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Community Empowerment in Peri-Urban Areas through Solar Technologies: A Case Study in Central Mexico

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Abstract

This article explores a strategy to empower vulnerable communities by transferring solar technology as a path to energy justice development. The proposed methodology is based on preliminary research on energy uses according to the needs, practices, and customs of the communities. The study focuses on the cases of three women with productive vocations based on entrepreneurship in different phases of incubation found in a peri-urban community in central Mexico. In this community, productive energy uses include a) the development of value-added products for retail and b) electrical implementation for machinery, lighting, and security. Therefore, a methodology was designed and implemented that combined social and technical interventions for empowerment. The social intervention included focus groups and semi-structured interviews. In contrast, the technical intervention evaluated the viability of solar technologies considering the available irradiation, energy consumption, and the cost of the monthly electricity rate. The results revealed each woman's prior knowledge about

renewable energy, their concerns, and the importance of productive uses of energy. The methodology allowed women to develop a strategic business plan for their ventures, highlighting the benefits of solar energy. The document emphasizes the importance of adapting renewable technologies to the specific activities and needs of communities, as well as the analysis of productive uses of energy by region, including economic activities, home occupations, transportation, and rest time.

Keywords
Peri-urban; local studies; women empowerment; solar technologies; solar energy

1. Introduction

Studying geographic spaces is essential to understanding how socioeconomic factors affect health, behavior, and resource access. Geographic areas are usually classified according to their sociodemographic density into rural, urban, and peri-urban areas. The concept of peri-urban area refers to areas located at the interface between urban and rural environments, characterized by a mix of land uses that combine urban and rural methods. This concept has evolved, and several scholars have contributed to its development and understanding, especially in urban planning and development. Currently, peri-urban areas are recognized as critical for addressing issues related to urban expansion, resource management, and sustainable development [1].

Access to resources that guarantee fundamental rights is key to empowerment. In particular, access to reliable energy, as well as related information and practices, can significantly contribute to the development of vulnerable communities. Previous studies have shown that access to electricity improves well-being indicators and expands employment opportunities by reducing the barriers of gender inequality [2]. Furthermore, decentralizing energy systems allows communities to exercise a more significant voice in energy production and consumption [3], strengthening decision-making and collective participation in energy transitions [4].

This research focused on transferring technologies to empower women in peri-urban communities and postulates that access to clean energy can strengthen and consolidate local businesses. In this context, the study addresses the following research questions: How do sociocultural and economic contexts influence the acceptance and appropriation of new energy technologies? And what is the impact of the solar technology transfer on women's empowerment through the creation and consolidation of local businesses.

The importance of this study lies in the documentation of a participatory action methodology based on technical and social principles designed to transfer solar energy technologies to empower local entrepreneurship cases in a peri-urban area. In this context, the decision-makers were women from the community, who proved to be able to generate significant changes through technological adoption. However, this methodology is adaptable to other social profiles in similar peri-urban communities.

The social implications, analyzed in greater depth in the discussion section, include understanding the role of energy in entrepreneurial activities and its impact on female empowerment through local economic initiatives. Meanwhile, the practical implications focus on

aspects related to the installation and use of the technologies, as well as on the technical and social factors that could represent barriers to their adoption, offering strategies to address them from the project planning stage.

Consequently, this research focuses on the methodological application and the social and technical practices necessary to develop a detailed analysis of the relevance of providing solar technologies to local economies. This approach seeks to facilitate collective empowerment, strengthening the capacity of communities to take advantage of the benefits of renewable energy in their economic activities.

The following section presents a literature review focusing on peri-urban contexts, empowerment, and contextualization of solar energy. The context of the project and the characteristics of the community in which it was carried out are described below. Subsequently, the methodologies and conditions involved in the work are explained. Afterward, the results of the social and technical interventions can be observed with the participating women. In the penultimate section, the relevant findings and opinions of the project are discussed, and it concludes with concluding observations and proposals for future research.

1.1 Peri-Urbanism

Peri-urbanism arises from the human demand for well-being caused by urbanization and population growth [5], the transition from traditional agricultural economies to urban economies, and the diversification of land use that combines or replaces agricultural, residential, and industrial uses [6]. It is also influenced by urban planning and policy strategies to control sprawl [7] and access to transportation networks and essential services in previously rural areas [8].

Peri-urban areas often face neglect or disadvantages due to a lack of economic or cultural resources. Common problems include a lack of infrastructure in essential services, poor condition of roads, and inadequate and unsafe transportation services [9]. Furthermore, unplanned urban growth and social inequality, exacerbated by unequal access to economic opportunities, such as land tenure, can perpetuate cycles of poverty and marginalization [10]. These problems must be addressed through proposals for justice and solidarity promoted by local governments, community organizations, and projects aimed at sustainable development. Frequent social issues are also observed in peri-urban areas, such as social disintegration, food insecurity derived from inadequate public policies, and the lack of resources to confront poverty, exclusion, and inequality [11]. Furthermore, an increase in urban poverty and inequality is observed, resulting in high rates of informal trade and high rates of early birth [12].

1.1.1 Energy Context in Peri-Urban Areas

Peri-urban areas often face deficiencies in essential services due to a lack of strategic solutions and opportunities. In this context, access and use of energy are presented as a way to address both social and technical conflicts. However, access to reliable electricity networks is often limited due to problems such as frequent power outages and poor infrastructure, as well as inadequate management of electricity rates for residential and commercial sectors. This situation results in an insufficient understanding of the specific energy problems of peri-urban areas, which makes it difficult to formulate effective energy policies. These regions present unique consumption and production patterns that differ from those observed in purely urban or rural environments [13].

The integration of solar energy is gaining importance in peri-urban development, given its ability to improve energy access and equity [14]. This transition towards renewable sources seeks to increase sustainability and reduce greenhouse gas emissions in peri-urban areas, which are usually less regulated than urban spaces [15].

1.1.2 Energy Uses in Peri-Urban Areas

The use of traditional energy prevails in peri-urban areas due to the persistence of rural customs and the continued dominance of conventional fuels. This situation makes it difficult to formulate energy policies effectively [16]. Therefore, the specific challenges and opportunities presented by peri-urbanism must be addressed, considering both current needs and future strategies [17].

An aspect rarely mentioned in peri-urbanism studies is the impact of the final uses of energy on gender. While in rural areas, women usually use traditional fuels for cooking and domestic activities, in peri-urban areas, there is gradual participation of LPG and electricity as cleaner fuels [18]; there is also a high dependence on traditional biomass fuels that causes indoor air pollution and affect respiratory health [19]. In peri-urban areas, cooking and household fuel use is influenced by the availability and affordability of these fuels [20]. In small businesses that require energy for operations such as food processing, access to energy can increase household income [21]. As incomes rise, people may adopt coal and eventually LPG or electricity [22].

The energy transition in peri-urban areas is crucial, considering that energy quantification is fundamental for designing sustainable food and work chains that empower people who interact with energy systems. Decentralized renewable energies represent an opportunity to face present technical and sociopolitical barriers.

1.2 Empowerment

Empowerment involves processes aimed at strengthening social groups that have been historically violated. In this context, gender determines access to decision-making, capacity development, information acquisition, and economic stability. Women's empowerment requires a critical awareness of gender-based power relations, allowing them to gain control over their own lives [23].

This process cannot be based on sequential methodologies that ignore life's sociocultural context and traditions. Female empowerment involves fundamental elements such as power, autonomy, and subjectivity [24] and requires the interaction of essential factors for the complete fulfillment of women. Education is crucial in increasing the likelihood that women make informed decisions, pursue meaningful careers, and actively contribute to their communities [25]. The economy gives women control over resources, assets, and income, enhancing their negotiation capacity [26]. Awareness of rights and legal protection mechanisms allow women to claim their rights and defend themselves against discrimination [25]. Furthermore, cultural activities are essential to promote gender equality and create environments where women can thrive without fear of discrimination [27]. Support networks are decisive in promoting awareness and offering resources, facilitating their ability to overcome barriers and achieve their objectives [28].

Empowerment through technology transfer in renewable energy goes beyond the mere adoption of energy devices, to include the generation and management of knowledge associated with these technologies. Technology transfer projects are essential in improving social well-being, especially in

developing countries, by facilitating the exchange of knowledge, skills, and technologies that promote access to energy and sustainable development.

In 2014, China and Ghana implemented a project to transfer renewable knowledge and technologies, promoting local absorption of these solutions with social objectives such as poverty reduction through job creation and climate change mitigation [29]. Similarly, Nigeria launched an initiative focused on energy resources such as solar, wind, and hydroelectric energy to close technological gaps, reduce costs, and strengthen local capacities [30]. In another case, the US Cooperative Technology Association promoted installing solar-powered water pumps for agriculture, generating economic development while addressing rural poverty. In Latin America and the Caribbean, the Inter-American Development Bank (IDB) explored mechanisms to transfer technologies related to renewable energy and energy efficiency, identifying barriers and sharing lessons to optimize their adoption [31]. These projects highlight how technology transfer can improve access to energy, foster economic development, and strengthen environmental sustainability, contributing significantly to the social well-being of communities.

1.2.1 Female Empowerment

The empowerment of women in peri-urban areas is essential to promote gender equality, economic growth, and sustainable development. In these areas, women often have a lower labor participation rate compared to men [32], which motivates them to perform informal work or participate in small-scale income-generating activities, which are often poorly paid and lack job security [33].

Previous research has developed empowerment strategies focused on women's economic and social autonomy, including psychological and legal support for women victims of violence [34], food sustainability initiatives, and assistance to women in community gardens [35], sanitation, hygiene, and water access programs [36], and education and community participation programs aimed at girls [37]. More research is required on strategies that integrate social, educational, and economic support to develop capabilities that promote autonomy and leadership in women.

The consistent use of solar technologies can transform behaviors and life goals, especially for women. It complements sustainable business models and fosters economic and personal empowerment. A prominent example is the Barefoot College program in India, which trains rural women to become solar engineers. After six months of training, these women return to their communities to install and maintain solar energy systems, improving local access to clean energy [38].

In Qinghai Province, China, a project focused on women's access to renewable energy technologies included training in these technologies and supporting the establishment of women-led agricultural cooperatives, promoting their role in the local economy [39]. Likewise, in Indonesia, the ACCESS initiative focused on women-headed households, facilitating access to clean energy through community solar panels. This project included women in decision-making processes and trained them as local operators [40]. Other projects have demonstrated the transformative impact of technology transfer on gender equity and community development. In Tanzania, the Rural Women Light Up Africa program trained mature women as solar engineers, enabling them to electrify homes with solar lighting units, improving their economic independence and access to sustainable energy. In several communities, solar-powered water purification systems have

empowered women by training them to operate these systems, providing safe drinking water, and generating income by selling purified water [41]. In Africa, the ENERGIA initiative supported women entrepreneurs in the clean energy sector, offering them training and resources to establish and expand businesses related to renewable technologies [42]. Finally, the "Mobility for Africa" project in Zimbabwe introduced renewable energy-powered electric vehicles to transport pregnant women and new mothers to healthcare facilities, improving access to essential services and the employability of local women [43].

These cases reflect how technology transfer not only fosters the adoption of renewable technologies but also empowers female leadership, local economic development, and sustainability in vulnerable communities.

1.2.2 Empowerment with Solar Energy

Using decentralized renewable energies facilitates access, management, and benefits for vulnerable communities. The empowerment process focuses on community participation and education through using technologies, reducing energy costs, transitioning to sustainable practices, and making energy decisions. At the individual level, energy transformation empowers by developing knowledge and skills. At the macro level, changes in power structures are required, supported by strong communities and government support [44].

A popular technology in vulnerable areas is solar energy due to its energy resilience, low operating costs, and potential to reduce energy dependence [45]. In peri-urban areas, solar empowerment must address issues of social justice and equitable access, such as unequal grid connectivity and lack of long-term connection plans [46]. Solar technologies can foster individual and collective growth, create jobs, and improve local economies [47]. In addition, solar drying contributes to food security and innovation in entrepreneurship [48]. These technologies can also improve living conditions through heating and hot water and reduce health risks related to poor sanitation and inadequate heating [49].

In summary, solar energy contributes to sustainable human development, offering benefits in health, economic growth, environmental sustainability, and energy transition. Empowerment through solar energy promotes economic and ecological justice through financial assistance, community projects, and decentralized systems, benefiting vulnerable populations.

Fair energy management, focusing on supply to ensure fundamental rights and improve quality of life, is an essential pillar of energy justice. However, social development and community empowerment often seem like disciplines that are distant from the practical analysis of energy in everyday life. Although methodologies linking technological adoption with improved quality of life are limited, several projects highlight how renewable energy can positively impact social well-being. For example, New York City's Community Solar Program allows residents to benefit from solar energy without installing panels on their properties, facilitating access to clean energy for low-income households and promoting community participation in the energy transition [50]. In Indonesia, Muara Enggelam's solar PV grid has replaced diesel generators with a sustainable energy source, improving local incomes and providing electricity for essential services in a remote village [51].

In Zambia, the Mwembeshi solar mini-grid provides reliable electricity to over 600 homes, schools, and rural health clinics, creating jobs and improving local quality of life [52]. Similarly, the

Kalumbila Sustainable Rural Energy Project has increased access to solar energy in rural communities in northwestern Zambia, generating economic opportunities and promoting sustainable development [53]. In Puerto Rico, Casa Pueblo led recovery efforts following Hurricane Maria by deploying solar systems in homes and community buildings, moving towards energy self-sufficiency in Adjuntas [54]. Meanwhile, Barefoot College International trains older women to install and maintain solar systems, electrifying communities while fostering gender equality and economic independence [35]. Initiatives such as Lifeline Energy, which distributes solar media players in sub-Saharan Africa to provide education and health resources, or community energy cooperatives in Europe and other regions, which enable communities to invest in renewable projects collectively, highlight how energy can be managed as a common good, strengthening resilience and reducing energy poverty [35, 55]. The above projects show that renewable energy can transcend the technical realm to become a tool for social development and community empowerment.

1.3 Justice and Energy

A widely used technology in vulnerable areas is solar energy, due to its energy resilience, low operating costs, and ability to reduce energy dependency [45]. In peri-urban areas, solar energy empowerment must address issues related to social justice and equitable access, such as unequal connectivity to the electricity grid and the absence of long-term connection plans [14]. In this sense, energy intervention for social development must be based on energy justice principles. This implies ensuring the equitable distribution of energy and related technologies, considering the needs and opinions of communities for their proper use, and valuing the experiences and experiences of the groups involved to achieve an honest and effective integration of these technologies.

1.3.1 Energy Justice

Additionally, energy justice can provide development and empowerment strategies if approached from the principles of a "just life", which implies guaranteeing sufficient energy to meet basic needs. This approach can be grounded in the environmental justice framework that integrates three key concepts: distributive, procedural, and recognition justice [56]. Distributive justice refers to equitable access to energy-related services and benefits, ensuring that all people, including minority and vulnerable groups, enjoy a healthy environment. In social terms, equitable energy use for well-being fosters a fair distribution of the burdens and benefits of social cooperation among people with diverse needs and conflicting demands. Procedural justice, on the other hand, highlights the importance of participatory processes and collective decision-making to reach equitable agreements. Finally, recognition justice addresses the need to recognize the particularities of underserved groups, ensuring their inclusion in decision-making processes. In addition, it values the unique experiences and histories of individuals and communities, which influence their perceptions of what is fair from distributive and procedural perspectives [57].

1.3.2 Public Policies and Energy

Implementing public policies based on energy use for community development is a growing interest, especially in Europe, where the social acceptance model of Wüstenhagen et al. is applied. This model divides acceptance into socio-political, market, and community dimensions, underlining

the importance of transparency in energy planning. Communities often reject projects if they perceive that the costs fall on them while the benefits go to external actors, or if they are not included in decision-making [58, 59]. Technology transfer and creating human and institutional capacities in developing countries are fundamental to fostering technological leadership. Energy decentralization at the local level, such as creating community energy authorities, has been effective in sub-Saharan Africa with Rural Electrification Agencies supporting local projects. The International Renewable Energy Agency (IRENA) highlights the need for clear policies with incentives that attract investments, promote local companies, and develop alternative business models. In addition, government support can facilitate access to financing [60]. Community energy, recognized in England as a key social tool, promotes collective benefits, although it faces administrative barriers that hinder its implementation [61, 62]. In Latin America, renewable energies are relevant in sectors such as construction and mobility. Comprehensive planning of the electricity sector is essential to guarantee the sustainability of electromobility, considering economic, social, and environmental aspects [63]. This analysis highlights the need for comprehensive and local public policies that overcome social, economic, and administrative barriers, promoting an inclusive and sustainable energy transition and a harmonious technological adoption.

2. Materials and Methods

This section details the locality selection process, the research methods used and the intervention carried out with the selected participants. The research focused on issues related to society and energy, using qualitative methods such as in-depth interviews, focus groups, and energy literacy tools and workshops to collect relevant data. The study was conducted in the peri-urban town "Rubén Jaramillo", located in Temixco, Morelos. The fieldwork was carried out during the years 2020 and 2021.

2.1 Selection of Peri-Urban Locality for Study

The P70 project of CeMIE-SOL, titled “Validation of strategy for empowerment through the use of solar energy”, was a social innovation initiative designed to be a successful model for managing interdisciplinary projects with a Middle-Out approach. In this context, productive energy uses were selected as the central theme to develop a methodology to empower local enterprises through solar technologies.

Temixco covers an area of 102.89 km^2, which represents 2.1% of the total state of Morelos. Currently the population is made up of 48.2% men and 51.8% women. The main economic activities of Temixco include agriculture (especially floriculture), industry, and commerce. According to data provided by INEGI, in 2020 Temixco had a population of 122,263 with an illiteracy rate in Temixco of 5.14%, where the highest percentage was associated with the female gender.

The peri-urban town of Rubén Jaramillo in Temixco was selected due to its educational infrastructure, which ranges from basic education to postgraduate academic training. It was founded on March 31, 1973, and this neighborhood has approximately 9,410 inhabitants and 2,390 homes. Although electricity was installed in 1974 and 92.8% of Temixco has access to it, the neighborhood faces security problems and vulnerability to blackouts and loss of service during heavy rains. Retail trade and home maintenance services are the main economic activities in the area, so it is common to find businesses related to the sale of food, personal use items, and repair

of vehicles and appliances. The community also has high rates of displacement, due to its inhabitants emigrating to other states of the republic or countries with better living conditions or to provide for their families at a distance.

2.2 Research Methodology

Three women with entrepreneurial activity in the peri-urban locality were selected, each in a different phase of their entrepreneurship: nascent, relocated and consolidated. The in-depth interviews were conducted in their respective locations, with the permission of each participant, while the focus groups were conducted at an academic institution. During the interviews, the women showed the products derived from their ventures, explained their interests, opportunities, and challenges, and mentioned their long-term goals. The uses of energy (both electrical and thermal) in each product were identified and the energy consumption per unit or work day was calculated.

Two types of interventions were carried out: social and technical. The social intervention included semi-structured interviews and focus groups. After explaining the objectives and foundations of the project, the interviews were conducted with the participants' approval. Additionally, the women attended energy literacy workshops to acquire basic knowledge about renewable energy and solar technologies.

The technical intervention evaluated the resources, dimensions, and possibilities for installing solar technologies that would be transferred according to specific needs. In this phase, the monthly energy consumption, the use of cooking fuels, the daily energy uses, the space available for technologies, the potential risk of installation, and the average daily insolation and shading due to neighboring obstructions.

The technical and social intervention was summarized in a 7-step scheme, which included: the characterization of the locality as a peri-urban community, the identification of the participating women, and the preparation for the intervention. This preparation served as the basis for surveys and focus groups, and, based on the identified energy needs, energy literacy workshops were carried out. Technical information was collected, and each participating woman selected the most appropriate solar technology according to her productive vocations. Finally, each woman was accompanied by an expert to develop a strategic business plan that would allow her to achieve her goals and technological appropriation. The methodological process can be summarized according to Figure 1.

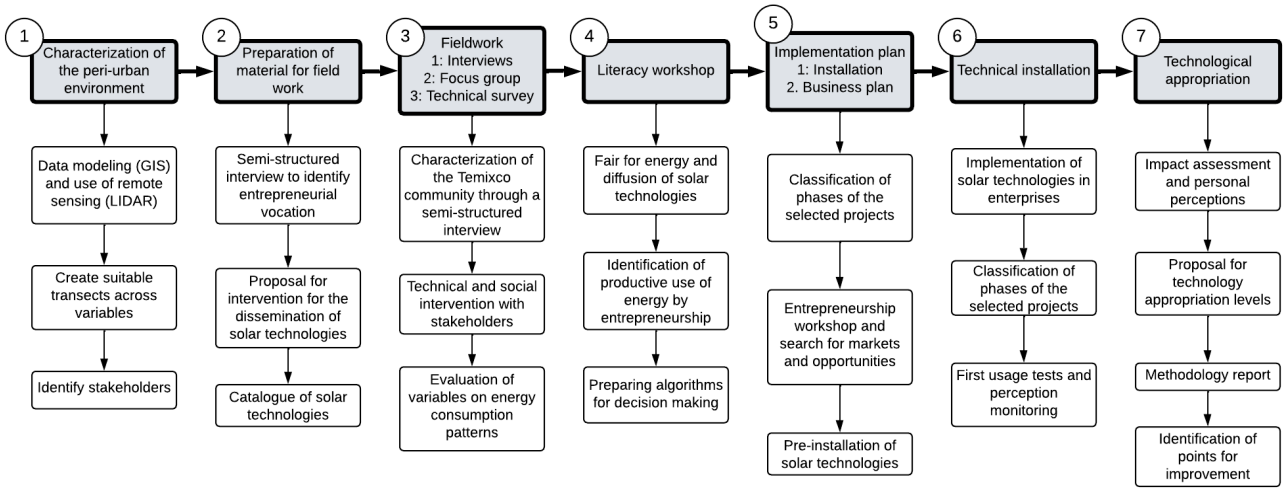

Figure 1 Methodology for the validation of solar technologies in the empowerment of women entrepreneurs.

2.2.1 Co-Selection Tools

Following the energy literacy workshops and the acquisition of basic concepts about renewable energy and solar technologies, three flowcharts were used to help the women select an appropriate solar technology for their energy needs. Each diagram consisted of a series of questions with options that led to subsequent questions, to identify a suitable solar technology for their situation. The flowcharts focused on three main areas: solar dehydration, electrical power generation and heating of water for sanitary use. Topics were addressed, such as type of fuel used, available solar resources, cleared area, access to energy, number of users, and the possibility of economic financing for the technology.

This tool, based on a co-selection system, was designed with the objective of implementing solar technologies for community empowerment. This tool was designed to evaluate and determine the most appropriate technology for each context, considering social, technical, economic, and governance aspects, both at the community and individual levels. Figure 2 shows a base diagram as an example. It should be noted that one was designed specifically for each type of solar technology.

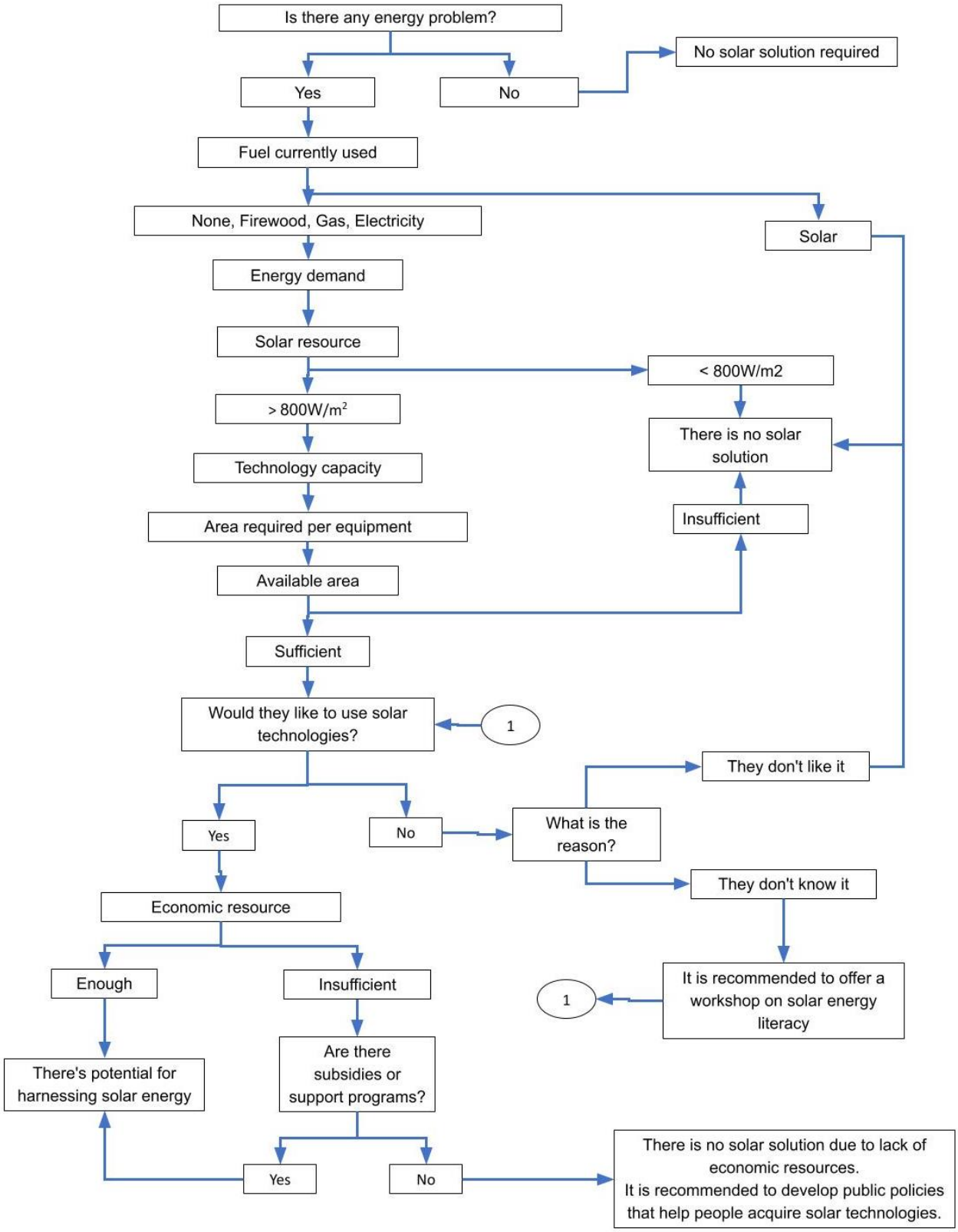

Figure 2 Example of the solar technologies co-selection tool.

The algorithm guides towards the co-selection of the technology by answering the questions in an orderly manner:

1.- Is there an energy problem to solve?

This question determines whether or not to proceed with the search for a solar solution.

2.- What fuel is currently used to cover the energy need to which the identified problem is related?

Here, the form of energy is to be replaced, and the relationship of the collaborators with that energy is determined. There is a possibility that no energy is used yet or that they are currently using solar energy; if the latter is the case, there is no solar solution.

3.- Are there enough solar resources available to install a technology?

This response is determined by measuring the physical variables of the place: incident solar intensity, peak solar hours, area available for installation, ambient temperature, etc., and determines whether or not it is possible to install solar technology.

With the answer to this question and the previous one, we can proceed to the tentative sizing of the solar installations.

4.- Would the collaborators like to use solar technology?

This question is answered by the collaborators themselves, without the influence or advice of anyone from anyone. This question focuses on a cycle in which, if the answer is “no,” you are asked the reason, and if this is “because you do not know solar technologies”, then energy literacy methods are suggested, subsequently the question is does it again, this way the collaborator can make an informed choice. If the answer is still “no,” there is no solar solution.

5.- Do the collaborators have the necessary financial resources to acquire solar technology?

If the answer to this question is “yes”, it is directly determined that the “solar solution” and the “solar exploitation potential” exist; if the answer is “no”, we proceed to the next question.

6.- Are there subsidies or public policies that support the installation of solar technology?

If the answer to this question is “yes”, it is directly determined that the “solar solution” and the “solar exploitation potential” exist, but if the answer is “no” in addition to determining that “there is no solar solution”, it is issuing the recommendation to generate public policies that support collaborators to access solar technologies, since up to this point it is known that the problem exists, that there is a sufficient solar resource, that the conditions for the installation are adequate and that the collaborators want the solar solution and the only limitation is the economic resource.

The answers to the questions posed by the co-selection tool are obtained from both the technical and the social intervention.

2.2.2 Business Plan

Practical and theoretical workshops were carried out to develop business models adapted to the needs of each participant. The first two sessions, 5 hours each, focused on answering key questions such as: Who is my client? What is my business model? What is my value proposition? How do I organize my finances? How do I grow my business? The second part of the program included individual consultations, where participants discussed their businesses in depth and received specific guidance on topics of interest to them. The current state of each company was evaluated, and strategies were developed for its long-term growth.

2.2.3 Focus Group

It consisted of a semi-structured session with questions and activities focused on interests and priorities, opportunities and challenges, and the relationship with energy. It was divided into two sections of 45 minutes each. During the first section, each woman's current activities and intentions to open new businesses were discussed. An activity was carried out to identify personal, home and

business needs. In the second section, the challenges, opportunities and interests of each participant were addressed, as well as the history and objectives of their companies. The women expressed interest in learning new skills and discussed their capabilities. Finally, knowledge about solar energy, its scope and opportunities for use were explored. The session was recorded on audio devices after the consent of the participants, the audio was transcribed for subsequent analysis.

2.3 Case Studies

The selection criteria for the participating women were: a) being a resident of the peri-urban locality belonging to Temixco; b) being the owner of a business or business idea that has been started; c) being willing to participate. The essential characteristics of each participant are described below. Names are withheld to protect the women's privacy.

2.3.1 Case 1

45-year-old woman, originally from Taxco, Guerrero, with 28 years of residence in Temixco. Her business is the preparation and sale of tamales and atole on her premises, passed down from generation to generation, with a loyal clientele. She is interested in learning about new technologies to reduce costs in the production of tamales. She describes herself as a leader who is organized and loyal to her religion. In her spare time she organizes non-profit novenas and seeks to learn about solar technologies to benefit her family and community.

2.3.2 Case 2

Woman with training in Agricultural Engineering, who is dedicated to cleaning and rescuing stray dogs in her free time. She has lived in Temixco for 15 years and wants to start a soap and scented candle business. She has observed that drying flowers and fruits in the sun is faster than other methods but requires technologies that preserve ornamental characteristics. Her business is incubating, having made prototypes and contacted potential clients. She has expressed the need for economic, technological, and consulting resources to plan and manage her business.

2.3.3 Case 3

The woman is originally from Jacala, Hidalgo, and has more than 60 years of residence in Temixco. Previously she had a daily food business in a neighboring municipality, but due to COVID-19 problems she moved her business to Temixco in recent years. She considers energy essential for using refrigerators and hot water in her business. She highlights the need for local authority responsibility for environmental issues, waste management, and access to water. She observed that solar radiation has become more intense and rain is scarce. She also identified that solar energy is useful for drying clothes, heating water for bathing and maintaining the natural cycle.

2.4 Ethics Statement

Participating women signed an approval document both to be interviewed and to place solar technologies at the site of their entrepreneurship.

3. Results

3.1 Results of Social Intervention

Below is a summary of the information collected for each case. To obtain this data, interviews and focus groups were conducted with the participants, which made it possible to learn about their current activities, ideas for new businesses, and evaluate their individual needs, interests, and capabilities. Previous knowledge about energy and solar technologies was also assessed. The results were classified into interests, goals, opportunities and perception of energy before the literacy intervention (Table 1 and Table 2 - Own elaboration)

Table 1 Previous perceptions about energy in each case.

Case	Energy uses	Renewable Energy/Solar Energy
Case 1	**Electrical lighting**: Electric lighting is essential for food preparation, used from 4:00 a.m. until approximately 6:30 a.m. **Cooling and grinding**: Electricity is also used in refrigerating ingredients and in the grinding process, which is essential to preserve the inputs. **Gas use**: Gas is used to cook atolls and tamales. Its role is crucial in the cooking process, providing the temperature necessary to prepare these foods.	**Knowledge and observation:** She has not found detailed information about renewable energies in the nearby environment, but she has found general knowledge about solar panels. It is understood that these panels capture energy from the sun's rays and are used to save electricity. She recognizes its presence on the roofs of homes, as well as its shape, size and color. **Economic evaluation:** She perceives that solar energy can be an effective option to reduce electricity expenses, especially after recovering the initial investment in installing the panels. **Renewable energy sources:** Since water heating depended on the gas reserve, she considered the adoption of renewable technologies to be essential for its replacement. These alternatives had to minimize gas or electricity consumption and be economically viable, in order to reduce the environmental impact and costs associated with their business.

Case 2	**Kitchen efficiency**: She used electrical energy for appliances such as blenders, microwaves and mixers, optimizing their use to reduce costs and environmental impact. **Minimization of consumption:** She tried to reduce the use of electrical appliances to reduce expenses and the carbon footprint. **Exclusion of firewood:** She mentioned not using firewood for cooking or heating water, opting for more energy efficient methods.	**Renewable energy sources:** She was aware of several renewable sources, including biomass, solar photovoltaic, and tidal energy. She knew these sources were mainly used for generating electricity for daily consumption. **Knowledge and observation:** She had already started experiments using glass on a box to accelerate the dehydration of the flowers and achieve a uniform final color. She considered using a solar dehydrator could optimize this technique, allowing better control of times, quantities and processes. This would make it easier for her to conduct more precise experiments and obtain more consistent results. **Economic evaluation:** She had previously used microwaves and electric ovens to dehydrate herself, but feared high electricity bills.
Case 3	**Appliances:** In her daily life, the appliances she uses most are the refrigerator, the stove and the television. **Devices in the business:** In her company, a refrigerator and a blender were used to prevent food from spoiling. **Energy for cooking and transportation**: She used gas to make tortillas by hand and gasoline to travel daily from her house to her business. **Use of firewood:** She occasionally used firewood to prepare dishes for her consumption.	**Knowledge and observation:** She had heard that solar energy was used to heat water, but she did not know other uses of this technology at the time of the intervention. **Economic evaluation:** She mentioned that using solar energy to heat water could benefit her business by helping to cut grease from utensils, as well as reducing gas consumption and, therefore, costs. **Home installation:** She considered installing a solar water heating system. She used gas to heat water for bathing, which was relevant to her because she suffered from bone pain.

Table 2 Qualitative social characteristics in each case.

Case	Interests	Goals	Opportunities
Case 1	She wanted to improve her health conditions through regular medical visits and the consumption of vitamins. She also wanted to promote spirituality within the family nucleus. She was interested in saving fuel for daily use at home. She wanted to implement methods to preserve the environment and share these practices with acquaintances.	She wanted to help people in need by donating food or clothing, and also to achieve the professionalization of her children. She wanted to expand her business and increase production.	She considered cleaning her home and business as responsibilities that must be carried out systematically. She perceived herself as a natural leader, interested in talking to people about a variety of topics. She participated in religious activities through prayer, allowing her to form community groups and foster collaboration in her environment.
Initial status case 1: The local food company, inherited from her family (particularly her mother), has been in operation for over 20 years. Her current establishment employs family members, including her husband and daughters, and has a single outlet.			
Case 2	She wanted to secure her family's financial future to provide long-term stability and opportunity. She also wanted to strengthen the family through good customs and education. She wanted to continue with altruistic activities, especially related to caring for street animals. She learned about new technologies and continued to develop professionally, integrating this knowledge into her household activities.	She wanted to achieve economic stability and ensure a suitable living environment for her family. She wanted to acquire real estate, such as a home or a consolidated business. She wanted to see her family grow and support them in their development as professionals and experts in their respective professional fields.	She considered herself a methodical and critical person with a rigorous approach to life. She was interested in researching and reading about politics, cooking and techniques to improve her activities. She enjoyed teamwork, excelling in social skills and effective communication, facilitating interaction and establishing conversations.

Initial status case 2: A woman with a startup business focuses on preserving flowers and plants to create decorative products such as candles, soaps and keychains. It plans to expand its venture into other areas, including producing pet treats based on dried meat and cleaning products for canines, thus diversifying its offering and taking advantage of its drying techniques.

Case 3	She values preserving her health to continue her business, generate income, and meet her basic needs. She considers rest essential, but her responsibilities at home and in the business prevent her from getting enough rest. She shows no interest in personal possessions such as clothes or shoes. She is focused on fixing the damage to her house caused by the rains. She considers sewer access necessary in her business to improve customer service.	She wanted to achieve the recognition of a more significant number of people and, through recommendations attract more clients. This will improve business conditions and benefit the family. She wanted to have more time for recreational activities, such as walking and resting, as well as pursuing personal interests, such as taking cooking classes. Although she previously enjoyed cooking desserts such as cakes, cookies, and tamales, lack of time has prevented her from resuming this hobby.	People recognize the taste of her food, which has led them to frequent her business since the beginning of her sales. She maintained loyal customers from her previous location in the neighboring municipality, who moved to continue enjoying her food. She considers herself a leader concerned about cleanliness and the delegation of tasks to ensure the proper functioning of her business.

Initial status case 3: The business, dedicated to selling food with varied menus, started to generate income after the owner's sudden unemployment. The main difficulty has been balancing motherhood with running the business.

3.2 Results of the Technical Intervention

After the technical intervention, the results shown below were obtained (Table 3 - Own elaboration). As can be seen, the purpose of the technical surveys, receipt reviews, and interviews on consumption patterns was not to define what technology would be installed but rather to know the energy demand in each case and determine if it was physically possible or not to install technologies that would allow the use of solar energy.

Table 3 Initial energy state of cases.

Case	Electrical consumption status	Thermal consumption status	General conditions
Case 1	Two average bimonthly electric service contracts of 350 kWh and 600 kWh at a 1 A rate	43 kg LPG/monthly average.	It had an area of 8.25 m^2 available for installation, access to the public water network with a storage capacity of 1.1 m^3 and 2.2 m^3, and a 14.47 Mbps broadband Internet connection.
Energy assessment: High monthly electricity consumption with risk of electricity rate adjustment with a higher price per kWh consumption.			
Case 2	Average bimonthly consumption of 250 kWh in 1 A rate	13 kg LPG/monthly average.	It had an area of 25.8 m^2 available for installation, access to the public water network with a storage capacity of 1.1 m^3 and a 6.27 Mbps broadband internet connection.
Energy assessment: Thermal energy demand for the dehydration of plant matter at low temperature.			
Case 3	Average bimonthly electricity consumption of 66 kW in 1 A rate	170 kg LPG/monthly average.	It had an area of 27 m^2 available for the development of a roof that would support the technology. Access to public water network with storage capacity of 1.1 m^3, 5 Mbps broadband internet connection.
Energy assessment: Thermal demand for heating water for sanitary use.			

The last word on what would be installed in each case belonged to the collaborator; the results of the technical intervention only supported the empowerment process that helped her decide about the future of her business in a conscious and informed way.

Regarding infrastructure, specific problems were detected in the participants work areas. In Case 1, an electrical leak was observed attributable to poor installation and inadequate wiring. In Case 2, a change in the participants location was reported, resulting in modifications to the original technical assessment. In Case 3, the need for a structurally sound roof capable of supporting solar technology was identified. Based on the results obtained, participants chose solar technologies as alternative solutions. In Case 1, the need for a photovoltaic installation was determined to reduce the rate of electrical consumption. In Case 2, a hybrid solar dehydrator was selected for food and sweets production. Finally, in Case 3, the importance of a vacuum tube solar heater for hot water heating was determined. Each technology was installed in the women's workshop locations.

3.3 Financial Metrics

Although the main objective of the intervention made in the community with this project was the empowerment of women with productive vocations, the financial metrics offer a glimpse of the economic profitability of the introduction of solar technologies. For this economic analysis, the following economic indicators were calculated for each case: Return on Investment (ROI), Levelized Cost of Electricity (LCOE), and Investment Recovery Period (IRP), considering the initial investment, maintenance costs, savings generated by the substitution of conventional energy sources, helpful life, maintenance frequency, etc. (Table 4 - Own elaboration).

Table 4 Financial metrics for each case.

Case	IRP	ROI	LCOE
Case 1	14.4 years	80.83%	0.053 USD/kWh
Case 2	4.60 years	320.00%	0.022 USD/kWh
Case 3	3.31 years	602.43%	0.028 USD/kWh

In the central region of Mexico, the energy cost, regardless of the technology used for final consumption, is 0.18 USD/kWh for electricity and 0.072 USD/kWh for liquefied petroleum gas (LPG). Therefore, it can be determined that in all three cases, solar technology represents a more economically viable option compared to conventional energy sources.

3.4 Development of Business Plans

The identified characteristics of each business, as well as the direct effects caused by energy aspects such as electricity costs and energy consumption per time, are summarized in the following table (Table 5 - Own elaboration).

Table 5 Characteristics of entrepreneurship in each case.

	Customer profile	Management strategies	Identified barriers
Case 1 consolidated entrepreneurship	The business is aimed at customers who need a quick breakfast in the morning hours. These include students from	**Accounting for Indirect Expenses:** Associated expenses, such as gas, electricity, and gasoline, to get a	**Data Sales Variability:** She was facing irregularities in sales throughout the week, which can affect the

	nearby educational institutions, vendors from the neighboring local market, and regular residents who maintain a traditional relationship with the business.	complete view of operating costs. **Determination of Unit Prices:** Unit prices for each product, adjusting profits according to established priorities to optimize profitability. **Identification of Cash Flows:** Detailed analysis of business cash flows to improve financial planning and decision making. **Price Adjustment:** A possible 20% increase in original prices was recommended to cover additional costs and improve profitability.	financial stability of the business. **High Electricity Costs:** High electricity costs resulting from using semi-industrial refrigerators represent a significant burden on the business. **Personnel Limitation:** The lack of sufficient personnel prevents the optimization and increase of food production, limiting growth capacity. **Electrical Energy Consumption:** Food preparation begins at dawn, requiring a considerable amount of electrical energy for lighting and the operation of the equipment.
The sale of food, specifically tamales and atoles, has been an established activity for over 20 years in the town. The business was consolidated, operating in its premises at the time of the intervention, offering products mainly in the mornings.			
Case 2 relocated entrepreneurship	Since the business specializes in food, its clientele is primarily made up of individuals seeking food during the evening hours due to work or academic commitments. Most customers are graduate students from nearby institutes and employees of local businesses. The owner	**Record of Income and Expenses:** A detailed record is made of the income generated by each product sold, as well as additional daily expenses. **Weekly Menu Planning:** A menu is prepared to anticipate supplies and	**Difficulties in Financial Organization:** Challenges in organizing and managing her finances. **Identification of Popular Dishes:** It has not been identified which dishes are in most significant demand, which makes

	indicated no particular trend observed in terms of age, gender or economic status of the clients.	transportation expenses. **Warehouse Inventory:** An inventory of inputs is maintained to use those with the most significant quantity and prevent the impact of possible price increases.	strategic decision-making difficult. **Using Famous Dishes:** Difficulty utilizing the restaurant's popular dishes when planning special events and creating menus or themed packages. **Menu Planning Methods:** Challenges in finding menu planning and organization methods that fit the owner's available times.
The business offers a different menu every day, and a specific menu twice a week. The company was relatively new in the town, but there was previous experience in other areas.			
Case 3 entrepreneurship incubation	The venture proposed as a key value "Promote the health and well-being of consumers by offering dehydrated edible products with high quality and low cost." Potential customer profiles could include people with a healthy and routine lifestyle and micro and small-scale businesses dedicated to crafts and jewelry manufacturing.	**Customer Profile Validation:** Offer products for resale in businesses in the identified market niche. **Business Expansion:** Expand the offer as suppliers of dehydrated products, including fruits, vegetables, flowers and meat. **Identification of Points of Sale:** Establish nearby points of sale in schools, gyms and cultural centers. **Market Assessment:** Compare products with similar items in the area to evaluate demand and innovation	**Integration of Marketing Strategies:** Combine actions on social networks with physical product activations, such as tastings and workshops. **Target Market Identification:** Find a suitable market for initial products, including scented candles, self-defense items and key chains, that have shown interest among potential customers. **Business Scalability:** Overcome the challenge of scaling the business without

	opportunities in the sector.	sufficient sales and revenue.
The venture was in the initial incubation phase, in which prototypes were being developed, and commercial opportunities were being evaluated. Various ideas are considered for making crafts using dehydrated flowers, to produce and market these items as decoration products.		

4. Discussion

Although the projects presented above have achieved remarkable findings regarding the adoption of solar technologies, they do not consider the perception and needs of each person who makes up that group. Our methodology differs from previous community empowerment projects by focusing on specific personal needs to employ solar technologies in ventures, rather than focusing on community energy or collective training. In addition, it matures business models aimed at productive uses of energy, facilitating technological adoption by women. It includes seven steps: characterization of the peri-urban environment, preparation for field work, tools for social intervention, energy literacy, planning with the maturation of business models, technical installation, and evaluation of technological appropriation. Unlike other projects, our methodology incorporates a participatory intervention, reports long-term impact metrics, and promotes a comprehensive technical-social approach.

The following section offers a critical analysis of the potential impacts of the previously described methodology on significant research on the role of energy as a factor in regional development and as a tool for community empowerment.

4.1 Intersection of Periurbanism and Energy Empowerment

The methodology showed that the prior evaluation of specific characteristics of peri-urban areas, such as the combination of land uses and socioeconomic transition, affects the access and use of energy resources in the daily and economic activities of the region. This has been observed mainly in peri-urban areas, such as the geographic areas of Temixco and Morelos. In these areas, difficulties associated with energy justice issues have been experienced, such as lack of access to electricity, inadequate infrastructure, and frequent power outages. These deficiencies have limited capacity development among residents to efficiently take advantage of energy opportunities. The lack of adequate energy policy formulation in peri-urban contexts has prevented residents from accessing the information necessary to use energy resources optimally.

The present study facilitated a preliminary evaluation of the use of solar technologies as a viable tool to overcome barriers arising from the lack of local energy regulations and training programs. The implementation of decentralized solar technologies not only provided access to reliable energy but also offered additional benefits in terms of sustainability and cost reduction, thus promoting the economic empowerment of women entrepreneurs. In addition, it improved the quality of information on the use of renewable energy and counteracted misinformation, facilitating the dissemination of reliable data.

It is relevant to highlight that energy literacy played a crucial role in women's selection of solar technologies and identifying their benefits. This shows that people with knowledge of energy can use it efficiently, actively participate in energy decision-making, and contribute to constructing more

equitable energy futures [64]. Furthermore, energy literacy is configured as an essential tool for community empowerment.

4.2 Impact on Women's Empowerment

The empirical evidence obtained from social and technical interventions suggests that the integration of training aimed at acquiring specific technical information for selecting technology used in business has had a notable impact on the empowerment of women entrepreneurs. In the context of consolidated companies, such as Case 1, implementing electrical energy allowed a significant reduction in operating costs. In contrast, Case 3 exemplifies how an entrepreneurship model based on thermal energy was designed by the technical scope of said energy source.

The participant's ability to select and apply solar technologies based on their particular needs demonstrates that informed decision-making, supported by specialized technical knowledge, can directly influence economic autonomy and business expansion. These findings align with the literature on female empowerment, highlighting that power and influence are closely related to active participation in decision-making [23, 24].

Consequently, consensual technology transfer, literacy focused on the internalization of prior information, and training on the application of savings derived from solar technologies emerge as key tools whose impact on empowerment is manifested in the economic autonomy of women entrepreneurs.

Women's early interactions with solar technologies allowed them to understand the associated environmental and economic benefits, as well as evaluate the possibility of reducing operating costs and improving efficiency in their productive vocations. This finding suggests that theoretical information presented in an unschooled manner, through energy literacy strategies and training in the management of technologies, facilitates more effective technological acceptance. The indirect benefits of this adoption include increases in income and economic stability, greater security and sustainability in their endeavors, as well as an increase in available free time. These positive effects are consistent with previous studies indicating that access to appropriate energy technologies can have a transformative impact on the lives of women in vulnerable contexts [44, 45].

4.3 Challenges and Opportunities in the Implementation of Solar Technologies

Although the participants recognized in the first work sessions the potential direct benefits of implementing solar technologies, multiple technical challenges related to energy vulnerability were identified. These challenges included uncertainty associated with the technical robustness of the equipment, long-term effectiveness and durability, as well as confidence in the technical information provided during the interviews.

Although each participant managed to address these issues, it is clear that energy vulnerability at the local level manifests itself in several critical aspects. These include the security and stability of energy supply, the ability to install and adapt solar technologies, the affordability of energy solutions, and the design, orientation, and materials of buildings. Furthermore, integrating energy systems represented a significant challenge in peri-urban areas.

The technical evaluation revealed limitations in infrastructure, resources and economic barriers that impacted the adoption process of solar technologies. These challenges align with literature

highlighting the lack of strategic solutions and unequal access to energy technologies in peri-urban areas.

Adapting solar technologies in peri-urban areas could accelerate the transition to an urban environment, promoting economic development, improving education and training, and raising living conditions. Potential benefits include innovation in products and services, such as solar-powered dehydration of ingredients or renewable electricity supply, which could facilitate the standardization of these technologies at a local level.

Implementing decision-making tools and energy literacy training allowed participants to acquire the knowledge necessary to overcome barriers related to the adoption of solar technologies. Significant progress was seen in the understanding of various solar technologies and their applications in both home and business. The success of these interventions underscores the importance of designing empowerment strategies based on a detailed assessment of local needs, livelihoods, and energy use patterns. Although the general methodology includes several steps, these must be adapted to the specific socioeconomic and cultural characteristics of each community.

Furthermore, it is crucial to foster a personal relationship between participants and their work communities, promoting a horizontal structure and mutual learning, as suggested by good practices in energy literacy. The integration of technical and educational components was essential, since it allowed individual progress to be addressed within small communities, in line with the recommendations of [46, 47].

4.4 Adoption of Solar Technologies

One of the main contributions of energy literacy as a research approach is generating knowledge about energy, which enables technological adoption thanks to the management of knowledge about the efficiency, management and maintenance of solar technologies. In addition, it seeks to generate information based on the experience of the beneficiaries, which can be shared with their close circles.

However, for this knowledge cycle to be effective, it is crucial to achieve successful technological adoption, which is not easy to measure. It is essential to identify and evaluate the most relevant factors to generate tacit knowledge based on experience, which drives the frequent use of these technologies. These factors can be classified as technical, social and cultural. Technical factors include the perceived usefulness of the technology, understood as the direct benefit to the user, the ease of its management and maintenance, and the availability of the necessary technological resources, such as solar resources in this case. On the other hand, cultural factors have a significant impact. The acceptance of technology or knowledge is influenced by national culture, which tends to build a "collective truth" when it is widely disseminated, in contrast to more individualistic attitudes that may show skepticism. Likewise, certain attitudes may resist technological change if it challenges traditional customs or beliefs associated with the energy resource. For this reason, it is essential to characterize the beneficiaries and include cultural activities that ensure adequate technological transfer. As for social factors, these can limit the adoption of renewable energy technologies if the norms, influences, and individual beliefs of the beneficiaries are not respected. To mitigate these limitations, it is necessary to build networks of trust that facilitate communication and collaboration, promoting the transfer of knowledge and integrating solar technologies. Finally, effective leadership is crucial in fostering a culture of innovation and learning, encouraging people

to adopt new practices and knowledge. This type of leadership can significantly facilitate the acceptance and sustained use of renewable technologies or help people make informed decisions autonomously.

Although the purpose of the methodology presented was to promote the adoption of solar technology in the daily life and entrepreneurial processes of each beneficiary, it is crucial to consider factors that could affect the long-term sustainability of these technologies, which can be divided into technical and social. Regarding technical aspects, they highlight the need to correctly manage knowledge about periodic maintenance, avoid energy overloads that damage the facilities and apply practices that extend the useful life of the equipment. The perception of usefulness and ease of use are determining elements in technological adoption, so it is suggested to integrate the Technology Acceptance Model (TAM) in future replicas of the methodology, which facilitates appropriation by highlighting these aspects [65].

On the other hand, social factors can hinder sustainability due to resistance to change in contexts where technologies are not widely accepted or disseminated. Likewise, the replicability of benefits over time and the identification of new opportunities for use are essential to consolidate their usefulness. Social influence also plays a key role, as collective recognition of the technology as a standard benefit and active participation in its management are crucial for its successful integration.

Some economic barriers that could hinder technological adoption could involve costs associated with maintenance, component replacement, or energy price inflation. It is, therefore, essential to raise awareness among beneficiaries about the economic benefits, such as reduced use of conventional fuels, energy savings, and access to higher energy consumption through appropriate facility design. In addition, involving them in calculating financial metrics, such as the return on investment period, can help understand the lifespan, maintenance, and replacement times of components, promoting informed management of the technologies. This knowledge can be developed in energy literacy workshops or an additional manual detailing the technical, social, and environmental benefits of solar technologies.

4.5 Recommendations for Public Policies

In this framework, the authors propose the study of the technological adoption of decentralized renewable energies to identify successful strategies for integrating into the productive uses of communities. In this way, a fair energy transition is promoted based on the principles of distributive, procedural, and recognition justice. Public policies must prioritize the transfer and technological adoption of solar technologies in local ventures, especially in peri-urban and vulnerable communities. Distributive justice must guarantee equitable access to these technologies, ensuring their affordability and availability. Procedural justice requires inclusive decision-making processes in which local entrepreneurs, especially women and underrepresented groups, actively participate in the planning, implementation, and evaluation of projects. Likewise, recognition of justice must be reflected in the respect and appreciation of the experiences, knowledge, and cultural contexts of the beneficiary communities. It is necessary to design strategies that respond to their specific needs, promoting their role in technological adoption. These actions will not only strengthen the sustainability of the projects. Still, they will also generate collective empowerment, boost local economic development, and consolidate equity in the transition to renewable energy sources.

Public policies must be based on participatory methodologies and an inclusive approach to promote the transfer of solar technology and the empowerment of women and entrepreneurs. It is essential to involve beneficiaries in the design of the programs, considering their needs, barriers, and local contexts. This includes strengthening female community leadership and adapting technical training to teach practical skills in installation, maintenance, and efficient use of solar technologies, as well as business management and market access. In addition, accessible financial mechanisms must be implemented, such as microcredits, subsidies, or community revolving funds, to facilitate the acquisition of solar technology and the development of sustainable businesses. Policy design must prioritize tax incentives and simplify administrative barriers to encourage female participation in the energy field.

It is also essential to establish specific indicators to measure the impact on the quality of life, income, and confidence of beneficiaries, using methodologies such as Most Significant Change to capture their perceptions and long-term outcomes. Policies must ensure a legal infrastructure that recognizes the value of community energy and promotes gender equity at all stages. To broaden the scope, it is crucial to disseminate local success stories, establish strategic alliances with public and private actors, and develop awareness-raising campaigns on the social, economic, and environmental benefits of solar technologies. This comprehensive approach not only facilitates technological adoption but also promotes sustainability, improves the quality of life, and fosters gender equity in vulnerable communities.

5. Conclusions

The study results highlight the importance of integrating technical and social approaches to address energy challenges in peri-urban areas and promote women's empowerment. The originality of this study lies in integrating social intervention and technological innovation to promote community empowerment through renewable energy-based technology transfer. In addition, the development of co-selection tools is proposed to empower beneficiaries in making decisions related to energy management. In this context, solar energy is a key tool to improve the quality of life and support economic development in vulnerable communities, establishing a solid foundation for future initiatives and policies oriented towards sustainability and equity. The acceptance of energy technologies is influenced by familiarity with existing practices and the cultural perception of new technologies, as well as by initial investment and operational costs, which can restrict adoption of these technologies. These findings have important implications for policy formulation and future research. Energy policies and empowerment programs must be tailored to the specific characteristics of peri-urban areas and consider technical and socio-economic barriers. However, technical training not only improves individuals' skills but also increases their confidence to manage and expand their businesses, facilitating the more active participation of women in the economic sphere and reducing the gender gap in access to opportunities and resources.

Although the present study describes a methodology implemented in three distinct phases, the need to replicate this approach with other groups of people in similar peri-urban contexts is highlighted. Likewise, future research could address the comparison between the methodology reported in this article and other strategies implemented in projects that seek to promote social development through the use of decentralized renewable energy.

On the other hand, additional work derived from this research could focus on the proposal of specific indicators to measure the technological appropriation and empowerment of beneficiaries to understand the relevance that each of them gives to solar technologies in their lives. Furthermore, the application of participatory practices is suggested to evaluate the impacts and individual perceptions of the beneficiaries on the changes experienced in their lives as a result of the implementation of solar technologies, after a significant period of time.

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Author Contributions

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Competing Interests

The authors have declared that no competing interests exist.

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