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Methodology for selecting rural energy alternatives applied to the Colombian context.

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Abstract- Rural electrification is a current need, especially in developing countries; in this context, the selection of energy alternatives is an important challenge that goes beyond simply providing energy, as the processes must guarantee the triple bottom line for the sustainability of the solution. There are several methodologies that have considered this aspect, but they are not applicable in all contexts, as there may be limitations in the regions where the analysis is required for community electrification. In the case of Colombia, the entity responsible for implementing energy solutions in non-interconnected areas is the Institute for Planning and Promotion of Energy Solutions, IPSE. This study has analyzed the processes documented by IPSE for the evaluation of energy alternatives in rural areas and found that they have a general approach and require greater specificity to identify the most appropriate energy alternative according to the location, revealing the opportunity to offer greater robustness in the processes, selection, and weighting of criteria.

In order to identify opportunities for improvement and to arrive at a successful methodology, a comparative analysis was carried out against existing state-of-the-art rural electrification methodologies, accompanied by institutional guidance documents. As a result of the comparison, a proposed methodology scheme was constructed that includes the relevant criteria for the Colombian context, including the implementation of microgrids as an alternative.

Keywords: Rural electrification, methodology, Colombia.

I. Introduction

Nowadays, access to electricity service is a necessity and a focus of interest for many governments and corporations. Around 900 million people do not have access to energy, despite global efforts for a sustainable future [1]. This service is essential for the development and improvement of the quality of life of communities to cover their basic energy demand [2].

The main challenge of energization in the world lies in supplying electricity in rural areas lacking quality and uninterrupted power supply. These areas are characterized by the difficulty and high costs of extending the conventional power grid to remote sites [3].

Therefore, in recent years, methodologies for rural energy planning have been developed, highlighting the complexity of decision-making to select the best alternative that meets the needs of the population to electrify the rural area [4].

In Colombia, non-interconnected areas (ZNI) represent 52% of the national territory [5], areas that are served by the Institute for Planning and Promotion of Energy Solutions, the entity in charge of supply the energy needs of the ZNI. The complexity of the terrain and the considerable distance from grid connection points make it difficult to extend the grid to remote areas that lack electricity service [4]. In addition, the low population density, and their ability to pay aggravate the expansion of the Interconnected System to these places [3]. Given these challenges, microgrids emerge as a viable solution to address the lack of access to electricity in rural areas of Colombia, offering a decentralized and adaptable alternative to local needs [6]. A review did not find a clearly defined methodology or defined processes for decision making in rural electrification in Colombia, the methodologies found are not articulated with each other and additionally, are not aligned to the procedures of IPSE, and in the same way, consider microgrids as an option for energization [4], [7], [8].

In order to obtain a proposed methodology for the Colombian context, the processes that are currently carried out by the structurers or contractors to present the analysis of energization alternatives to the IPSE were identified and characterized. Subsequently, a review of documents that address the energization of non-electrified rural areas was carried out and contrasted with the current processes in Colombia. Finally, possible improvements were analyzed and a methodology for rural electrification that integrates microgrids as an energy solution was proposed.

II. METHODOLOGY

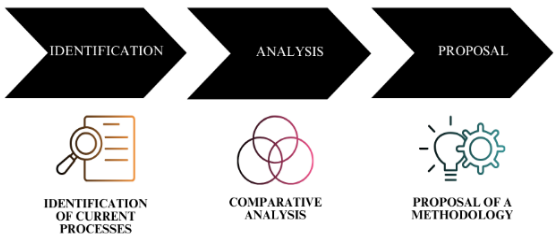

Figure 1. Methodology

The development of this work follows the process shown in Figure 1. It begins with an identification of the current processes, where documents and feasible projects for the energization of ZNI were reviewed and their stages were characterized, with their respective limitations and challenges. A comparative analysis was also carried out, which consisted of a bibliographical review related to the electrification of remote areas, together with a contrast with the processes currently carried out by IPSE. Finally, a methodology was proposed based on an analysis of the possible improvements that can be made and an integration of microgrids as an energy solution in the Non-Interconnected Zones.

III. IDENTIFICATION OF CURRENT PROCESSES.

Within the analysis and documentary review that was carried out, various institutional methodologies were identified that provide specific guidelines for carrying out this type of analysis, such as the Adjusted General Methodology of the National Planning Department, the Indicative Plan for the Expansion of Electricity Coverage and Sustainable Microgrids in ZNI of Colombia Inteligente.

The identified process is presented in Figure 2, describing each stage carried out by the structurers to date. As can be seen, the processes are very superficial and lack detail to contrast the alternatives, even considering the possibility of extending the electricity grid. It also highlights the need to develop more defined and detailed criteria to assess the viability and effectiveness of microgrids in the Colombian context.

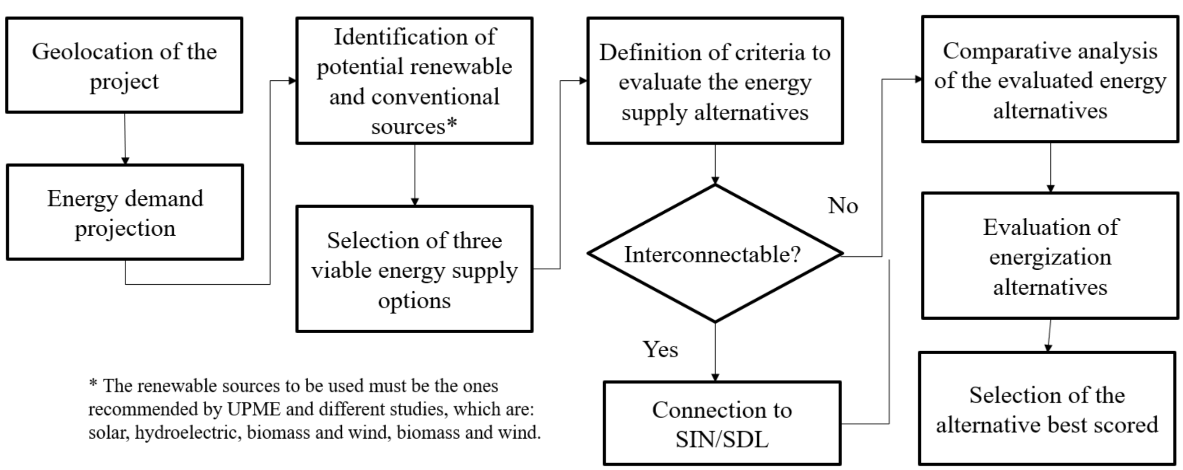

Figure 2. Processes identified from the analysis of energization alternatives in the Colombian rural zones.

The analysis of alternatives is an important step in IPSE's decision-making. The different energy options or solutions are evaluated. It begins with a characterization of the community, where the area where the project will be carried out is identified and geographically located, and a projection of the demand for electricity is made. The next activity consists of identifying the energy sources, whether conventional or non-conventional, and based on their potential, the 3 options with the greatest energy supply viability are selected, discarding them for logic or low technical viability, as recommended in the Conceptual Manual of the Adjusted General Methodology (MGA), designed by the National Planning Department [8]. The next step is the definition of criteria for the subsequent evaluation of alternatives, ranging from technical criteria to environmental and social components.

Additionally, the connection to the National Interconnected System or to the Local Distribution System is evaluated according to the conditions of the nearest connection point [9].

IV. COMPARATIVE ANALYSIS

In 2018, M. Patel and S. Kumar Singal, from a state-of-the-art review of methodologies for modelling and implementing renewable energy systems, found that most areas without access to electricity services have high potential for alternative energy [7]. S. Bohra, Anvari-Moghaddam and Mohammadi-Ivatloo, in 2019, presented a multi-criteria decision model based on the Analytical Hierarchical Process (AHP) for the planning of energy sources in microgrids [9]. They performed an analysis of different combinations for the microgrid, taking the electricity grid as the main source, reflecting the importance of solar photovoltaic energy in microgrids. Similarly, Ciller categorizes the tools and methodologies that support the design, formulation and planning of rural electrification projects according to their level of modelling complexity. Thus, these tools can be used in: i. Pre-feasibility studies; ii. Intermediate (feasibility) studies; and iii. Detailed analyses, including electrical designs for all grid extensions and microgrids. As the complexity of the modelling increases, the uncertainty tends to decrease [10].

Ciller, 2020, approaches an analysis of the rural electrification problem from an integrated perspective, identifying the need to solve three interrelated sub-problems: i. The choice of electrification mode for each consumer, either through grid extension, the implementation of mini-grids or stand-alone systems, as well as the grouping of consumers into clusters; ii. The design of generation systems for each off-grid system, including generation technologies and capacities, as well as their dispatch strategy to meet demand at different times of the day; iii. The grid design for each microgrid and the medium voltage grid extension [10].

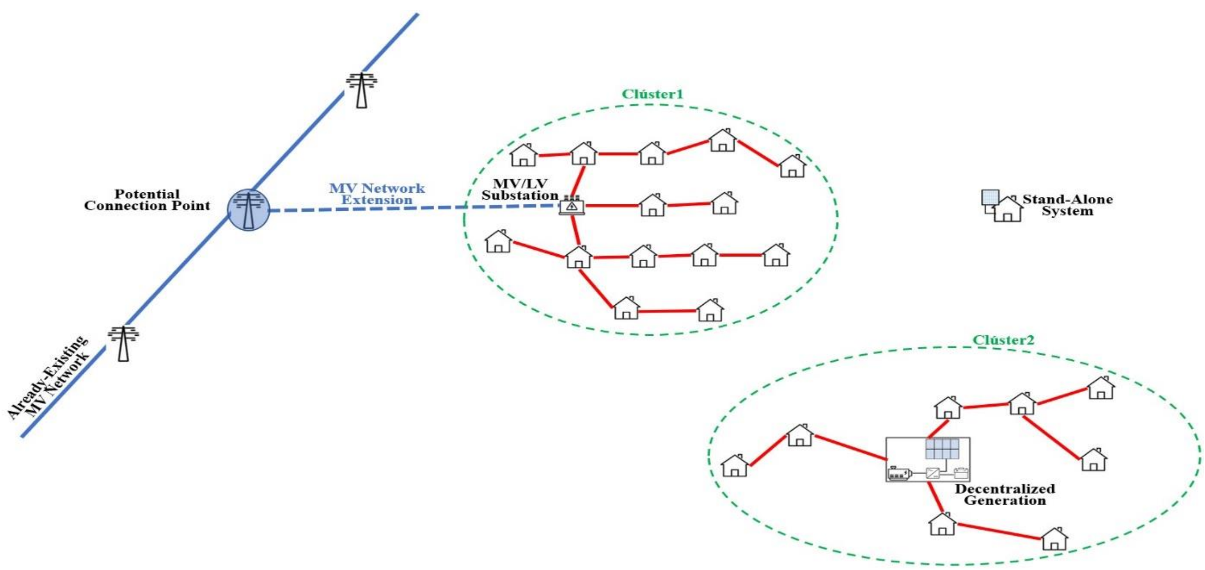

Fig 3. Outline of the rural electrification problem. Cillier

Elkadeem, in 2020, has developed a methodology that supports the recommendations of the Adjusted General Methodology. He mentions that energy planning is summarized in 3 main stages: pre-feasibility, feasibility, and optimality. In pre-feasibility, the input data are orography, topography, location, and site constraints. For feasibility, meteorological and energy demand profile data are incorporated to enable modelling of power system configuration for a rural off-grid area. In the paper, they use the HOMER software to optimize the evaluated scenarios according to the economic, technical, social, and environmental criteria proposed by three expert panels for the calculation of weights and scores [8].

In the specific case of Colombia, the US - National Rural Electric Cooperative Association NRECA published a report in 2018 presenting a national rural electrification strategy for remote/isolated areas with willingness to pay, specifically an electrification plan for the department of La Guajira, considering three electrification solutions: i) grid extension; ii) isolated solar photovoltaic systems configured in distributed generation mini-grids; iii) individual isolated systems. The report found that grouped dwellings within 600 meters of the medium voltage (MV) grid were technically and financially feasible to connect to the grid, while those between 600 and 2000 meters should be assessed for the feasibility of grid extension [14].

After a thorough analysis of existing rural energy methodologies, opportunities for improvement were identified in the processes implemented by IPSE. In the methodological basis it was found that there was no defined strategy. Therefore, it was decided to support the proposal in a Multicriteria Decision Making (MCDM) methodology due to its recognized accuracy in obtaining weighted and equitable results compared to other methods [11]. In particular, the lack of user clustering in the IPSE methodology was noted, a practice that several authors have highlighted in their publications as an essential element for detailed electrification planning in rural areas without energy services [10].

During the analysis, there was a lack of technical support to support the selection of only three viable energy supply options in the IPSE methodology. This limitation at this stage constrains the process, as greater flexibility is required in the selection of options, supported by detailed analysis and the potential available in the area. In addition, there is

the technologies to be analyzed. Finally, in optimality, the alternatives are qualified according to the evaluation method relevant to the case and, as a result, the best ranked alternative is selected [9], which is a very relevant stage for decision-making processes. In the same year, Ali, Aghaloo, Jaudat, Chiu and Ahmad conducted a state-of-the-art study with the aim of finding the best hybrid

no clarity on the types of generation systems to be evaluated in the analysis of alternatives.

Regarding the criteria, it was noted that the current methodology lacks a comprehensive definition for generic application and weighted weighting of the criteria. In response, it is proposed to include specific criteria, carefully selected according to best practices from the literature reviewed, and a weighted weighting calculation according to the AHP methodology.

For the decision between grid expansion or proposing an off-grid solution, the recommendations of NRECA in its 2018 report and Colombia Inteligente are evaluated, considering the dispersion of users and their distance to the nearest grid connection point.

In addition, the inclusion of institutional criteria is proposed, in line with the trends and inconveniences generated by some projects because they are not in line with the government's current plan. This improvement aims to consolidate a set of robust and adaptable criteria that contribute to a more complete and objective evaluation of the energy alternatives.

Based on the methodologies reviewed [4], [6], [11], [12], [13], [14], [16], [17], the most relevant elements were synthesized and unified. Connections between the different approaches were established and common elements and areas of convergence were identified in order to achieve a robust methodology. (Fig. 4) Among the common steps identified is the input of geographical data and characteristics of the rural area and its electricity demand. At the same time, the available energy resources, mainly renewable, are identified. The criteria for qualifying the alternatives are then defined according to the bibliography or authors consulted. Finally, the best ranked alternative capable of meeting the community's needs is selected.

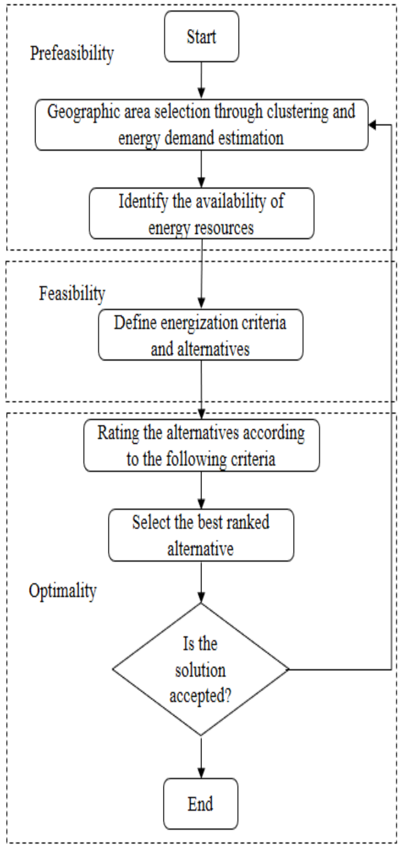

Fig 4. Rural electrification generic methodology

V. PROPOSED METHODOLOGY

The comparative analysis of existing methodologies for the selection of energy alternatives in isolated areas, carried out in the previous chapter, allowed us to identify both current practices and emerging trends in this area. From this evaluation, specific aspects were highlighted that represent opportunities for improvement and greater efficiency of the current methodology.

The proposed methodology seeks to address these identified limitations, to be in line with the generic methodology identified (Fig. 4) and, at the same time, to comply with the standards established in rural electrification and the requirements of the financing funds dedicated to this type of project in Colombia When carrying out the geographical and energy characterization of the community, a clustering of the area is included. After identifying the energy potentials, the supply options that present the greatest viability are selected. Next, the previously defined selection criteria are applied through a bibliographic review and with scores assigned by approximation to the mean of the values used by the authors of the review.

Finally, with the information collected in geolocation about the distance to the nearest grid connection point, a decision is made to determine the viability of implementing an off grid system compared to an on grid system.[12], and based on the dispersion of users without electric energy service identified in the clustering, the energization alternatives are evaluated using based on the dispersion of users, according to the proposal from Colombia Inteligente (Table 1), to be subsequently rated according to the criteria and weightings based on the revised methodologies, shown in Table 2, to select the one that obtains the best score.

The final proposed methodology is shown in Figure 5

	Attribute	Expansion to grid (1)	Microgrid (2)	Independent (3)	Comments
Greografics	Grid distance (km)	X < (5 to 15)	X < (10 to 20)	NA	Evaluate comprehensively with the demand
	Dispersion (kW/km2)	X > (1 to 2)	X > (1 to 2)	X < (1 to 2)	
	Dispersion (Homes/km2)	X > (10-50)	X > (10-50)	X < (1-10)	

Table 1. Attributes for the expansion of Red. Colombia Inteligente [9]

Criterion	Sub criterion	Description	Weighing
Financial	Investment cost	Total cost of equipment, transportation, and labor	0.231
	O&M cost	Operating costs including salaries and repairs	0.167
	Energy cost	Evaluates the expected cost of electricity produced by a power plant over its useful life.	0.143
Technical	Reliability	Safety against system limitations due to generator or faults	0.112
	Technological maturity	Expertise in equipment maintenance and operation	0.088
	Resource availability	Resource potential in the area	0.074
Social	Employment creation	Number of direct and indirect jobs generated	0.044
	Social acceptability	Degree of acceptance by the local community	0.051
Environmental	land use	Amount of space required for facilities	0.030
	GHG emissions	CO2, CH4 and N2O emissions during the project life cycle	0.026
Institutional	Tax benefits	Incentives and tax discounts for investment	0.019
	Institutional alignment	Integration into national energy policy	0.015

Table 2. Criteria for selecting alternatives.

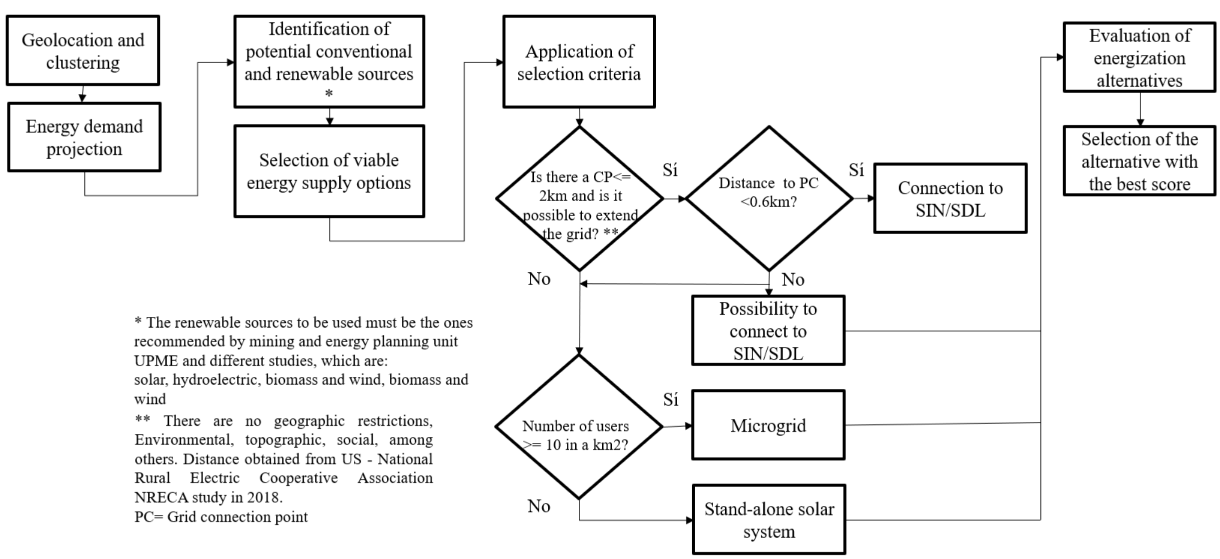

Fig 5. Proposed methodology for the selection of rural electrification alternatives in Colombia

VI. CONCLUSIONS

The analysis carried out on the documented processes in Colombia for the evaluation of rural electrification alternatives shows that they have a very general approach and require greater specificity in order to identify the most appropriate electrification alternative according to the place.

As a result of the contrast made between the documentation found with rural electrification methodologies referring to the state of the art, accompanied by institutional guidelines documents. An alignment with the general processes was identified, but specifically it revealed the opportunity to offer greater detail and solidity in the processes, as well as to consider criteria more aligned with successful experiences in other contexts, considering expert references for their weighting.

Based on the guidelines established by government agencies and the methodologies reviewed in the literature, a proposed methodology scheme was constructed that includes the relevant criteria for the Colombian context, including the implementation of microgrids as an energy alternative.

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