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Santa María del Loreto: a successful example of rural electrification in the Cuban countryside

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ABSTRACT
This study explores the key socio-technological aspects of the 25-year electrification process using photovoltaic solar technology in the rural community of *Santa María del Loreto*, emphasizing its crucial relationship with beneficiaries. Participation, training, and adherence to resource usage guidelines are identified as primary variables facilitating the assimilation of this technology, prompting users to collectively modify energy consumption habits and customs. These efforts have effectively promoted local capacity building for community adoption of photovoltaic technology as a replacement for diesel generators in the electrification process.

Keywords: rural electrification, centralized photovoltaic system, local community development.

1 INTRODUCTION

Electrification plays a pivotal role in both personal and national contexts, driving significant benefits and advancements. At a personal level, electrification enhances quality of life by providing reliable access to electricity, powering homes, appliances, and devices crucial for daily living. On a national scale, electrification is vital for economic development and sustainability. It powers industries, stimulates job creation, and fosters innovation in sectors ranging from manufacturing to digital technology. Reliable electricity supports infrastructure development, including transportation networks and healthcare facilities, thus improving overall public welfare [1-2].

However, there still exist regions in several countries, primarily in developing nations, that lack electricity [3-5]. Building electrical distribution networks in mountainous terrain, dense forests, or isolated regions is costly and technically complex [6-7]. The cost of extending electrical grids to remote areas can be prohibitively expensive compared to densely populated urban areas. This is due to the need to cover long distances and overcome geographic challenges. Deloitte, for example, estimated that USD 51,418/km would be required to construct a 40 km line to reach a rural community comprising 200 households [8]. According to the IEA, in 2022, 760 million people remained without electricity worldwide [9].

In the case of Cuba, according to the National Office of Statistics and Information, the country achieved an electrification level of 95% by 1997* [10]. Cuba has an irregular topography, with approximately 25% of its territory occupied by mountains. Most of these mountains are located in the eastern region of the island, specifically in the Sierra Maestra and Sierra Cristal ranges, where altitudes can exceed 1,200 meters. These mountainous areas are significant not only for their natural beauty, biodiversity, and their importance in the country's culture and history, but also because electrification in these regions was deficient (*currently, the level is 99,5% [11]).

Historically, the option for rural electrification in Cuba has been the use of diesel generators. However, this approach comes with significant environmental concerns due to emissions of gases and spills of fuel and lubricants in fragile ecosystems. Moreover, communities face challenges such as high fuel costs, transportation difficulties, and unstable distribution. These factors result in limited electricity generation for only a few hours a day, which does not fully meet users' needs. An increasingly common solution to the energy shortages has been the use of renewable sources, with solar photovoltaic energy being the most widely adopted.

Solar photovoltaic energy is widely applied in two main types of systems:

- Decentralized systems: these systems are installed directly at the point of consumption, such as homes, schools, or small rural communities.
- Centralized systems: these systems are connected to the main electrical grid and use large-scale solar photovoltaic plants to generate electricity for commercial or industrial purposes. The energy produced is then distributed through the grid to various consumption points.

Both options operate independently of the main electrical grid, using solar panels to generate electricity locally.

The *Centro de Investigaciones de Energía Solar*, founded in 1987 and located in the eastern region of Cuba — which is the highest mountainous region — pioneered the use of photovoltaic solar energy for electrification in the country. Its first instalation was a rural school within a mountain community, with one panel of 20 Wp. Other small isolated users were electrified in the following years, all in form of decentralized systems.

In 1997, the electrification of a bigger application was decided, and a rural community was selected. During the planning of the project, the centralized option was considered [12]. Choosing between centralized and decentralized systems depends on specific electrification needs, considering factors such as resource availability, geographical location, and associated costs [13-15]. For our specific project, the potential involvement of local residents in the care and maintenance of the installation(s) was also considered. According to various records, community involvement is crucial for the success of renewable energy installations [16-18]. A team composed of sociologists and engineers visited the community on several occasions to inform the residents, understand the community's characteristics and dynamics, and verify the community agents' activities on-site [19]. Considering these elements and the costs, the centralized system was selected. Also considered was the advantage of this option for possible future expansion [20].

2 THE FIRST STEPS: CHARACTERIZATION OF COMMUNITIES AND SELECTION

Some rural communities were analyzed to receive the electrical (photovoltaic) application. Several criteria were considered for the selection, including the number of houses, the presence of a medical post and/or school, their proximity to each other, the difficulty of access to the community, its dynamism, and the strength of local leadership. Also considered was the presence of residents with a high level of education, due to the need for technical training to supervise the operation of the installation.

After several rounds of analysis, visits to the communities, and exchanges with municipal government representatives, *Santa Maria del Loreto* was selected. This community is located in the Santiago de Cuba province, in the Sierra Maestra mountain range, at an altitude of 650 meters, with access via a winding and rugged mountain road. The nearest electrical grid is 11 km away.

Santa María del Loreto is a settlement that emerged at the beginning of the 20th century, founded by Spanish or their descendants interested in agricultural production. During this period, coffee cultivation and exploitation in the mountains were one of the country's main economic activities. Other agricultural crops such as fruits and vegetables were also cultivated. As of 1997, these remained the primary economic activities of the community

Like other communities, *Santa Maria del Loreto* used diesel generators for electrical production, with a microgrid connecting all users. Initially, the system was comfortable, but economic activity attracted new workers and new houses were built. The last generator used did not have sufficient capacity, was inefficient, and suffered from frequent breakdowns, providing low-quality electricity. When it operated, the community received an average of 2 hours of electricity per day, mostly during the nigh.

At the time of the photovoltaic electrification, the community consisted of 30 houses, a medical post, a small school, and a social center. The survey conducted revealed that the main consumer devices were primarily inefficient incandescent light bulbs, some radios (6), high-consumption black-and-white televisions (4), and 2 refrigerators. The community's quality of life was very low, lacking nightlife, basic medical equipment, computers in the school, and with limited access to major media outlets. On a positive note, the community was very close-knit, composed of workers with educational levels above ninth grade of schooling, many of whom had technical training. In total, 121 people, including adults (84) and children (37), lived in the community.

Several meetings were held with the residents by CIES specialists to explain photovoltaic technology, system operation, the funding source, the need for rational electricity use, and installation care, as well as the finite electrical power available. It was agreed that households should use a proportionate amount of power based on the number of residents, which would be monitored through energy meters. A nominal fee of 0.19/kWh was established for electricity service, aimed at regulating consumption. The community leader, who had technical training, was already responsible for managing the existing electrical system and continued in this role, receiving training to oversee the photovoltaic system regarding management and basic maintenance. The leader also retained local administrative functions, including reading energy meters in houses, collecting service fees, etc.

The enthusiasm was widespread in the community with the new technology, and the residents participated in every stage of the project, from rehabilitating the road, unloading the equipment, and selecting the installation site, to the construction and assembly works.

3 THE PHOTOVOLTAIC INSTALLATION: TECHNICAL CHARACTERISTICS

Up until the installation, photovoltaic systems installed in Cuba were customized, consisting of a photovoltaic panel, battery, and charge controller. Some users received light bulbs and other direct current (DC) consumers. A few received a small power inverter.

Maintaining this option in *Santa Maria del Loreto* would represent at least 30 systems of that type. The centralized system was chosen, which has the following characteristics:

- 2 PV panels, with 7.5 kWp and 7.05 kWp, respectively.
- 2 battery banks, each with 1080 Ah.
- 1 inverter, with 2 AC outputs, and 5 kVA.
- 2 distribution networks.
- Energy meters (one for each user).

Two independent systems were configured, forming two networks, considering the distribution of houses in the central area of the community, as shown in Fig.1. The photovoltaic panels consist of 80 modules, with power ratings between 120 and 250 Wp. The battery bank consists of 2V lead-acid cells. The panels and bank were connected to operate at 48V. The inverter operates with a 48V DC input and output 120V AC. The frequency is 60 Hz. These values, 120V and 60 Hz, are the same as those used throughout the country by the Electroenergetic System. Fig.2 shows the photovoltaic plant.

Figure 1. Community map: location and order of some houses.

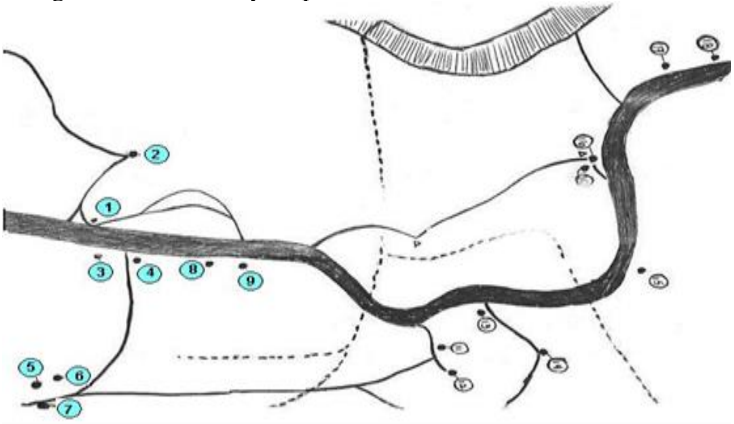

Figure 2. *Santa María del Lotero* photovoltaic plant.

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4 SOCIOECONOMICAL RESULTS

The photovoltaic electrification brought a series of positive socio-economic benefits to the community of *Santa María del Loreto*. Some of these can be summarized as follows:

Improved quality of life: The introduction of reliable electricity significantly enhanced residents' quality of life, providing adequate lighting for study, work, and leisure activities during the night, and facilitating the use of essential electrical appliances. Electricity availability increased from 2 to 24 hours. A new collective laundry was inaugurated.

Local economic development: The availability of electricity stimulated local economic activities, including small businesses such as a flower garden and a caffee shop. It also increased the production of food, fruits, and vegetables for community self-consumption, as well as encouraging milk production and coffee harvesting in the community area.

Environmental sustainability and cost reduction: The photovoltaic system eliminated dependence on fossil fuels, which had caused various environmental impacts over the years through transport, storage, and handling. It also contributed to reducing CO2 emissions, thus mitigating climate change and preserving the environment. Resources previously allocated to fuel, transportation, and diesel generator maintenance and repair were made available to municipal authorities for other social purposes.

Enhanced community resilience: More accessible and reliable electricity enabled the establishment of a community telephone center, ensuring continuous communication with local authorities, health agents, and other stakeholders. Actions like this strengthen community resilience against external shocks such as natural disasters (fires, hurricanes, etc.).

Social empowerment: Residents' involvement in the planning, implementation, and maintenance of the photovoltaic system strengthened community cohesion. As an energy-independent community, *Santa María del Loreto* became a regional reference, attracting new residents and temporary workers. The number of people from nearby communities traveling to or visiting *Santa María del Loreto* also significantly increased.

5 TECHNICAL RESULTS

The improvement in the community's standard of living and the revitalized economic activities attracted new residents, resulting in the construction of 18 new residences by 2021 []. Of these, 7 still need to be electrified. The number of electrical appliances has significantly increased, with a growth rate of 2.29 units per year, totaling: 31 televisions, 12 refrigerators, 11 blenders, as well as fans, radios, energy-saving lamps, LED bulbs, and other appliances.

From a technical standpoint, the photovoltaic installation has achieved an efficiency level of 88%, meeting internationally established parameters (80 to 85%). This success can be attributed to the presence of a local technician with extensive training and long-term commitment to the community, as well as the cooperative spirit among community members in managing energy resources, which has been actively fostered.

Preliminary studies of electricity consumption in the rural community of *Santa María del Loreto*, conducted by CIES between 2005 and 2021, have enabled the monitoring of changes in the lifestyle habits of the rural population following electrification [21]. These studies highlight crucial factors for load demand management, considering the accelerated increase in consumption, where the residential sector accounts for 76% of the total energy produced by the photovoltaic plant.

The photovoltaic plant represents a significant advancement in community development. However, like all energy sources, this photovoltaic system has its limitations. For instance, inclement weather can adversely affect its operation, and electrical surges have caused failures in the system, particularly impacting the inverters, which are the most vulnerable components in such systems [22]. Additionally, the photovoltaic modules are nearing the end of their useful life, typically around 25 years, and they exhibit a high level of degradation compared to their initial condition.

In light of the accelerated growth in consumption, there is a proposal to limit the acquisition of new high-power consumers and to enforce rules for common or collective use among users. Nevertheless, it can be affirmed that technological substitution has brought about significant changes in the community over its 25-year lifespan.

6 ACADEMIC AND CIENTIFIC RESULTS

The photovoltaic system in Santa María del Loreto, along with the community's adaptation to the new technology, has served as a foundation for the development of academic and scientific research. This has resulted in one completed doctoral thesis and one in progress, two master's dissertations, as well as several undergraduate projects and publications in scientific journals, conferences, and other events.

7 CONCLUSIONS

1. The processes of active participation and training have facilitated the development of local capacities for the community's adoption of photovoltaic technology in *Santa María del Loreto*.

2. The electrification of the rural community of *Santa María del Loreto* with photovoltaic solar energy has had broad social repercussions and has yielded significant achievements in health, education, economic development, and cultural heritage over its more than 25 years of operation.

3. The success of the photovoltaic installation in the rural community of Santa María del Loreto can be attributed to its initial viability, bolstered by the collective commitment of its residents, the presence of a highly trained local technician, and a strong user adoption of the technology. These factors have enabled the community to achieve local management of the resource, a critical aspect for centralized photovoltaic solar systems.

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