditure</strong></td>
<td>$84,184.00</td>
<td>$76,976.00</td>
<td>-$7,208.00</td>
<td>-9%</td>
</tr>
<tr>
<td>Utility</td>
<td>$21,896.00</td>
<td>$65,824.00</td>
<td>$43,928.00</td>
<td>201%</td>
</tr>
</tbody>
</table>
5.4 BARRIERS TO PV SYSTEM IMPLEMENTATION

The main technical factors are the little knowledge and experience of renewable energy system suppliers in Latin America, which limits the ability to implement photovoltaic systems; The slow growth of the market does not allow a reduction in installation costs and components. On the economic side, several of us have high tariffs for the import of components without tax aid and credit from financial firms. Among the socio-political factors, it is mentioned that some countries have not yet approved energy efficiency policies and regulations, with a deficit in the labeling of high-efficiency appliances without mentioning construction standards.

While in the local part it has been shown that the use of photovoltaic systems for rural electrification is a valid option with some advantages, however, there are a number of factors that limit medium-scale implementation, among technical, economic, political and social factors (Garlet et al., 2019).

One of the cases that has prevented the implementation is Puerto Roma, in 2010 the National Electricity Council (Conelec), initiated the plan to install solar panels in several towns in the Gulf of Guayaquil, with a cost of approximately USD 1.5 million. In the year 2016 as part of the link with the society the place was visited, of 150 photovoltaic systems worked only 2 to 10% of their capacity the reason for the lack of maintenance in the battery bank that required completing the electrolyte and cleaning of the terminals since it is a saline environment, in Figure 6 the status of the batteries is shown. In this specific case, the photovoltaic storage battery broke down, the user, not having the purchasing power and knowledge, bought an automotive battery, has no connection terminals, has a false contact.

The bad experience of the inhabitants spreads to inhabitants of other islands that limit the implementation of new individual systems, to this is added the use or replacement by poor quality or falsified equipment, failures experienced in the photovoltaic solar system, damage to luminaires and other equipment, mainly batteries. (Ghimire & Kim, 2018).
Another limitation is the economic barrier, users are people with limited economic resources and photovoltaic components are extremely expensive compared to other countries due to tariff issues, so users buy poor quality elements and have short-term problems, regulated product suppliers encourage to apply for bank loans for the purchase of systems but only a small percentage of users are creditors of bank loans because low purchasing power is another limitation for implementation.

The after-sales, technical and training service is zero according to the surveys conducted, when the systems were delivered the operation of this was explained, but they did not return to give the maintenance or explain the type of maintenance required to operate the planned service life.

6 CONCLUSIONS

The specialized literature indicates that the implementation of photovoltaic systems is the beginning of development of isolated communities, however, there is little information regarding the short-term socio-economic impact of the inhabitants after its implementation. A survey reveals the vital importance of access to electricity, prioritizing communication to receive virtual classes at the basic level, followed by entertainment through television series and access to satellite internet. The significant monthly savings of $25 in fuel is highlighted as a third important benefit, which translates into a significant reduction in the emission of greenhouse gases, ceasing to emit 0.0241 kg/year of particulate matter. Electrification marks a critical milestone in the quality of life of residents.
The installed photovoltaic systems, consists of 405 Wp in solar panel, two 100 Ah batteries, 12V, a 250 VA inverter, the initial cost of the system is $1663.05, the leveled cost of energy is $0.258 USD per kWh. The initial cost poses a significant barrier to new individual projects, especially considering poverty levels in Latin America,

REFERENCES


