



Data Article

Data set for the generation of strategies in the selection of renewable energies in Colombia: Evaluation of AHP and FAHP from regional potentials towards a sustainable future



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ABSTRACT

This analysis examines the evaluation of alternatives using the AHP (Analytic Hierarchy Process) and FAHP (Fuzzy Analytic Hierarchy Process) methodologies in five scenarios (SC1 to SC5), with the aim of comparing the effectiveness of both approaches in incorporating environmental and technical criteria. The findings reveal that, in the SC1 scenario, AHP assigns weights of 14.35 % to A1 and 16.22 % to A2, while FAHP shows a greater dispersion and highlights A6 with 35.22 %. In SC2, AHP favors A1 with 14.16 % and FAHP increases the weight of the environmental criterion to 21.18 %. In SC3, A1 remains the preferred option in both methodologies, although AHP and FAHP exhibit a close weight of 34.00 % and 32.98 %, respectively. In SC4, AHP and FAHP maintain a similar trend, with A1 standing out with 11.12 % and A4 with 34.87 %. Finally, in SC5, the findings show that AHP allocates 8.52 % to A1, while FAHP indicates 10.73 %. The observations suggest that FAHP allows a greater sensitivity to variations in the sub-criteria, thus facilitating a more accurate assessment aligned with sustainability objectives. The relevance of environmental and social criteria across the different scenarios

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highlights the need to integrate more sustainable approaches into decision-making. It is deduced that, although AHP provides consistent outcomes, FAHP might be more suitable for evaluating alternatives in contexts where complexity and uncertainty are significant. It is recommended to perform sensitivity analysis to delve into the influence of variations in the weights of the criteria on final decisions.

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Specifications Table

Subject	Implementation of renewable energies
Specific subject area	Use of metaheuristic methods for the selection of the best source of renewable energy according to the energy potential of each area
Type of data	Table and graph raw
Data collection	The data were collected by means of surveys to a group of experts on the subject, for the survey an online program called QuestionPro was used, in these surveys it was important to know in advance the energy potential of each geographical area of Colombia. The results of these surveys were downloaded and processed and analyzed by AHP and FAHP programming using Excel.
Data source location	the data were collected and analyzed on computers belonging to and located at the Universidad de la Costa, said institution is located in Barranquilla, Colombia, it is located approximately at 10.9632° latitude and -74.8063° longitude.
Data accessibility	Repository name: Mendeley Data https://data.mendeley.com/datasets/vzwegpxw2w9/1

1. Value of the Data

The data collected and analyzed in this research are important due to:

- They establish a unique and unprecedented investigation in the Colombian territory.
- It allows to lay a foundation for future research, not only in the Colombian territory but also at the LATAM level
- These collected data allow evaluating and comparing the implementation of two metaheuristic methodologies such as AHP and FAHP.
- They concentrate relevant information on the perception of experts on the weighting of criteria and/or sub-criteria, as well as the selection of renewable energy sources according to potentials of an area

2. Background

In recent years, there has been a growing acknowledgment within the international community of the pressing need to combat climate change and transition toward sustainable economies. A critical aspect of this shift is the adoption of renewable energy sources, which serve as cleaner alternatives to fossil fuels and hold the potential to drastically cut greenhouse gas emissions [1]. Nevertheless, the deployment of renewable energy technologies encounters significant obstacles due to the variability of natural resources and the unique geographic and climatic conditions in different regions. These elements have a direct impact on the technical and economic viability

ity of renewable energy projects, complicating the efficient design of energy matrices in diverse geographical areas [2].

Globally, nations such as Germany, the United States, and China have advanced in diversifying their energy portfolios by incorporating a higher proportion of renewable energy sources, including solar, wind, and hydroelectric power. However, energy planning in these countries remains a complex process, necessitating the consideration of multiple factors to identify optimal energy options tailored to regional characteristics and energy demands. Multicriteria decision-making methodologies, such as the Analytic Hierarchy Process (AHP), have been widely documented in the scientific literature as effective tools for this purpose [3]. These methodologies simplify complex decision-making problems by organizing them into hierarchical structures, enabling evaluations based on technical, economic, social, and environmental dimensions.

In Colombia, a nation with extraordinary geographical and climatic diversity, transitioning to a more sustainable energy system presents distinct challenges. Despite having abundant renewable energy potential—such as solar resources in the Caribbean and Orinoquía regions or wind energy in La Guajira—the country's energy matrix remains insufficiently diversified. Currently, Colombia's reliance on hydropower, which constitutes roughly 70 % of its installed capacity, has made it vulnerable to extreme weather phenomena such as El Niño, which disrupt power supply stability [4]. This dependence underscores the urgent need to broaden the country's energy portfolio to enhance the resilience and reliability of its energy system [5].

Energy planning in Colombia is further complicated by regional disparities. The country's distinct geographical zones—such as the Altiplano Cundiboyacense, the Eastern Plains, and the Pacific region—each have unique climatic, geographic, and infrastructural conditions. Consequently, implementing a uniform national energy strategy is unfeasible. Therefore, there is a pressing need for a regionally adaptive energy planning approach that identifies the most suitable energy sources using multicriteria analysis [6].

Previous studies have explored various methodologies to tackle this challenge. AHP, pioneered by Thomas L. Saaty in the 1970s, has proven to be a powerful tool in energy planning by breaking down complex decisions into hierarchies that include criteria and sub-criteria [7]. This approach allows both qualitative and quantitative comparisons of alternatives. Despite its effectiveness, a key limitation of AHP is its inability to adequately handle the uncertainty and subjectivity inherent in human judgments, particularly when information is incomplete or vague [8].

To overcome this limitation, the Fuzzy Analytic Hierarchy Process (FAHP) was developed, integrating fuzzy logic to address uncertainty and ambiguity. Introduced by Lotfi A. Zadeh in 1965, fuzzy logic offers a mathematical framework to accommodate subjective evaluations that cannot be precisely quantified. FAHP has demonstrated particular efficacy in contexts with incomplete or imprecise data, such as evaluating renewable energy options across geographically diverse regions [7]. However, the application of FAHP in Colombia's energy planning is still in its early stages, and research that combines this approach with the country's specific geographical and climatic characteristics remains limited [9].

This study seeks to address this gap by comparing the performance of AHP and FAHP methodologies in selecting renewable energy sources for different Colombian regions [10]. The central hypothesis posits that integrating FAHP with traditional AHP provides a more robust decision-making framework, capable of better handling uncertainty and subjectivity [3]. The research evaluates energy alternatives—such as solar photovoltaic, onshore and offshore wind, biomass, geothermal, and both large- and small-scale hydropower—based on multidimensional criteria encompassing technical, economic, social, and environmental factors [11].

The implementation of these methodologies will not only allow for a more precise and adaptable evaluation of energy alternatives but also lead to more efficient and sustainable energy planning, tailored to the specific characteristics of each region. By integrating AHP and FAHP, this study will provide a practical guide for decision-making in Colombia's energy planning, offering a methodological tool that can be replicated in other contexts with similar characteristics [5].

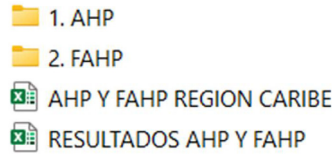


Fig. 1. Structure of the database.

3. Data Description

Fig. 1 shows how the database used in this research is organized.

The folder named "AHP" contains the mathematical development and the results of the implementation of the AHP metaheuristic methodology, for each of the areas studied, while the folder named "FAHP" contains the mathematical development and the results now with this new methodology for each of the areas studied in this research. The other two Excel files found in this database contain the synthesis of the results found for each of the study areas and each of the implemented methodologies.

4. Experimental Design, Materials and Methods

The Hierarchical Analytical Process (AHP) is a methodology developed by mathematician and economist Thomas L. Saaty in the 1970s. This technique has become a fundamental tool in multi-criteria decision-making and has found applications in a wide variety of fields, from investment selection to natural resource management and strategic planning [6]. Thomas L. Saaty, a leading scholar in the field of game theory and operations research began developing the ideas that would lead to AHP in the early 1970s. The motivation behind their work was to provide a framework that would allow people to make more informed and logical decisions in complex situations involving multiple criteria and alternatives. Saaty formulated the mathematical foundations of the AHP, which are based on matrix theory and mathematical logic [7].

The central idea of the AHP is to break down a decision-making problem into a hierarchical structure of criteria and sub-criteria, and then use a comparison matrix to capture the preferences and relationships between these elements [41]. In 1980, Thomas L. Saaty published the book entitled "The Process of Analytic Hierarchy" (AHP), in which he exhaustively presented the AHP methodology and its applications in decision-making. This book became a fundamental reference in the field of multi-criteria decision-making [8].

As the benefits of the AHP methodology spread, its adoption in various disciplines increased. It has been used in investment project selection, natural resource management, decision-making in strategic planning, choice of technologies, and more recently in artificial intelligence and machine learning applications [9]. Over the decades, Saaty and other researchers have continued to develop and refine the AHP, introducing variants and extensions of the methodology to address specific problems and improve its applicability in real-world situations.

The methodology section of this article deploys a meticulous and rigorous approach to addressing the particular challenges associated with the evaluation of renewable energy sources in Colombia. The implementation of metaheuristic methods, specifically TOPSIS and TOPSIS with fuzzy logic, constitutes the backbone of our methodological strategy. These approaches were carefully selected due to their demonstrated ability to deal with the complexity inherent in decision-making in a changing and diverse environment such as Colombia's [10]. The choice of TOPSIS and TOPSIS with fuzzy logic as metaheuristic methods is the result of careful evaluation of their suitability to address the variables and uncertainty associated with the selection of renewable energy sources. TOPSIS, with its ability to handle multiple criteria and provide trade-

Table 1

List of alternatives.

A1	Hydroelectric
A2	Wave
A3	Tidal
A4	Biomass
A5	General wind power
A6	PV
A7	Geothermal

offs, offers a robust basis for the weighting and prioritization of energy options [11]. On the other hand, the integration of fuzzy logic in TOPSIS is justified by its ability to model the imprecision inherent in the variability of renewable energy sources, ensuring a more realistic and adaptive approach [12].

The methodology developed takes into account the geographical diversity of Colombia, characterized by variations in altitude, climates and topographies. The application of these methods is tailored to the particularities of each region, recognizing that there is no single approach that can encompass the complexity of the country's geographical conditions. The adaptability of TOPSIS and TOPSIS with fuzzy logic is presented as an essential element in ensuring that renewable energy decisions are contextually relevant and strategically informed [13]. The methodology section details the key Steps of implementation, from data collection to final evaluation [14]. Specific criteria, such as the availability of natural resources, environmental impact and economic viability, are included to ensure a holistic assessment of each renewable energy source. In addition, sensitivity analyses are integrated to evaluate the robustness of the results in the face of possible changes in environmental or technological conditions [15].

The validation of the results obtained by applying AHP and AHP with fuzzy logic is done through comparisons with conventional approaches and the review of experts in the field [16]. This validation process guarantees the reliability and practical applicability of the results, strengthening the contribution of this research to the emerging field of efficient renewable energy management in Colombia [17], for this research, 7 energy alternatives were used as evidenced in Table 1 and were implemented in 5 possible scenarios, according to the 5 geographical regions that comprise the study area, as evidenced in Table 1.

Colombia has a great diversity of natural and climatic resources that make it possible to generate renewable energy in all its geographical regions, by taking advantage of these resources in a sustainable, responsible way and with the right decision-making, the percentage of success in planning, execution and commissioning of energy generation projects with non-conventional sources would increase [18].

Caribbean Region (SC1):

Colombia's Caribbean Region, known for its cultural richness and Caribbean coastline, offers great potential for renewable energy generation. With a tropical climate, this region has abundant solar resources that make it ideal for the installation of photovoltaic solar energy systems. In addition, its extensive coastline provides opportunities for offshore wind energy, taking advantage of the winds that blow over the Caribbean Sea. Biomass is also a promising source in this region, given the availability of agricultural and forestry residues for energy production [19].

Pacific Region (SC2):

The Pacific Region of Colombia, known for its biodiversity and its coastline on the Pacific Ocean, has great potential for renewable energy generation. Its dense jungles and humid climate offer optimal conditions for energy production using biomass and biogas, using organic waste and agricultural waste. In addition, its coastline exposed to Pacific winds makes it ideal for offshore wind energy, taking advantage of the strong winds that blow over the ocean [20].

Andean Region (SC3):

Colombia's Andean Region, characterized by its mountainous topography and fertile valleys, presents great potential for a variety of renewable energy sources. Its high mountains offer op-

Table 2

Methodology implementation scenario.

SC1	CARIBBEAN 1
SC2	PACIFICA 1
SC3	ANDEAN
SC4	AMAZONIAN
SC5	ORINOQUIA

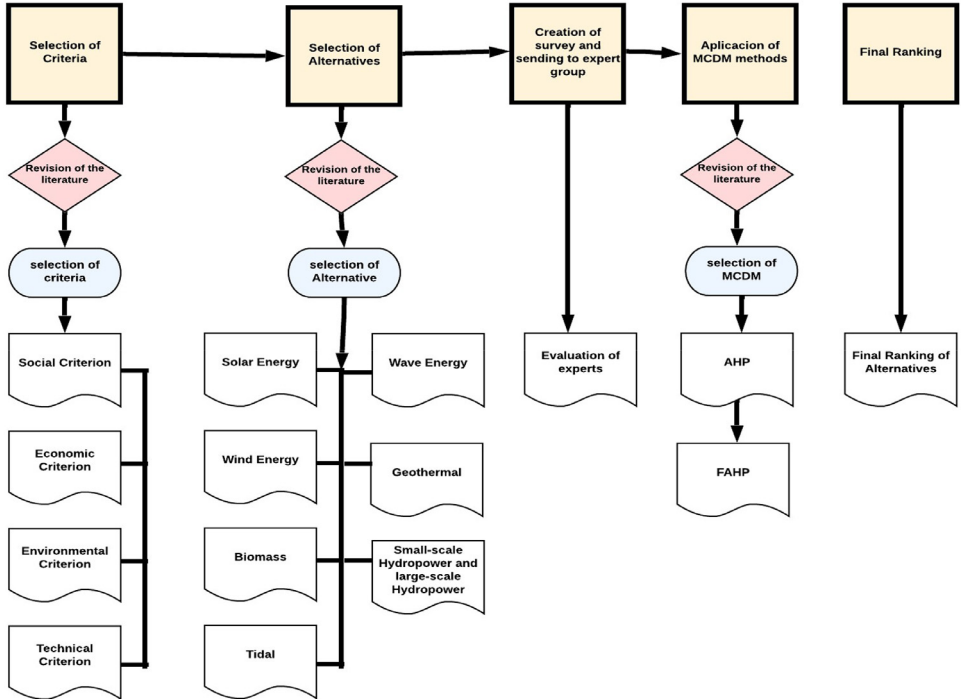


Fig. 2. Methodological process.

portunities for large-scale hydroelectric power, taking advantage of the mighty rivers that descend from the Andes Mountains. In addition, its temperate climate and high altitude make it conducive to solar photovoltaic and wind energy in mountainous areas [20].

Amazon Region (SC4):

Colombia’s Amazon Region, known for its lush rainforest and unique biodiversity, offers great potential for renewable energy generation. Its dense vegetation and humid climate make it ideal for energy production using biomass and biogas, using organic waste and forest waste. In addition, its extensive network of rivers, such as the Amazon River and the Caquetá River, offers opportunities for large-scale hydropower, harnessing the flow and energy of these waterways [20].

Orinoquia Region (SC5):

Colombia’s Orinoquia Region, characterized by its vast plains and rushing rivers, offers great potential for renewable energy generation. Its wide lowland areas and tropical climate make it ideal for the installation of large-scale solar PV systems. In addition, its many rivers, such as the Meta River and the Orinoco River, offer opportunities for hydropower and biomass energy from agricultural and forestry residues [20]. [Table 2](#)

As a synthesis of the methodology implemented in this research, it is expressed in [Fig. 2](#), however, in the following subsections a general explanation of each of the steps is made

4.1. AHP methodology

In summary, a series of explanatory steps for the implementation of the hierarchical analytical process methodology are presented, it is expected that this summary will be easy to understand:

Table 3

AHP Methodology [4].

Definition of the problem	<ul style="list-style-type: none"> • Identify and clearly define the decision-making problem. • Establish the objectives and criteria for evaluating the alternatives.
Hierarchization	<ul style="list-style-type: none"> • Decompose the problem into a hierarchy of criteria and sub-criteria. • Identify and organize the key factors influencing the decision.
Peer-to-peer comparison	<ul style="list-style-type: none"> • Perform peer-to-peer comparisons to assess the relative importance of criteria and sub-criteria. • Assign numerical values that represent the preferences of the experts.
Comparison matrix	<ul style="list-style-type: none"> • Build a matrix that reflects the preferences of the experts. • Collect the comparisons between pairs to calculate the weights.
Standardization	<ul style="list-style-type: none"> • Normalize the comparison matrix to ensure that the weights add up to one. • Ensure the consistency of the weights
Calculation of global weights	<ul style="list-style-type: none"> • Calculate the overall weights based on comparisons and normalization. • Determine the contribution of each element to the final decision.
Consistency	<ul style="list-style-type: none"> • Evaluate the consistency of comparisons using the consistency index. • Make adjustments in case of inconsistencies in the matrix.
Multicriteria analysis	<ul style="list-style-type: none"> • Use the calculated weights to evaluate the alternatives. • Conduct a multi-criteria assessment to determine the most appropriate option.
Synthesis of Results	<ul style="list-style-type: none"> • Synthesize the results of the evaluation. • Present the alternatives ordered according to their performance in relation to the criteria.
Sensitivity	<ul style="list-style-type: none"> • Perform a sensitivity analysis to assess the impact of changes in preferences. • Determine how variations in judgments affect decisions.
Decision-making	<ul style="list-style-type: none"> • Use the results of the AHP analysis to make informed decisions. • Select the best alternative considering the weightings of the criteria.

4.1.1. Implementation of the AHP methodology

Step 1: Modeling

In this phase, the hierarchical sequence of problems is implemented and the objectives, criteria and alternatives to be implemented are defined according to the criteria of the experts. Next, the alternatives through which the criteria to be evaluated are established; These criteria should take into account the problem and identify attributes that help make good decisions [17]. These criteria should be measured at the level, which is the fundamental goal we must achieve to solve the problem, and at the second level, the criteria will be positioned according to a descending hierarchy of one or more variables for each criterion. The third and final layer will be the alternatives in decision-making [13].

Step 2: Reviews

Once the alternatives are understood and the criteria defined, each criterion is classified and weighted when selecting the alternatives. The intent of this process is to measure the impor-

tance that decision-makers assign to each criterion or alternative i , compared to each criterion or alternative j . A baseline scale of 1 to 9 was used to assess the relative preference of the items, Table 4 [20].

Table 4
Implementation of the Saaty scale according to the degree of importance (Saaty, 1980) [13].

Value	Definition
1	Equal importance
3	Moderate importance
5	Great importance
7	Very important
9	Extreme importance
2, 4, 6 and 8	Intermediate values

In this way, we proceed to construct the matrix of paired comparisons, where we obtain a square matrix $A_{n \times n} = [a_{ij}]$, with $1 \leq i, j \leq n$. For the construction of the matrix, the following axioms must be considered:

Axiom of reciprocity: If A is a matrix of paired comparisons, then it is true that if $a_{ij} = x$ then $a_{ji} = 1/x$ with $1/9 \leq x \leq 9$

For the property of reciprocity, only $n(n-1)/2$ comparisons are made:

Axiom of homogeneity: The elements that are compared with each other will be of the same order of magnitude and hierarchy.

Axiom of independence: When the decision-maker makes the comparisons, it is assumed that the criteria do not depend on the different alternatives.

By complying with the above axioms, it is possible to determine the desired comparison matrix, Table 5

Table 5
Example of a comparison matrix.

	A1	A2	A3
A1	1	A12	A13
A2	A21	1	A23
A3	A31	A32	1

Step 3. Prioritization and synthesis

After comparing the paired matrices, we proceed to calculate since this is a priority to be made. This underscores the importance that decision-makers attach to each element.

The priority is represented as a vector or vectors, assuming that it is a matrix A ($n \times n$), as obtained by making comparisons in pairs, we call the solution of the equation eigenvalues or eigenvectors of A ($\lambda_1, \lambda_2, \lambda_n$): $\det(A - \lambda I) = 0$. The principal eigenvalue (λ_{max}) of the matrix is the maximum value of the eigenvalue obtained by performing the above formula.

The principal eigenvalue of $\{A\}$ and $\{a\}$ is the associated eigenvector. The eigenvectors associated with the value of probabilities are the weighting vectors that must be achieved.

Thus, the eigenvector achieved is that of the criteria matrix, which we call V_c , which represents the relative importance of each criterion selected in the joint evaluation of the alternatives on which we work. When the eigenvector obtained is the eigenvector of the surrogate matrix for a given criterion, we call it V_{ai} (column vector), which represents the relative importance of each surrogate matrix for criterion i where we obtain as many eigenvectors as standard. Something to keep in mind is that the final decision is the consistency of the decision-maker's decision when completing the matching matrix.

In this way, the decision made by the insured is a personal judgment, which leads to an inconsistency that is evaluated to determine if the limits are below what corresponds.

Step 4. Consistency Analysis

This analysis considers the subjectivity of manufacturing decisions. When performing a process of comparing matrices in pairs, subjectivity is as real and objective as possible because the different elements of one matrix are in turn compared with another matrix.

On the other hand, there is a procedure to calculate it. If acceptable, the decision-making process can continue, but if not, more in-depth analysis is required, as it can review judgments about peer comparisons. Calculate the consistency ratio using Eq. 1, see Table 5.

Standard Matrix A:

$$Anormalized \left[\frac{a_y}{\sum_{k=1}^n a_{kj}} \right] \tag{1}$$

The sum of the rows is obtained from Eq. 2:

$$\begin{aligned} \frac{a_{11}}{\sum_{n=1}^n a_{n1}} + \frac{a_{12}}{\sum_{n=1}^n a_{n2}} + \dots + \frac{a_{1n}}{\sum_{n=1}^n a_{nn}} &= b_1 \\ \frac{a_{21}}{\sum_{n=1}^n a_{n1}} + \frac{a_{22}}{\sum_{n=1}^n a_{n2}} + \dots + \frac{a_{2n}}{\sum_{n=1}^n a_{nn}} &= b_2 \\ \frac{a_{n1}}{\sum_{n=1}^n a_{n1}} + \frac{a_{n2}}{\sum_{n=1}^n a_{n2}} + \dots + \frac{a_{nn}}{\sum_{n=1}^n a_{nn}} &= b_n \end{aligned} \tag{2}$$

The priority vector B that is formed is given by Eq. (3):

$$\left[\frac{b_1}{n}, \frac{b_2}{n}, \dots, \frac{b_n}{n} \right]^T \tag{3}$$

The product of the original matrix A and the priority vector B forms a matrix of column C, Eq. (4):

$$A * B = C = [c_1, c_2, \dots, c_n]^T \tag{4}$$

Table 6

Comparison between the obtained CI and the random CI.

Die Size (n)	1	2	3	4	5	6	7	8	9	10
Random consistency	0.0	0.0	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

CI: Consistency Index

Consequently, the quotient between the column of matrix C and the priority vector B is calculated, obtaining another vector of column D, Eq. (5):

$$\frac{C}{B} = D \tag{5}$$

By adding and averaging its elements, the value of the consistency index (CI), Eq. (6), is obtained:

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{6}$$

Subsequently, the CI obtained is compared with the random CI in Table 3:

The random consistency (CI) value as a function of the matrix size represents the CI value that would have been obtained if the numerical judgments of the scale had been entered into the comparison matrix in a completely random manner [15].

Therefore, the CI is divided by random consistency, thus obtaining the Inconsistency Index (IR), Eq. (7):

$$IR = \frac{CI}{Random\ consistency} \tag{7}$$

Finally, a consistent matrix is considered when the values stipulated for the size of each matrix are not exceeded, [Table 6](#). If a matrix exceeds the consistency coefficient, the valuations performed are checked and modified.

4.2. FAHP methodology

The Hierarchical Analytic Process with Fuzzy Logic (FAHP) methodology is an extension of the AHP (Hierarchical Analytic Process) that incorporates fuzzy logic to address uncertainty and ambiguity in multi-criteria decision-making. Although the exact history of its development is not as widely documented as that of the AHP. Fuzzy logic, developed by [60] in the 1960s, provides a framework for representing and managing uncertainty in data and judgments. In an effort to combine the advantages of AHP with fuzzy logic's ability to deal with uncertainty, researchers began exploring the extension of AHP with fuzzy logic [6]. Throughout the 1990s and 2000s, there was significant growth in research and literature related to FAHP. Researchers from various disciplines, such as engineering, management, and artificial intelligence, contributed to the development and adaptation of FAHP methods for specific applications. As the FAHP methodology gained popularity, specific variants and extensions were developed to address particular problems. These variants are tailored to the needs of a variety of applications and industries, including project management, engineering decision-making, and strategic planning. Although there is no specific event or prominent figure behind the development of the FAHP as in the case of the AHP, its evolution is a testament to the adaptability and versatility of multi-criteria decision-making methods in response to decision-making needs in uncertain environments [18]. The FAHP methodology has proven to be a valuable approach to addressing complex problems in which uncertainty and ambiguity are key elements.

In the same way that the steps for the AHP methodology were explained, the steps to achieve the implementation of the fuzzy hierarchical analytical process FAHP are now summarized, see [Table 7](#)

Table 7
FAHP methodology.

Definition of the problem	<ul style="list-style-type: none"> Identify and clearly define the decision-making problem. Establish the objectives and criteria for evaluating the alternatives.
Hierarchization	<ul style="list-style-type: none"> Decompose the problem into a hierarchy of criteria and sub-criteria. Identify and organize the key factors influencing the decision.
Peer-to-peer comparison	<ul style="list-style-type: none"> Perform peer-to-peer comparisons to assess the relative importance of criteria and sub-criteria. Assign numerical values that represent the preferences of the experts
Comparison matrix	<ul style="list-style-type: none"> Build a matrix that reflects the preferences of the experts. Collect the comparisons between pairs to calculate the weights.
Standardization	<ul style="list-style-type: none"> Normalize the comparison matrix to ensure that the weights add up to one. Ensure the consistency of the weights.
Calculation of global weights	<ul style="list-style-type: none"> Calculate the overall weights based on comparisons and normalization. Determine the contribution of each element to the final decision.
Consistency	<ul style="list-style-type: none"> Evaluate the consistency of comparisons using the consistency index. Make adjustments in case of inconsistencies in the matrix.
Multicriteria analysis	<ul style="list-style-type: none"> Use the calculated weights to evaluate the alternatives. Conduct a multi-criteria assessment to determine the most appropriate option.
Synthesis of Results	<ul style="list-style-type: none"> Synthesize the results of the evaluation. Present the alternatives ordered according to their performance in relation to the criteria.
Sensitivity	<ul style="list-style-type: none"> Perform a sensitivity analysis to assess the impact of changes in preferences. Determine how variations in judgments affect decisions.
Decision-making	<ul style="list-style-type: none"> Use FAHP analysis results with fuzzy logic for informed decisions. Select the best alternative, considering the uncertainty.

This section presents the fundamental concepts that guided this study. The intention is not to cover all topics, but to provide essential support information to understand in a very good way the objective of the research, the context and the results, in this research initially a characterization of a specific population, I seek to evidence the social, economic, environmental and energy reality of this. To carry out this characterization, the different existing government and research databases were consulted.

It happens that the characterizations of the population nature manage to obtain as results information on the structure and large number of identity attributes of various groups of people with evolutionary continuity over time, which according to their differences configure particular ways of being and being in a territory, in this research it was taken to the department of La Guajira in the country of Colombia, Because this area is a territory very rich in natural resources, which makes it a potential in the implementation of renewable energy sources, however despite this natural disposition, this area of that country is one where its inhabitants suffer from a poor quality of life.

These studies that characterize a population in relation to its energy potential also allow us to focus attention on guaranteeing or restoring the effective enjoyment of the rights of population groups, the recognition of their diversity and multiculturalism as social wealth, the particularities and inequalities that hinder or enable their access to the dynamics and benefits of social and territorial development. The importance of correctly directing the appropriate forms of population characterization exercises lies in the fact that they allow the design, adjustment, and implementation of public policies to be based with a view to transforming situations considered problematic and offering goods and services that satisfactorily respond to the needs and interests of population groups.

On the other hand, the hierarchical analytical method with fuzzy logic was implemented with the aim of prioritizing the barriers that may arise in the implementation of energies with renewable sources, in the aforementioned study area for The explanation of this methodology was separated into sections for a better understanding.

4.2.1. Fuzzy assembly operations

- The complementary set of a fuzzy set \bar{A} One is one whose characteristic function is defined by

$$m_{\bar{A}}(x) = 1 - m_A(x) \quad (8)$$

- The union of two fuzzy sets A and B is a fuzzy set $A \cup B$ in U whose membership function is:

$$m_{A \cup B}(x) = \max(m_A(x), m_B(x)) \quad (9)$$

- The intersection of two fuzzy sets A and B is a fuzzy set $A \cap B$ in U With feature function:

$$m_{A \cap B}(x) = \min(m_A(x), m_B(x)) \quad (10)$$

The main operators that meet the conditions for t-conorms are the maximum operator and the algebraic sum

$$m_{A \cup B}(x) = m_A(x) + m_B(x) - m_A(x) m_B(x) \quad (11)$$

And the main operators that meet the conditions to be t-standards are the minimum operator and the algebraic product

$$m_{A \cap B}(x) = m_A(x) m_B(x) \quad (12)$$

4.2.2. Fuzzy relationships

$$R(U, V) = ((x, y), m_R(x, y)) | (x, y) \in U \times V \quad (13)$$

Suppose

$R(x, y)$ and $S(x, y)$

They are relationships in the same product space $U \times V$. The intersection or union between R and S , which are compositions between the two relations, are defined as:

$$m_{R \cap S}(x, y) = m_R(x, y) * m_S(x, y) \tag{14}$$

$$m_{R \cup S}(x, y) = m_R(x, y) * m_S(x, y) \tag{15}$$

If $R \circ S$, R and S belong to discrete universes of discourse. It is defined as a fuzzy relationship in $U \times W$ whose membership function is given by:

$$m_{R \circ S}(x, z) = \sup_{y \in V} [\mu_R(x, y) * \mu_S(y, z)] \tag{16}$$

where the SUP operator is the maximum and the operator* can be any T-standard. Depending on the t-standard chosen we can obtain different compositions; The two most commonly used compositions are the maximum-minimum composition and the maximum composition of the product:

- The max-min composition of the fuzzy relations $R(U, V)$ and $S(V, W)$, is a fuzzy relationship $R \circ S$ in $U \times W$ defined by the membership function

$$\mu_{R \circ S}(x, z) = \max_{y \in V} \min[\mu_R(x, y) * \mu_S(y, z)] \tag{17}$$

Where $(x, z) \in U \times W$

- The composition of the maximum product of the fuzzy relations $R(U, V)$ and $S(V, W)$, is a fuzzy relation to $R \circ S$ in $U \times W$ defined by characteristic function

$$\mu_{R \circ S}(x, z) = \max_{y \in V} [\mu_R(x, y) * \mu_S(y, z)] \tag{18}$$

Where $(x, z) \in U \times W$

4.2.3. Fuzzy implication

As we have already seen, in terms of the theory of fuzzy logic, the proposition "if you is A, then v is B", where $u \in U$ and $v \in V$, has an associated characteristic function that takes values in the interval. Examples of possible associated characteristic functions, drawn from the application of the analogies between operators and the aforementioned tautology, are

$$m_{A \rightarrow B} = (x, y)$$

$$m_{A \rightarrow B}(x, y) = 1 - \mu_{A \cap B}(x, y) = 1 - \min[\mu_A(x), 1 - \mu_B(y)] \tag{19}$$

$$m_{A \rightarrow B}(x, y) = \max[1 - \mu_A(x), \mu_B(y)] \tag{20}$$

$$m_{A \rightarrow B}(x, y) = 1 - \mu_A(x)(1 - \mu_B(y)) \tag{21}$$

In fuzzy logic, the Modus Ponens extends to what is called Generalized Modus Ponens and can be summarized as follows:

Premise 1: "u is A"

Premise 2: "if you are A THEN v is B"

Consequence: "v is B"

where the fuzzy set A^* does not necessarily have to be the same as the fuzzy set A of the rule's antecedent and the fuzzy set B^* does not necessarily have to be the same as the fuzzy set B that appears in the rule's consequence.

Thus, the generalized Modus Ponens is a fuzzy composition in which the first fuzzy relation is the fuzzy set A^* and which can be expressed:

$$\mu_{B^*}(y) = \sup_{x \in A^*} [\mu_{A^*}(x) * \mu_{A \rightarrow B}(x, y)] \tag{22}$$

Taking into account that, in the applications of fuzzy logic to engineering, the characteristic function of the implication is built with the minimum and product operators, which in addition to being the simplest preserve the cause-effect relationship, we will have two options to choose from:

$$\mu_{A \rightarrow B}(x, y) = \min[\mu_A(x), \mu_B(y)] \tag{23}$$

$$\mu_{A \rightarrow B}(x, y) = \mu_A(x) \cdot \mu_B(y) \tag{24}$$

4.2.4. Methods of organizing

- Maximum Method: The output variable for which the characteristic function of the fuzzy output set is maximum is chosen. In general, it is not an optimal method, as this maximum value can be reached by several outputs.
- Centroid method: Uses the center of gravity of the output characteristic function as the output of the system. Mathematically [7]

$$y = (\int y \mu_A(y) dy) / (\int y \mu_B(y) dy) \tag{25}$$

It is the most widely used method in applications ranging from fuzzy logic to engineering as a single solution is obtained, although it is sometimes difficult to calculate.

- Height method: The center of gravity of the diffuse output set B_m is calculated for each ruler and then the system output is calculated as the weighted average:

$$y_h = (\int \bar{y}_m \mu_{B_m}(\bar{y}_m) dy) / (\int \mu_{B_m}(\bar{y}_m) dy) \tag{26}$$

4.2.5. Fuzzy logic analysis

If it is a set of objects and a set of objectives, according to Chang's (1996) extended analysis method, the extended analysis is developed for each of the values of the objects; In this way they can be obtained for each objective $X = \{x_1, x_2, x_3, \dots, x_n\}$ $U = \{u_1, u_2, u_3, \dots, u_n\}$ [26] Therefore, the extended analysis values of m can be obtained with the following notation [27]:

$$M_{gi}^1, M_{gi}^2, \dots, M_{gi}^m = 1, 2, 3, \dots, n. \tag{27}$$

where everything is fuzzy triangular numbers. $M_{gi}^1 (j = 1, 2, 3, \dots, m)$

Key steps of the model proposed by Chang (1996)

Step 1: The value of the object - th of the extended analysis is defined as:

$$S_i = \sum_{j=1}^m M_{gi}^j \otimes \left[\sum_{i=1}^n \sum_{j=1}^m M_{gi}^j \right]^{-1} \tag{28}$$

To obtain, the fuzzy addition operation of m values of the extended analysis is performed for a particular matrix, such that: $\sum_{j=1}^m M_{gi}^j$

$$\sum_{j=1}^m M_{gi}^j = \left(\sum_{j=1}^m l_j \sum_{j=1}^m m_j \sum_{j=1}^m u_j \right) \tag{29}$$

To get, perform the fuzzy sum of values operation, so that: $[\sum_{i=1}^n \sum_{j=1}^m M_{gi}^j]^{-1} M_{gi}^1 (j = 1, 2, 3, \dots, m)$

$$\sum_{i=1}^n \sum_{j=1}^m M_{gi}^j = \left(\sum_{i=1}^n l_i \sum_{i=1}^m m_i \sum_{i=1}^m u_i \right) \tag{30}$$

Then the inverse vector of the equation is calculated, as follows:

$$\left[\sum_{i=1}^n \sum_{j=1}^m M_{gi}^j \right]^{-1} = \left(\frac{1}{\sum_{i=1}^n u_i}, \frac{1}{\sum_{i=1}^n m_i}, \frac{1}{\sum_{i=1}^n l_i} \right) \tag{31}$$

Table 8

Fuzzy triangular conversion scale.

Linguistic scale	Triangular Diffuse Triangular
Just the same	(0,0,0)
Degradably important	(0,1,3)
Important	(1,3,5)
Much more important	(3,5,7)
Very strongly more important	(5,7,9)
Absolutely more important	(7,9,9)

Step 2: The degree of chance of it occurring is defined as: $M_2 = (l_2, m_2, u_2) \geq M_1 = (l_1, m_1, u_1)$

$$V (M_2 \geq M_1) = \sup_{y \geq x} [\min(\mu_{M_1}(x), \mu_{M_2}(y))] \tag{32}$$

And it can be expressed equivalently as follows:

$$V (M_2 \geq M_1) = \text{hgt}(M_1 \cap M_2) = \mu_{M_2}(d) = f (d)$$

Yes $m_2 \geq m_1$

$$\text{Yes } l_1 \geq u_2 = \begin{cases} 1, & \\ 0, & \\ \frac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)} & \end{cases} \tag{33}$$

Where d is the ordinate of the highest point of intersection D between y To compare and the values of y are required $\mu_{M_1} \mu_{M_2} M_1 M_2$

$$V (M_2 \geq M_1) V (M_1 \geq M_2)$$

Step 3: The degree of chance that a fuzzy convex number is greater than k

Convex numbers are defined as:

$$V (M \geq M_1, M_2, \dots, M_k) = V[(M \geq M_1) y (M \geq M_2) y (M \geq M_k)] = \min V(M \geq M_i), i = 1, 2, 3, \dots, k$$

Therefore, assuming that:

$$d' (A_i) \min V (S_i \geq S_k) \tag{34}$$

For. The weight of the vector is given by: $k = 1, 2, 3, \dots, n; k \neq i W' = (d' (A_1), d' (A_2), \dots, d' (A_n))^T$

Where are n elements? $A_i (i = 1, 2, 3, \dots, n)$

Step 4: Vector normalization is presented as follows:

$$W = (d (A_1), d (A_2), \dots, d (A_n))^T \tag{35}$$

Where W is not a fuzzy number, but the set of weights of each matrix.

In this case, it must be taken into account that W are no longer fuzzy numbers, but vectors with the final weights. Table 8 shows the values used in the conversion of the linguistic syntax used by the experts and their respective assessment into fuzzy triangular and triangular numbers. Finally, Fig. 3 presents a diagram that explains how the hierarchical analytical process can be implemented or developed with fuzzy logic, with this scheme it is intended to provide an explanatory tool of this process for future research.

4.3. Identification of problems and alternatives

Colombia, a nation characterized by its geographical and climatic diversity, faces a diverse energy problem in its different regions. Historical dependence on non-renewable sources and

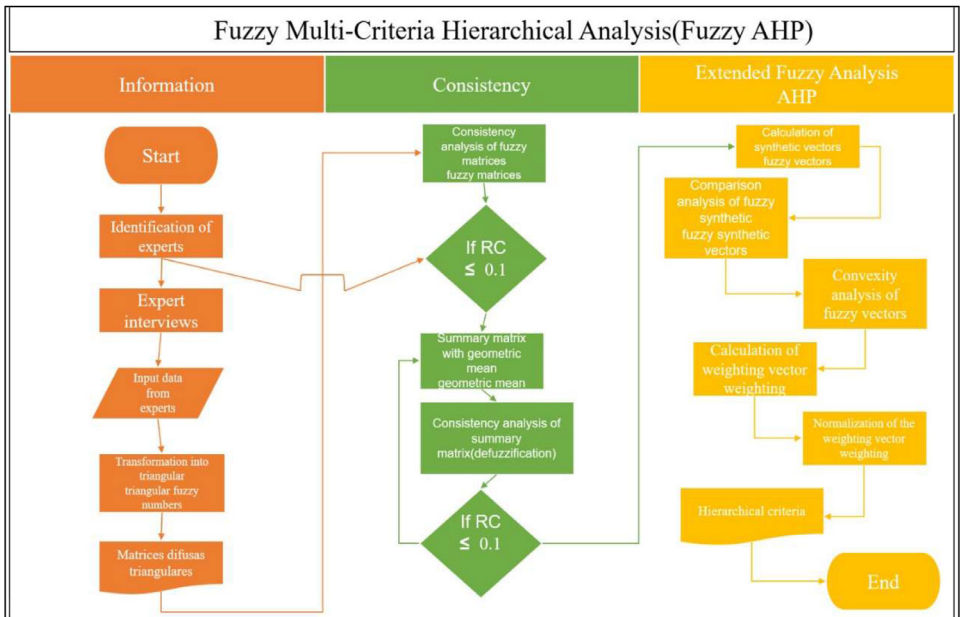


Fig. 3. FAHP Implementation Scheme.

variability in the availability of energy resources have led to significant challenges in the supply of sustainable and reliable energy. In response to this problem, a meticulous evaluation of energy alternatives is required, considering the economic, social, political and technical contexts of each region [48, 66].

4.4. Regional energy problems

Caribbean (SC1): Coastal regions face high potential for solar and wind energy, but lack of investment and political instability have limited the development of renewable projects. Vandalism and terrorism are also a concern in some areas.

Pacific (SC2): Despite their abundant hydropower and biomass potential, the Pacific regions face challenges in terms of infrastructure and limited grid access. In addition, the social acceptance of projects can be a problem.

Central and Western Andes (SC3): These mountainous regions present great potential for large-scale hydroelectric power generation. However, existing infrastructure needs to be updated and adapted to topographical challenges. In addition, the lack of grid access in some areas requires decentralized solutions, such as solar and small hydropower.

Amazon and Orinoco (SC4 and SC5): These vast regions have enormous potential in biomass and hydropower. However, the ecological impact and concerns about technological maturity require careful assessment.

4.5. Identification of problems, criteria and sub-criteria

4.5.1. Workarounds [66]

To address this diverse energy problem, several alternatives are being considered:

Solar Energy (A6): Take advantage of solar radiation in regions with this potential.

Table 9

Characteristics of the experts consulted.

Number	Occupations	Years of experience
1	Field Engineer (Mechanical Engineer)	5
2	Field Engineer (Mechanical Engineer)	8
3	Field Engineer (Mechanical Engineer)	6
4	Field Engineer (Mechanical Engineer)	4
5	Field Engineer (Electrical Engineer)	5
6	Field Engineer (Electrical Engineer)	8
7	Field Engineer (Electrical Engineer)	7
8	Field Engineer (Electrical Engineer)	4
9	Field Engineer (Electrical Engineer)	4
10	Field Engineer (Electrical Engineer)	5

Wind energy (A5): Use of wind speed in coastal and mountainous areas.

Biomass (A4): Use of agricultural and forestry residues.

Tidal and wave movement (A2 and A3): Exploiting the potential of the Caribbean and Pacific coasts.

Small and large-scale hydropower (A1 and A9): Development of projects suitable for mountainous regions and vast river basins.

Geothermal (A8): Exploitation of geothermal sources in specific regions.

4.5.2. Evaluation criteria and sub-criteria [66]

The following criteria will be used to evaluate these alternatives in each region:

Social Criterion (C1): Considering sub-criteria such as social acceptance (C1.1), job creation (C1.2), obstacles in the area (C1.3), availability of the area (C1.4), vandalism and/or terrorism (C1.5).

Economic Criterion (2): Including sub-criteria such as initial capital (C2.1), op. and mat cost (C2.2), net present value (C2.3), general cost. Electricity (C2.4).

Environmental Criteria (C3): Addressing sub-criteria related to the Renewable Fraction (C3.1), the Carbon Footprint (C3.2) and the Impact on the Ecosystem (C3.3).

Technical Criterion (C4): Includes sub-criteria such as efficiency (C4.1), reliability (C4.2), source availability (C4.3), and technological maturity (C4.4).

It is important to note that the energy alternatives proposed in this research, as well as the criteria as well as the proposed sub-criteria, have been selected from previously carried out research and published in high-impact journals at an international level.

4.6. Expert information

For this research, a survey was carried out in a specialized program and 15 experts were consulted about their opinion regarding the evaluation of criteria, sub-criteria and the best source of selection of renewable energy for each of the geographical regions of Colombia, some general characteristics of the experts consulted can be seen in [Table 9](#).

4.7. Expression of the results

This research has generated significant results in the evaluation and selection of renewable energy sources in various regions of Colombia using the AHP and FAHP methodologies. When

Table 10
Alternatives vs SC1 methodology.

SC1						
Alternative vs Methodology	A1	A2	A3	A4	A5	A6
AHP	14.35 %	16.22 %	12.20 %	17.62 %	17.95 %	21.66 %
FAHP	14.34 %	4.89 %	5.46 %	18.72 %	21.37 %	35.22 %

exploring various energy alternatives, solar PV stood out as a promising option in most regions, supported by its feasibility and deployment potential. However, it is essential to recognize that each region has unique characteristics and resources that affect the weighting and classification of energy sources. The divergence in results between AHP and FAHP highlights the importance of considering uncertainty and subjectivity in energy projects. Each methodology offers valuable and complementary perspectives and should be evaluated according to the specific circumstances of each region and the objectives set. The implementation of AHP and FAHP revealed fundamental differences in their mathematical basis. While AHP is based on linear algebra, FAHP is based on fuzzy logic. A crucial distinction lies in the representation of uncertainty; AHP ignores it, while FAHP uses fuzzy logic to address it. In addition, AHP relies on subjective judgments, while FAHP minimizes subjectivity using de-fuzzification techniques.

In the first scenario (SC1), it is observed that the AHP methodology assigns a considerably higher weight to alternatives A1 and A2, with values of 14.35 % and 16.22 %, respectively. In contrast, the FAHP methodology shows a remarkable dispersion, with A6 reaching 35.22 %, suggesting that this methodology may better capture variability in preferences. When breaking down the criteria, the technical criterion stands out with a significant weight in both methodologies, although FAHP tends to give greater relevance to environmental aspects, which could indicate a trend towards more sustainable decisions. In the sub-criteria, FAHP shows a greater range of variation, suggesting a higher sensitivity to changes in the criteria assessed, see [Tables 10–12](#).

In the second scenario (SC2) [Tables 13–15](#), the results reflect a similar trend, where AHP assigns a higher weight to alternatives A1 and A2, while FAHP shows a more balanced approach in weight distribution. The environmental criterion remains relevant, with AHP awarding 14.16 % to A1, while FAHP presents 21.18 % for the same criterion. This scenario highlights the importance of considering sustainability in decision-making, especially in the context of environmental assessment. In the sub-criteria, FAHP shows greater variability, suggesting that this methodology may be better suited to capture the complexity of decisions.

The analysis of the third scenario (SC3) reveals that AHP assigns considerable weight to alternative A1, with 34.00 %, while FAHP presents 32.98 % for the same alternative. In terms of criteria, the environmental criterion remains predominant, with AHP awarding 22.73 % to A1, see [Tables 16–18](#). The variability in the sub-criteria is remarkable, with FAHP showing a wider range in weight assignment, suggesting that this methodology may be more sensitive to differences in the sub-criteria assessed.

In the fourth scenario (SC4), AHP and FAHP show a similar trend in the allocation of weights, although FAHP tends to give greater relevance to environmental criteria. A1 and A4 are the most prominent alternatives, with AHP assigning 11.12 % and 34.87 %, respectively. In the criteria, the environmental criterion remains a key factor, with AHP awarding 23.15 % to A1. Variability in sub-criteria is evident, with FAHP showing greater dispersion in weight assignment, suggesting that this methodology may be better suited to capture the complexity of decisions, see [Table 19–21](#).

Finally, in the fifth scenario (SC5) see [Table 22–24](#), AHP assigns a weight of 8.52 % to A1, while FAHP shows 10.73 % for the same alternative. In terms of criteria, the environmental cri-

Table 11
Alternative and methodology vs SC1 criteria.

SC1												
Alternative - Methodology vs Criterion	A1		A2		A3		A4		A5		A6	
	AHP	FAHP	AHP	FAHP	AHP	FAHP	AHP	FAHP	AHP	FAHP	AHP	FAHP
Technical	18.25 %	18.35 %	22.56 %	20.58 %	21.22 %	22.78 %	19.57 %	21.33 %	9.35 %	8.21 %	9.05 %	8.75 %
Environmental	8.73 %	15.39 %	10.65 %	15.14 %	14.67 %	13.58 %	25.54 %	14.17 %	22.18 %	20.18 %	18.23 %	21.54 %
Economic	20.03 %	22.68 %	22.69 %	21.56 %	16.57 %	14.87 %	18.32 %	14.12 %	12.24 %	15.62 %	10.15 %	11.15 %
Social	6.75 %	7.79 %	5.63 %	9.78 %	13.28 %	12.25 %	18.25 %	17.56 %	33.51 %	26.89 %	22.58 %	25.73 %

Table 12
Sub-criteria vs SC1 methodology.

SC1																
Sub-criteria vs Methodology	C1.1	C1.2	C1.3	C1.4	C1.5	C2.1	C2.2	C2.3	C2.4	C3.1	C3.2	C3.3	C4.1	C4.2	C4.3	C4.4
AHP	20.72 %	42.01 %	7.25 %	17.25 %	12.78 %	28.36 %	38.18 %	11.42 %	22.03 %	48.56 %	21.87 %	29.58 %	42.66 %	32.61 %	9.46 %	15.28 %
FAHP	35.62 %	25.62 %	8.64 %	14.08 %	16.03 %	2.98 %	28.26 %	34.66 %	34.09 %	6.06 %	85.01 %	8.93 %	8.76 %	43.54 %	22.18 %	25.52 %

Table 13
Alternatives vs SC2 methodologies.

SC2						
Alternative vs Methodology	A1	A2	A3	A4	A5	A6
AHP	6.23 %	7.58 %	8.96 %	24.57 %	25.10 %	27.56 %
FAHP	7.25 %	5.12 %	6.25 %	24.16 %	24.12 %	33.10 %

Table 14
Alternative and methodology vs SC2 criteria.

SC2												
Alternative - Methodology vs Criterion	A1		A2		A3		A4		A5		A6	
	AHP	FAHP	AHP	FAHP	AHP	FAHP	AHP	FAHP	AHP	FAHP	AHP	FAHP
Technical	14.16 %	21.58 %	20.22 %	24.23 %	25.35 %	28.81 %	18.51 %	10.23 %	14.23 %	8.52 %	7.53 %	6.63 %
Environmental	15.12 %	21.58 %	16.52 %	11.26 %	16.52 %	12.57 %	18.54 %	15.69 %	14.58 %	18.75 %	18.72 %	20.15 %
Economic	21.18 %	22.53 %	18.56 %	21.68 %	16.57 %	19.51 %	14.78 %	13.26 %	12.58 %	13.11 %	16.33 %	9.91 %
Social	13.18 %	9.60 %	10.35 %	12.75 %	14.17 %	14.58 %	18.75 %	18.46 %	21.41 %	21.86 %	22.14 %	22.75 %

terion remains relevant, with AHP awarding 14.68 % to A1. The variability in the sub-criteria is remarkable, with FAHP showing a wider range in weight assignment, suggesting that this methodology may be more sensitive to differences in the sub-criteria assessed.

On the other hand, the implementation of metaheuristic methods in decision-making for the selection of renewable energy sources in Colombia is crucial, in a geographically diverse context such as Colombia, where each region has unique characteristics, the application of conventional approaches could be insufficient. Metaheuristic methods, such as AHP and FAHP, make it possible to manage the complexity of the evaluation of various energy alternatives and multidimensional criteria.

The capacity of these methodologies to address uncertainty and subjectivity, particularly in dynamic contexts, offers valuable insights for decision-making processes. By addressing the limitations of traditional approaches, they emphasize the importance of accounting for the variability of energy potential and resource availability in different regions. In Colombia, the country's geographical diversity implies that certain renewable energy sources may be more appropriate for specific areas. Utilizing metaheuristic methods enables more precise and informed evaluations while supporting strategic energy planning and fostering environmental sustainability in the transition toward cleaner energy systems.

The outcomes of this research hold substantial relevance not only for Colombia but also for the broader Latin American region and potentially at a global level. For Colombia, the findings will provide policymakers, energy planners, and industry stakeholders with a systematic and flexible framework for selecting optimal renewable energy sources. This framework will aid in diversifying the nation's energy matrix and enhancing its resilience. By incorporating methodologies capable of managing the inherent uncertainty in regional energy planning, this study contributes to the development of sustainable and resilient energy solutions, particularly in regions characterized by limited data and high variability in natural resources.

Beyond Colombia, the approach outlined in this research has potential applications across Latin America, where countries face comparable geographic, economic, and environmental challenges. With their own diverse energy potentials, many nations in the region could benefit from a replicable framework that facilitates more tailored and region-specific energy planning. On a global level, this study offers a methodological advancement in energy plan-

Table 15
Sub-criteria vs SC2 methodology.

SC2																
Sub-criteria vs Methodology	C1.1	C1.2	C1.3	C1.4	C1.5	C2.1	C2.2	C2.3	C2.4	C3.1	C3.2	C3.3	C4.1	C4.2	C4.3	C4.4
AHP	20.19 %	42.32 %	6.75 %	16.96 %	13.78 %	26.89 %	40.53 %	10.96 %	21.63 %	40.45 %	29.75 %	29.81 %	44.00 %	29.10 %	11.13 %	15.76 %
FAHP	18.31 %	9.36 %	26.08 %	18.30 %	27.95 %	20.40 %	49.54 %	22.68 %	7.37 %	84.17 %	4.86 %	10.96 %	24.02 %	33.61 %	28.45 %	13.92 %

Table 16
 Alternatives vs SC3 methodologies.

SC3					
Alternative vs Methodology	A1	A4	A5	A6	A7
AHP	34.00 %	8.96 %	24.36 %	25.10 %	7.58 %
FAHP	32.98 %	7.25 %	24.16 %	28.65 %	6.96 %

Table 17
 Alternative and methodology vs SC3 criteria.

SC3										
Alternative - Methodology vs Criterion	A1		A4		A5		A6		A7	
	AHP	FAHP	AHP	FAHP	AHP	FAHP	AHP	FAHP	AHP	FAHP
Technical	15.23 %	22.76 %	21.78 %	25.95 %	24.58 %	30.91 %	20.36 %	11.23 %	18.05 %	9.15 %
Environmental	22.73 %	27.13 %	16.10 %	21.23 %	14.58 %	16.10 %	21.57 %	16.79 %	25.02 %	18.75 %
Economic	22.18 %	22.53 %	19.96 %	21.68 %	16.57 %	19.51 %	16.89 %	13.26 %	24.40 %	23.02 %
Social	25.68 %	19.90 %	10.45 %	18.59 %	19.03 %	16.58 %	22.69 %	21.46 %	22.15 %	23.47 %

ning, showcasing how the integration of AHP and FAHP can navigate the complexities of transitioning to renewable energy in regions with diverse geographic features and uncertain resource availability. This approach can serve as a model adaptable to other developing economies, contributing to worldwide efforts to combat climate change and promote energy sustainability.

Key recommendations include tailoring decisions to the unique characteristics of each region, accounting for the varying results of different methodologies, and encouraging the application of FAHP or other metaheuristic techniques to effectively address uncertainty in future energy planning projects.

Table 18

Sub-criteria vs SC3 methodology.

SC3																
Sub-criteria vs Methodology	C1.1	C1.2	C1.3	C1.4	C1.5	C2.1	C2.2	C2.3	C2.4	C3.1	C3.2	C3.3	C4.1	C4.2	C4.3	C4.4
AHP	19.25 %	36.26 %	9.23 %	15.80 %	19.46 %	25.55 %	36.43 %	12.49 %	25.53 %	50.18 %	19.53 %	30.29 %	41.01 %	28.21 %	12.18 %	18.59 %
FAHP	32.20 %	4.60 %	36.06 %	6.38 %	20.75 %	4.96 %	31.10 %	26.66 %	37.27 %	16.69 %	65.48 %	17.83 %	40.95 %	17.06 %	22.70 %	19.29 %

Table 19
 Alternatives vs SC4 methodologies.

SC4				
Alternative vs Methodology	A1	A4	A5	A6
AHP	11.12 %	34.87 %	25.96 %	28.05 %
FAHP	9.21 %	35.58 %	26.03 %	29.18 %

Table 20
 Alternative and methodology vs SC4 criteria.

SC4								
Alternative - Methodology vs Criterion	A1		A4		A5		A6	
	AHP	FAHP	AHP	FAHP	AHP	FAHP	AHP	FAHP
Technical	23.15 %	22.76 %	27.25 %	25.95 %	25.85 %	30.91 %	23.75 %	20.38 %
Environmental	22.73 %	25.13 %	31.16 %	33.28 %	19.54 %	19.56 %	26.57 %	22.03 %
Economic	22.18 %	22.53 %	25.64 %	28.24 %	25.46 %	24.51 %	26.72 %	24.72 %
Social	25.68 %	25.54 %	25.96 %	24.76 %	22.57 %	25.14 %	25.79 %	24.56 %

Table 21
Sub-criteria vs SC4 methodology.

SC4																
Sub-criteria vs Methodology	C1.1	C1.2	C1.3	C1.4	C1.5	C2.1	C2.2	C2.3	C2.4	C3.1	C3.2	C3.3	C4.1	C4.2	C4.3	C4.4
AHP	18.93 %	37.33 %	9.37 %	14.75 %	19.62 %	31.39 %	31.64 %	12.54 %	24.44 %	49.74 %	18.48 %	31.78 %	42.38 %	28.67 %	11.52 %	17.43 %
FAHP	25.16 %	34.19 %	30.38 %	0.90 %	9.36 %	20.94 %	22.95 %	27.94 %	28.17 %	41.00 %	27.84 %	31.16 %	33.70 %	22.82 %	15.10 %	28.39 %

Table 22
 Alternatives vs SC5 methodologies.

SC5					
Alternative vs Methodology	A1	A4	A5	A6	A7
AHP	8.52 %	33.22 %	22.14 %	25.89 %	10.23 %
FAHP	10.73 %	30.17 %	21.96 %	23.28 %	13.86 %

Table 23
 Alternative and methodology vs SC5 criteria.

SC5										
Alternative - Methodology vs Criterion	A1		A4		A5		A6		A7	
	AHP	FAHP	AHP	FAHP	AHP	FAHP	AHP	FAHP	AHP	FAHP
Technical	8.69 %	14.96 %	37.45 %	38.46 %	13.18 %	9.21 %	18.15 %	16.11 %	22.53 %	21.26 %
Environmental	14.68 %	15.51 %	19.68 %	25.46 %	16.13 %	15.23 %	23.75 %	21.22 %	25.76 %	22.58 %
Economic	16.37 %	20.60 %	33.56 %	31.87 %	22.25 %	17.89 %	12.13 %	13.10 %	15.69 %	16.54 %
Social	5.41 %	10.54 %	22.89 %	21.78 %	17.89 %	15.68 %	21.62 %	23.46 %	32.19 %	28.54 %

Table 24

Sub-criteria vs SC5 methodology.

SC5																
Sub-criteria vs Methodology	C1.1	C1.2	C1.3	C1.4	C1.5	C2.1	C2.2	C2.3	C2.4	C3.1	C3.2	C3.3	C4.1	C4.2	C4.3	C4.4
AHP	19.15 %	36.10 %	9.04 %	15.63 %	20.08 %	28.55 %	31.08 %	12.98 %	27.39 %	36.98 %	23.13 %	39.89 %	42.38 %	28.67 %	11.52 %	17.43 %
FAHP	19.35 %	21.20 %	24.76 %	14.20 %	20.49 %	14.34 %	5.61 %	39.77 %	40.28 %	32.02 %	48.35 %	19.62 %	1.65 %	34.81 %	22.18 %	41.37 %

Limitations

In this research we were faced with a variety of limitations, for example the collection of response by the consulted experts, the analysis of the index and radius of consistency of each of these answers, but the greatest limitation consisted in the processing and analysis of the data versus the implementation of each methodology, this is because Excel was used and each of these had to be programmed. Perhaps in the future in another research, with the use of some other program and programming language the processing and analysis of this data can be carried out more quickly.

Ethics Statement

The authors have read and follow the ethical requirements for publication in Data in Brief and confirming that the current work does not involve human subjects, animal experiments, or any data collected from social media platforms.

Data Availability

HP vs FAHP database (Original data) (Mendeley Data.)

CRediT Author Statement

Moreno Rocha Christian Manuel: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Data curation, Writing – original draft; **Arenas Buelvas Daina:** Conceptualization, Methodology, Software, Validation, Formal analysis, Data curation, Writing – original draft, Supervision; **Vega Machado Itzjak:** Conceptualization, Methodology, Investigation, Data curation; **Pacheco Peña Juan:** Conceptualization, Methodology.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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