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Evaluation of rural communities for the planning of renewable energy projects: a SWOT-AHP methodological framework

Evaluación de comunidades rurales para la planificación de proyectos de energías renovables: un marco metodológico FODA-AHP

RUIZ-SUAREZ, Alison†*, MOREIRA-ACOSTA, Joel, IBÁÑEZ-DUHARTE, Guillermo Rogelio and HERNÁNDEZ DOMÍNGUEZ, Erick Alejandro

Universidad de Ciencias y Artes de Chiapas. Instituto de Investigación e Innovación en Energías Renovables. Estudiante de doctorado en Materiales y Sistemas Energéticos Renovable.

ID 1st Author: *Alison, Ruiz-Suarez* / **ORC ID**: 0000-0003-4694-8465, **CVU CONAHCYT ID:** 796976

ID 1st Co-author: *Joel, Moreira Acosta* / **ORC ID:** 0000-0001-6740-7612, **CVU CONAHCYT ID**: 206687

ID 2nd Co-author: *Guillermo Rogelio, Ibáñez-Duharte* / **ORC ID**: 0000-0002-2437-1928, **CVU CONAHCYT ID:** 215574

ID 3rd Co-author: *Erick Alejandro, Hernández-Domínguez* / **ORC ID:** 0000-0001-9267-7681, **CVU CONAHHCYT ID:** 808885

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Abstract

Historically, we know that renewable energies have been a key element for the development of rural communities and have addressed social problems. If we talk about the implementation of renewable energies with the objective of solving social problems, these technologies will be understood as the means of intervention to improve a social, economic or environmental good of a region. The use of methodologies in project management has the benefit of organizing and providing tools to reduce the risks of projects to be implemented in a region. The purpose of this article is to test the suitability of an innovative methodological framework that integrates multicriteria for decision-making and analysis tools (SWOT-AHP). SWOT allows planners to gather relevant knowledge from local stakeholders (Uhunamure & Shale, 2021), while the AHP-Hierarchical Analytical Process allows the prioritization of alternatives. This in order to prioritize the needs to be met in the community, promotes social acceptance of the technology and contributes to the development of rural areas.

Methodology, Renewable Energies and Hierarchical Analysis

Resumen

Sabemos que a lo largo de la historia las energías renovables han sido un elemento clave para el desarrollo de las comunidades rurales y han hecho frente a problemas sociales. Y si hablamos de la implementación de energías renovables con el objetivo de solucionar problemas sociales, estas tecnologías se entenderán como el medio de intervención para mejorar un bien social, económico o ambiental de una región. El uso de metodologías en la gestión de proyectos tiene como beneficio organizar y proporcionar herramientas para reducir los riesgos de los proyectos a implementar en una región. El propósito de este artículo es probar la adecuación de un marco metodológico innovador que integra métodos multicriterio para la toma de decisiones y herramientas de análisis (FODA-AHP). El FODA permite a los planificadores recopilar conocimientos relevantes de las partes interesadas locales (Uhunamure & Shale, 2021), mientras que el Proceso Analítico Jerárquico AHP permite la priorización de alternativas. Esto con el fin de priorizar las necesidades a satisfacer en la comunidad, promueve la aceptación social de la tecnología y contribuye al desarrollo de las zonas rurales.

Metodología, Energías Renovables y Análisis jerárquico

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* Correspondence to Author (Email: alison.ruizs@e.unicach.mx)
† Researcher contributing first author.

Introduction

The implementation of renewable energies in sustainable development projects plays a fundamental role in the transition towards a cleaner and more sustainable energy future (Vanegas Cantarero, 2020). To achieve this objective, various methodologies have been developed that seek to contribute to the effective design of projects based on renewable energy (Guerrero-Liquet et al., 2016), taking into account the energy potential of the area and the environmental impact of said systems. However, it is important to highlight that each methodology is adapted to the specific objectives and criteria of the region in which they are implemented and others are used to develop strategic development plans (Aldossary et al., 2023). Some of the methods and techniques used to properly select renewable energy technologies are (Terrados et al., 2009):

- DELPHI
- Multicriteria methods
- SWOT
- ELECTRE
- PROMETHEE
- EFOM
- Territorial and rural energy planning methods
- Combined methods

Nevertheless, one of the crucial considerations when designing renewable energy projects is to take into account the worldview and needs of rural communities (Ghouchani et al ., 2021) . Worldview refers to the worldview and values rooted in the community, which often differ from mainstream Western approaches. Ignoring the worldview can lead to projects that do not align with the needs, desires and cultural practices of rural communities, which can result in a lack of acceptance and long-term sustainability of implemented energy solutions (Fressoli et al. , 2013) .

Therefore, it is crucial to adopt methodological approaches that recognize and value the worldview of rural communities. To carry out the design of projects based on renewable energy in rural communities, the combination of methodological approaches such as multicriteria methods is required, and the methods that allow evaluating and selecting the most appropriate renewable energy systems, so combining two methods such as SWOT and AHP can achieve a deeper understanding of the needs and priorities of a region (Ordoo et al., 2023), thus maximizing the chances of success and sustainability of the projects (Ottomano Palmisano et al., 2016).

Also, after this introductory section, this document is structured as follows: the methodology, Application of the methodology through a case study and results.

Methodology

The methodology used For a SWOT and AHP analysis to identify needs and priorities in Renewable Energy Projects in rural communities, we divide them into stages:

1. Identification of the rural community and initial data collection:
   - Select a rural community as the object of study.
   - Carry out an initial survey of the community, collecting demographic, socioeconomic information.
2. SWOT Analysis (Strengths, Weaknesses, Opportunities and Threats) (Cisilino & Monteleone , 2020) :
   - Conduct a SWOT analysis of the community, identifying internal strengths and weaknesses, as well as external opportunities and threats in relation to the implementation of renewable energy.
   - To collect relevant information, different techniques can be used, such as interviews with community members, participatory observation, and document review.

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3. Identification of necessities:

   - Use the results of the SWOT analysis to identify the specific needs of the community in relation to the implementation of renewable energy.

   - The needs may include environmental problems, deficiencies in access to basic services, limitations in the existing energy infrastructure, among other aspects.

4. Design of evaluation criteria:

   - Define the evaluation criteria that will be used to classify and prioritize the identified needs. These criteria may include socioeconomic, cultural, and technical factors.

5. Application of the AHP (Hierarchical Analytical Process):

   - Use the AHP method to perform a comparative evaluation and obtain a ranking of the identified needs.

   - Involve experts and key members of the community in decision-making and in assigning weights to established criteria.

   - Make a pairwise comparison matrix for each identified criterion and need, and calculate the relative weights by using preference scales.

   - Carry out the global comparison matrix to determine the final weights of each need and obtain the priority ranking.

6. Selection of sustainable projects:

   - Use the ranking of needs obtained through the AHP as a basis for the selection of sustainable renewable energy projects.

   - Identify projects that address the priority needs of the community and that are feasible in technical, economic, and cultural terms.

Application of the methodology

I. Identification of the rural community and initial data collection:

For this stage of the methodology, the community of San Antonio el Porvenir, La independencia in the state of Chiapas was selected as a case study. The choice is based on its relevance to understanding the challenges and opportunities of implementing renewable energy projects in rural communities. In addition, it presents a high degree of geographic isolation and limited access to basic services.

However, by selecting San Antonio El Porvenir as the object of study, the aim is to generate applied knowledge that allows the identification of the specific needs of the community in terms of sustainable energy solutions. This approach will contribute to making informed and culturally appropriate decisions, maximizing the chances of success and sustainability of the projects implemented in the region.

II. SWOT Analysis (Strengths, Weaknesses, Opportunities and Threats):

Data collection was carried out through a renewable energy workshop that It was designed as an interactive space in which information on different renewable energy systems was provided. The operation and benefits of each system were explained, and the active participation of community members was encouraged. During the workshop, participatory dynamics were carried out, such as debates and practical activities, to promote reflection and the exchange of ideas among the participants. This made it possible to collect information on the knowledge, attitudes and perceptions of the community, as well as to identify possible internal strengths and weaknesses.

Interviews were conducted with the help of the guidelines of the Economic Commission for Latin America and the Caribbean (CEPAL) (Villatoro S., 2012) emphasizing the well-being of the community, this in order to know their feelings with what now have and how they would feel about the implementation of renewable energy systems.

An ethnographic study was also carried out in the community in which some locals were accompanied to work in the coffee plantations, an important economic activity in the community (Rafiq et al ., 2019) . During this immersion experience, we sought to understand in a deeper way the local worldview, cultural practices and the relationship of the community with its natural environment. Through participant observation and informal conversations with locals, valuable information was collected on sociocultural, economic, and environmental aspects that could influence the implementation of renewable energy projects (Roddis et al ., 2020) . These activities allowed obtaining relevant information to identify the strengths, weaknesses, opportunities and threats related to their needs and contribute to the implementation of renewable energies in the community.

III. Identification of necessities:

To identify the needs, a process of review and grouping of the results of the SWOT analysis will be carried out. The identified weaknesses and threats will be considered as problem areas that require solutions, in this case that can be solved with renewable energy, while the strengths and opportunities could serve as a basis for taking into account the level of importance of each need.

IV. Design of evaluation criteria:

Selecting the evaluation criteria is based on considering different relevant aspects for the project and the community in question (Ferrer-Martí et al., 2018) . For this project, the criteria found in Table 1 were selected, These are relevant criteria for evaluating the impact caused by the needs in the community.

ID	Criteria	Description
C1	worldview	Evaluates the cultural values of the community, ensuring that the proposed solutions are congruent with their identity and way of life.
C2	personal well-being	Evaluates the impact of the needs on the well-being and quality of life of the community, considering aspects such as basic needs, social inclusion and community cohesion.
C3	Health	Evaluates the impact on the health of community members, including aspects such as water safety and quality, air quality, disease prevention, among others.
C4	Economic	This criterion evaluates the impact on the economic situation considering income losses, among others…
C5	Environmental	Evaluates the level of awareness of the community regarding pollution, damage to the environment, among others.
C6	Education	Evaluates the impact on education and access to knowledge of community members, considering aspects such as training, energy literacy and environmental awareness.

Table 1 Selected Criteria
Source: Own elaboration

V. Application of the AHP (Hierarchical Analytical Process):

In this stage, the AHP method (Analytical Hierarchy Process) will be applied to classify and prioritize the needs identified in the previous stage. The AHP allows decisions to be made based on multiple criteria and to rank needs according to their relative importance (Saaty , 2003) .

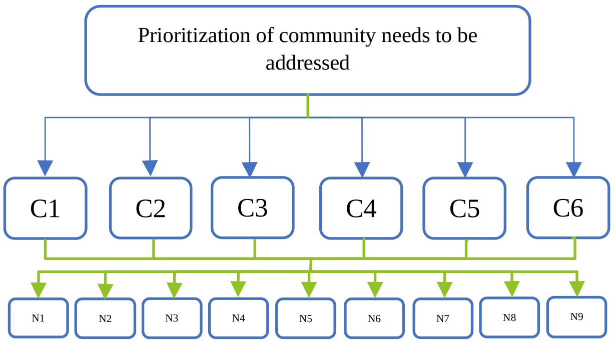

Figure 1 Diagram of the hierarchical structure for decision making where C are the criteria and N the alternatives. *Source: Own elaboration*

Intensity of importance	Definition	Explanation
1	equal importance	The two characteristics contribute equally to the objective
3	Moderate importance over others	Experience and judgment favor one over the other.
5	Strong or essential importance	Experience and judgment are strongly in favor of one over the other.
7	very strong importance	A criterion is strongly favored and its dominance can be demonstrated in practice
9	extreme importance	One of the criteria is strongly favored over another, in high order of affirmation
2,4,6 and 8	intermediate values	When your application is required

Table 2 Saaty scale
Source: (Saaty , 1990)

To use the AHP method we need as a first step to create a pairwise comparison matrix:

The pairwise comparison matrix is used to determine the relative importance relationships between the criteria or alternatives. In this matrix, a value is assigned that represents the relative preference between each pair of criteria or alternatives. The matrix has the following form:

$$X = \begin{bmatrix} x_1 & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{n1} & x_{n2} & \cdots & x_{nn} \end{bmatrix} \quad (1)$$

Where X represents the matrix x_{ij}, and the elements of x_{ij} are numerical values that represent comparisons between criteria or alternatives.

Then a normalization of the matrix (1) is performed in which each element in a column is divided by the sum of all the elements in that column.

$$Wij = xij / \sum(xij) \quad (2)$$

Where:

W_{ij} is the normalized weight of criterion i compared to criterion j, x_{ij} is the value assigned for the comparison of criterion i with criterion j, and $\sum(x_{ij})$ is the sum of all assigned values in the matrix of comparison.

The relative weights of the criteria or alternatives are calculated by multiplying the normalized preferences by the weighted sums of each column of the comparison matrix. The formula is the following:

$$Wi = \left(\frac{1}{n}\right) * \sum(Wij * bj) \quad (3)$$

Where:

W *i* is the relative weight of criterion i, n is the total number of criteria, W *ij* is the normalized weight of criterion i compared to criterion j, b_j is the weighted sum of column j of the comparison matrix.

The AHP method also makes it possible to assess the consistency of the comparisons made using the consistency index (CI). The following formula is used to calculate the CI:

$$CI = (\lambda max - n) / (n - 1) \quad (4)$$

Where:

λ_{max} is the maximum eigenvalue of the comparison matrix, n is the total number of criteria.

A reference value called the Random Consistency Index (RI) is used to assess the CI. The RI is obtained from Table 3 of predefined values based on the size of the comparison matrix. If the CI exceeds the RI, it is considered that there is inconsistency in the comparisons.

matrix size	2	3	4	5	6	7	8	9	10
random index	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Table 3 Random consistency index
Source: (Mu & Pereyra-Rojas, 2017; Saaty , 2003)

Results

SWOT

In the study carried out in the community of San Antonio El Porvenir de la Independencia, Chiapas, various weaknesses that affect their development and well-being were identified. These weaknesses represent areas where the community is facing challenges and needs improvement. Below is a summary of the weaknesses identified, see Table 4:

- Lack of purified water: The community does not have access to quality drinking water, which can put the health of its inhabitants at risk and make their daily activities difficult.
- Poor Sanitation: Lack of adequate sanitation systems can lead to hygiene problems and the spread of disease, affecting the quality of life in the community.
- Loss of post-harvest product: The community faces difficulties in the conservation of its agricultural products after harvest, which results in significant economic losses.
- Inefficiency of kitchen stoves: The use of non-efficient stoves can generate excessive consumption of firewood or other fuels, in addition to generating environmental pollution and affecting the health of the inhabitants.
- Poorly constructed tanks: The lack of properly constructed septic tanks can generate water and soil contamination problems, affecting the health and environment of the community.
- Limited affordable transportation: The lack of affordable transportation options within the community hinders access to external services and opportunities, limiting the development and mobility of the inhabitants.
- Intermittent electricity: The community faces problems of inconsistent electricity supply, which makes it difficult to use electrical appliances and affects the quality of life of the inhabitants.
- Absence of public lighting: The lack of public lighting can generate insecurity and limit night activities in the community.
- Insufficient health service: The community lacks an adequate health service that has the necessary supplies, which can make medical care difficult and affect the health of the inhabitants.

INTERNAL COMMUNITY FACTORS		EXTERNAL FACTORS TO THE COMMUNITY	
WEAKNESSES (-)		THREATS (-)	
1	They do not have purified water	1	Not having purified water represents a health risk
2	do not have sanitation	2	Not having sanitation represents a health risk
3	loss of product postharvest	3	Security economic
4	Kitchen with an inefficient stove	4	Despite having a stove with a fireplace, they cook some food on an open stove .
5	They do not have well-built pits	5	Not having well-implemented post-harvest discharge pits represents a risk of environmental contamination.
6	They do not have affordable transportation within the community	6	Motorcycle taxis are very expensive since they do not have access to fuel
7	Electricity intermittent	7	Education, Food preservation, safety.
8	They do not have public lighting	8	Security , affecting he wellness .
9	They do not have a health service with sufficient supplies	9	
STRENGTHS (+)		OPPORTUNITIES (+)	
1	are one community organized	1	Solar Dryers
2	They are willing to learn	2	Biodigesters
3	They have a main economic activity (Coffee harvest)	3	ecological stoves
4	They use coffee pruning as firewood	4	briquetting machine
5	They have rainwater collection systems	5	Car Water Purifier
6	They have discharge pits for post-harvest residues	6	Transport electric
7	It has public transport for the city	7	charging station
8	has electricity	8	power station photovoltaic
9	They have Telecommunications	9	centales hybrids
10		10	power stations autonomous
11		11	bombs solar
12		12	Kitchens solar
13		13	Solar Hydroponic Crops

Table 4 SWOT of the community of San Antonio el Porvenir de la Independencia. Chiapas. *Source: self made.*

Various threats were also identified that could be identified due to the weaknesses of the community and that represent risks to the health, economic security and well-being of the community, such as:

- Health risk due to the lack of purified water and adequate sanitation, the stoves also create respiratory health problems and environmental contamination.
- Economic insecurity, as the lack of access to affordable fuel makes mobility and transportation within the community difficult.
- post-harvest discharge pits can generate environmental contamination problems and affect the quality of agricultural

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products. In addition, they contaminate the subsoil and aquifers, which can cause health problems.

- Limitations in education and food preservation, which can hinder the development and food security of the community.
- Lack of security, which affects the well-being and quality of life of the inhabitants.

Finally, various strengths and opportunities were identified that can be used for the sustainable development of the community. The strengths of the community are the following:

- Community organization: The community stands out for its organizational capacity, which facilitates the implementation of projects and joint decision-making.
- Willingness to learn: The inhabitants of the community show an open attitude towards learning, which favors the adoption of new technologies and sustainable practices.
- Main economic activity: The coffee harvest is a central economic activity in the community, which provides a base for the development of projects related to the production and commercialization of sustainable coffee.
- Use of coffee pruning as firewood: The use of coffee pruning as a source of firewood demonstrates a sustainable approach to the use of natural resources.
- Rainwater collection systems: The community has systems to collect and use rainwater, so they are willing to make significant changes in their lives.
- Availability of public transport: deficient but the existence of public transport that connects the community with the nearby city facilitates the mobility of the inhabitants and the opportunities for access to external services.
- Access to electricity and telecommunications: Poor, but the community has electrical and telecommunications infrastructure, which favors connectivity and access to information.
- The opportunities that we find in this community are based on the renewable energy systems that can be installed and that can favor the development of the community:
- Solar dryers: The implementation of solar dryers can improve the quality of the coffee drying process and reduce dependence on conventional energy sources.
- Biodigesters: Biodigesters offer an opportunity to take advantage of organic waste and generate biogas as an energy source.
- Green Stoves: The adoption of green stoves can improve energy efficiency, reduce pollution, and reduce the risk of respiratory health problems.
- Briquetting machine : The installation of a briquetting machine makes it possible to convert agricultural waste into fuel briquettes, offering a sustainable alternative to firewood.
- Autonomous water purifier: The implementation of autonomous (solar) water purification systems can improve access to quality drinking water.
- Electric transportation: The adoption of electric vehicles as a means of transportation can reduce dependence on fossil fuels and decrease greenhouse gas emissions.
- Charging station: The installation of a charging station for electric vehicles provides an infrastructure that promotes sustainable mobility.
- Photovoltaic power plant, hybrid plants and autonomous plants.
- Solar Hydroponic Crop Systems to contribute to health systems and contribute to the harvest of food.

AHP

For the prioritization of the needs of the community based on the criteria mentioned in Table 1, a table was made (see Table 5) where we give numerical values to the responses and observations that were obtained in the community to obtain our matrix. of decisions that we can see in Table 6, for example in Table 6 we observe that C1 has a 10 in alternative 1 (A1) that means according to Table 5 that for people in the community it is not a problem not having water purified instead of alternative 4 (A4) and in criterion 1 (C1) indicate the number 1 which means that people in the community believe that cooking with inefficient stoves is a problem.

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Criteria	Measurement
C1	Normal, I don't know , I'm not sure, It's a problem. Assigning values from 1-10, where 1 is a problem, 4 don't know, 7 not sure, and 10 is normal.
C2	Good, more or less, I'm not sure, bad. Assigning values from 1-10, where 1 is bad, 4 is not sure, 7 is more or less, and 10 is Good.
C3	A lot, more or less, I'm not sure, NOTHING. Assigning values from 1-10, where 1 is not at all, 4 is not sure, 7 is more or less, and 10 is a lot.
C4	Good, more or less, I'm not sure, bad. Assigning values from 1-10, where 1 is bad, 4 is not sure, 7 is more or less, and 10 is Good.
C5	A lot, more or less, I'm not sure, NOTHING. Assigning values from 1-10, where 1 is not at all, 4 is not sure, 7 is more or less, and 10 is a lot.
C6	yes, more or less, I'm not sure, no. Assigning values from 1-10, where 1 is No, 4 I'm not sure, 7 more or less and 10 is Yes.

Table 5 Table of measurement values
Source: Own elaboration

	C1	C2	C3	C4	C5	C6
A1-They do not have purified water	10	10	7	1	1	1
A2-Postharvest grain losses	1	1	4	10	4	10
A3-They do not have sanitation	7	10	1	1	4	1
A4-Kitchen with an inefficient stove	1	4	4	7	7	4
A5-They do not count well-constructed pits	10	7	1	4	10	1
A6-They do not have affordable transportation within the community	10	10	1	1	1	4
A7- Intermittent electricity	10	10	1	1	1	4
A8-They do not have public lighting	4	10	1	1	1	4
A9-They do not have a health service with sufficient supplies	7	7	4	4	1	1

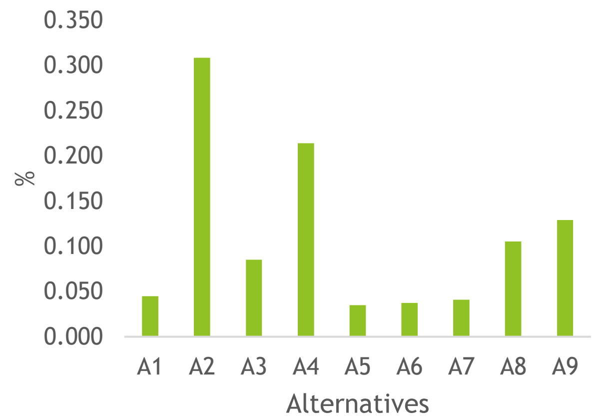
Table 6 Decision matrix
Source: Own elaboration

Then we have Table 7 of the weighting of the criteria that were described and evaluated by a group of 8 professionals with experience in the field. For this project, the worldview of the community was taken into account, with this their uses and customs will be respected, and it will help that this methodology is not invasive in their lifestyle.

Criteria	AHP Weighting
worldview	31%
Welfare	24%
Health	20%
Economic	15%
Environmental	4%
Education	6%

Table 7 Weighting of the criteria
Source: Own elaboration

As a result of the order of needs according to the AHP method, alternative 2 or the need for loss of coffee beans in the community would be the first to be addressed.



Graphic 1 Ranking of you need
Source: Own elaboration

Selection of renewable energies

For this case study, the first order of need was to treat the loss of the coffee product, this under expert opinion, alternatives were given to avoid this loss since the coffee harvest time is annual and in the rainy season, it is worth mentioning Since it is a community in a mountainous area and moving the coffee beans would be very expensive, the proposals for solving the problem based on renewable energy are hybrid solar dryers with a secondary source of biofuel or biogas energy.

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Conclusions

In conclusion, the SWOT analysis and expert opinion played a fundamental role in identifying priority needs in the rural community of San Antonio El Porvenir de la Independencia, Chiapas. During this process, it was recognized that the main criteria to be considered was the worldview of the community, since the proposed technologies and solutions could only be implemented and accepted if they were aligned with their values and ways of life.

The AHP method allowed to classify and prioritize the identified needs, and among them, the loss of coffee beans during the rainy season emerged as the most pressing need. This finding highlights the importance of addressing this challenge to improve the sustainability and economy of the community, especially considering that coffee harvesting is a core economic activity.

In this context, the relevance of focusing on solutions such as solar dryers, which could provide the community with a sustainable alternative for drying coffee during the rainy season, thus reducing economic losses and strengthening their well-being, is highlighted.

Ultimately, this study highlights the importance of taking into account the worldview and well-being of the rural community when designing and implementing renewable energy projects. By addressing priority needs and ensuring that proposed solutions are culturally appropriate and aligned with community values, the chances of long-term success and acceptance are increased. This guarantees that renewable technologies are not only effective in terms of sustainability, but also contribute to the integral development and well-being of the rural community, which in this case was San Antonio El Porvenir de la Independencia, Chiapas.

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