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Kontakt/Contact
ZBW – Leibniz-Informationszentrum Wirtschaft/Leibniz Information Centre for Economics
Düsternbrooker Weg 120
24105 Kiel (Germany)
E-Mail: *rights[at]zbw.eu*
https://www.zbw.eu/econis-archiv/

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Evaluation of Energy Alternatives through FAHP for the Energization of Colombian Insular Areas

Christian Manuel Moreno Rocha[1]*, Esnaider D. Florian Domíngue[1], Daniel A. Díaz Castillo[1], Kevin Logreira Vargas[1], Andres Alfredo Medina Guzman[2]

[1]Department of Energy, Universidad de la Costa (CUC), Barranquilla, Atlántico, Colombia, [2]Department of Science, Universidad de la Costa (CUC), Barranquilla, Atlántico, Colombia. *Email: cmoreno7@cuc.edu.co

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ABSTRACT

In this study, the methodology of the Analytical Hierarchy Process (FAHP) with fuzzy logic is implemented to provide decision criteria in the selection, planning and development of electric power generation projects from renewable energy sources in the insular regions of Colombia. In this study, six renewable energy sources were considered, biomass combustion, anaerobic digestion of biomass, biogas landfills, waste incineration, photovoltaic energy and hydrogen-generated energy, due to their energy potential in insular areas and not interconnected with the national electricity system. To determine the order of priority in the development of energy conversion technologies, a questionnaire was drawn up and sent to a group of experts. Given the need to generate electricity in a sustainable way, the information was analyzed under four main criteria: Technical, environmental, social and economic. Sixteen additional subcriteria were selected based on a literature review. In general, the economic criterion is the most relevant in the area due to the high investment and operating costs of electricity generation. The social criterion highlights the opportunity to create new jobs very important for the study area, while the environmental criterion highlights the component of renewable energy substitution and environmental care, a key aspect in the diversification of the energy matrix, which is part of the country's political agenda. Regarding the technological component, self-consumption photovoltaic energy seems the most favorable due to its low environmental impact and the considerable price reduction experienced by the solar panel market in recent years.

Keywords: Hierarchical, Analytical process FAHP, Renewable Energy, Decision making, Multi-criteria
JEL Classifications: C44, C45, C46

1. INTRODUCTION

The technological advances that have been presented in the energy sector have been able to respond to each of the aforementioned objectives or factors, and have contributed, to a greater or lesser extent, to satisfy social, economic and environmental demands (Ong et al., 2020) (Pinto, 2004)(Departamento Nacional de planeación Subdirección territorial y de inversiones públicas DNP, 2016), although much remains to be analyzed and researched. On the other hand, scientific studies have revealed the probable date of depletion of fossil fuels and certain minerals, taking into account how it has been the historical evolution in terms of their extraction and use (Ong et al., 2020), so that the study and use of renewable energy sources plays a key role in reversing this alarming situation. It would be very interesting that from universities in professional development students are motivated to energize their research projects with renewable energy sources, so projects such as (Manuel et al., 2022; Manuel and Rocha, 2022) developed in undergraduate courses would have a novel component referring to the implementation of a different energy source to conventional.

The daily use and consumption of electricity is a vital service for the development and evolution of a country, constituting the main input in the vast majority of industrial activities worldwide, which sustain

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the economy and the generation of jobs. Furthermore, electrical energy is an essential factor to guarantee the quality of life of the inhabitants (Kim et al., 2019). In Colombia, as in other countries in the region, there is great interest in increasing the coverage and electricity supply to the entire territory, guaranteeing the quality of said energy and achieving a diverse energy matrix where the use of renewable sources predominates of energy (Castro et al., 2010). Government policies can affect the two indicators mentioned and also the sales prices of renewable energy projects. Many policies are applied around the world to support research and development investments, for example, low interest rate investment incentives, tax incentives such as accelerated depreciation opportunities, fee incentives such as Feeding Fees (FIT), certificates negotiable, among others; however, the planning, evaluation and selection of alternative energies for an adequate investment is a complex decision. In the first place, it is very important to consider that in addition to satisfying the projected demand, electric power generation plants must be economically viable and be environmentally and socially sustainable. Taking into account these criteria and others that have been used in recent years (Jamal et al., 2020), our research aims to provide a solution that allows selecting the best investment alternative in terms of electricity generation using renewable energy sources, also considering the option of hybrid systems (Departamento Nacional de planeación Subdirección territorial y de inversiones públicas DNP, 2016; Mehrjerdi, 2020).

Companies investing in renewable energy must choose between different technologies, diverse structures and varied costs and uncertainties, so it is essential to select those that offer the highest return for a given level of risk (Robles-Algarín et al., 2018); however, making a proper selection among several alternatives is not an easy task. Renewable energy investment decisions depend mainly on economic, environmental and technical aspects, so there is a great need to develop tools to support the decisions of potential renewable energy investors (Moreno Rocha et al., 2022). The objective of this research is to develop a mathematical model that allows choosing the best investment alternative in the use of energy sources. This is why the decision-making aid method of the Hierarchical Analytical Process with fuzzy logic (FAHP) is proposed, which establishes, on the basis of the multicriteria decision method, the weights of importance of both the criteria and the alternatives evaluated (Şengül et al., 2015). The model has a differentiating factor in terms of other research that have developed due to the implementation of FAHP as a method of solution to address the best solution taking into account qualitative criteria such as economic and environmental and quantitative criteria such as technical, social, environmental, and roads. access, among others. In the development of the research, energy planning in Colombia in recent years is taken into account, considering the changes that may occur in the availability of resources and a limited investment budget. As a result, there is a tool that serves as a guide for government entities or other private companies to access electricity generation projects using renewable energies (Mayor et al., 2016; Yang et al., 2022). Similar investigations have been initiated in Colombia, with the support of the Ministry of Mines and Energy, with the aim of selecting the best energy generation alternatives to solve the problem of connectivity of Non-Interconnected Zones (NIZ) (Zhu et al., 2022).

In 1999, the Mining-Energy Planning Unit (UPME) contracted the design of a structural, institutional and financial plan for the supply of electricity to the NIZ of the national territory with the collaboration of the communities and the private sector (Díaz et al., 2022). The study carried out in (Baloch et al., 2022) indicates that in Colombia projects involving NIZ are analyzed taking into account technical feasibility and economic viability, without taking into account other evaluation criteria. However, this traditional scheme is modified by investigations such as those of (Aristóteles, 2015) where, in addition to technical and economic feasibility, other criteria such as social and natural are considered. In (Ozorhon et al., 2018) the methodology of sustainable livelihoods is used for the selection of projects that seek to supply electrical energy to the town of Calamar, Guaviare, Colombia, using renewable energy sources.

The study in (Deveci and Güler, 2020) shows the evaluation of the policies for the electrification of NIZ in the southwest of Colombia, and in (Aragonés-Beltrán et al., 2014) presents an analytical tool called the Sustainable Rural Energy Decision Support System-DSS, which aims to maximize the five main criteria that represent a location (physical, financial, natural, human and social), and whose variations depend mainly on the provision of electric energy and other productive projects and complementary social.

The Energy Institute of the National University of Colombia, campus Medellín, has developed planning tools and methodologies for the development of rural electrification, studying various objectives and genetic algorithms (Alptekin, 2012). In the work of (Moradi et al., 2020) a model of economic, technological and environmental optimization of power generation projects is developed with the aim of minimizing greenhouse gases, the economic costs of energy and increasing energy efficiency; the uncertainty treatment was carried out using the Monte Carlo simulation. These research, both nationally and internationally, help set an important precedent for future research on energy planning in Colombia and serve as a starting point for our work focused on energy planning in the Colombian insular region (Srinivasan et al., 2020).

This article is organized into three sections; the first presents a review of scientific results on various assessment methods on the application of renewable energies. In the second section, the method under study is applied, analyzing the selection criteria and sub-criteria. Third, the discussion of the results obtained and the comparison with those of other researchers is presented, and finally the conclusions of the work are provided (Aberilla et al., 2020).

Although it is one of the most striking destinations, it has a conventional electricity generation system which is a very expensive system to pay, the archipelago is within the non-interconnected areas of the Colombian energy system. Currently, the archipelago has a generation of electric energy with burning-derived fuels fossil (Diesel), around 100 million pesos a day are burned for this generation, of course is a factor highly polluting for the environment, this first generation (Ajayan et al., 2020).

As a second generation measure, it has a thermal exploitation plant in order to generate energy from urban solid waste (MSW), which are collected from the urban and non-urban sector of the islands.

As the last generation method, in 2015 a wind farm is installed that is located south of the island of San Andrés, in the sector of Bowie Bay. With this park estimated to avoid consuming 750,000 diesel gallons per year. This installation is based on wind calculation. A study by the inter-American development bank (IDB) estimated that 15 million diesel gallons per year are required to operate the generation units distributed throughout the archipelago of san Andrés, Providencia and santa Catalina (Ochoa Ramón, 2009).

The archipelago has an installed capacity of 83.6 MW, corresponding to 18 diesel generation units. Production per year is approximately 200 GWh, the island of Providencia has installed capacity of 4.6 MW distributed in 4 generation units, two units of 0.7 MW and two units of 1.4 MW. The total energy demand of San Andrés is 31.4 MW and that of Providencia is 1.8 MW.

The energy demand in the archipelago is fully covered 100%, this demand is met through a local distribution system with two substations and 16 circuits (Krejčí, 2018). Unfortunately this energy service has a high level of loss, in 2010 the losses were estimated at 24%. The service operator estimates in its design calculations a 12%, which means that the higher percentages of losses to this must be borne by the company. The distribution system of the archipelago is formed in san Andrés by 2 substations, called THE BIGHT, where the control center of san Andrés is also located, and school house, while in providencia there is a substation. In the same way san Andrés has 13 distribution circuits with a substation at the exit of the punta Evans generation plant, Providencia has 2 distribution circuits (Rosso Cerón et al., 2017).

The archipelago as a non-border area does not have border or connection substations, Environmental pollution is presented as the physical, chemical and biological alteration that an environment or territory may suffer due to the dynamics developed by natural and/or anthropic environments.

It is estimated that annually about 134,000 tons of CO_2 are emitted to the environment by diesel generation in the archipelago, (taking into account a factor of 0.67 kg CO_2/kWh and an average generation of 200 Gwh/year) (González, 2015). Taking into account the effects of generating energy with diesel, both economic, social and environmental, the objective is to contemplate a generation of energy more friendly with the environment, that reduces CO_2 emissions, is more affordable for the entire community that constitutes the archipelago and have a cleaner and better quality energy (García et al., 2013).

2. MATERIALS AND METHODS

This research performs an analysis to determine the renewable energy potential to be implemented in the insular region of Colombia using the diffuse hierarchical analytical process, also known as FAHP. In this analysis, it is necessary to evaluate a series of criteria and sub-criteria associated with the different energy alternatives of renewable energies and also the environmental, economic and social problems of the communities that make up this area. That is why this research aims to propose a hierarchy of use of renewable energy sources taking into account the energy potential of each particular area.

2.1. Renewable Energy Alternatives

In the study and analysis of the potential of renewable energies in the insular region of Colombia, technical, social, environmental and economic criteria are evaluated, as well as a series of sub-criteria associated with them. Alternatives for the use of renewable energies present in the area under study are also taken into account. Figure 1 shows the hierarchical structure of the decision-making problem according to the criteria, sub-criteria and alternatives considered.

On various occasions, the social, economic and environmental problems of the communities become more complex and to find the best solution requires the analysis of many variables, criteria, studies and other aspects that justify obtaining the most viable solution from all points of view. view. Therefore, it is proposed to use the AHP method due to its advantages to identify problems and propose solutions according to the best response to complex and difficult decisions (Moreno Rocha et al., 2022).

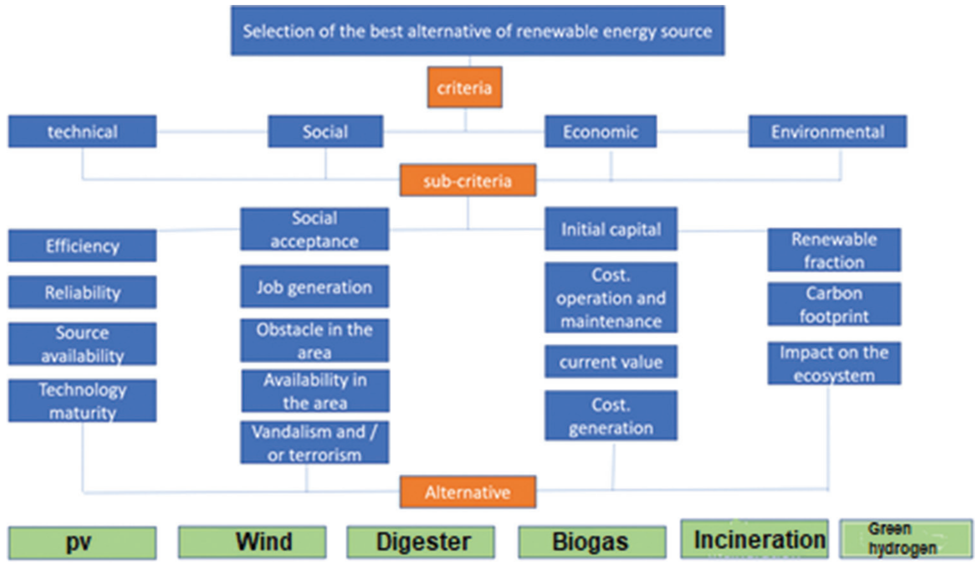
2.2. Model Training

Decision-making is a very important mechanism that becomes more complex every day, fundamentally due to the number of variables that are present and the constant transformation of the scenarios in which we work. In this context, multi-criteria methodologies are born as a way to face this type of challenge. The FAHP methodology contemplates the construction of a hierarchical structure to define the problem in its entirety and includes the creation of goals, the definition of evaluation criteria and sub-criteria, the identification of alternatives to solve the problem, until a ranking of the best options is obtained. to maximize and facilitate the choice of the best energy source that can be used in a certain area. Among the advantages of the FAHP method are that it presents mathematical support, allows to break down and analyze a problem by parts, analyzes quantitative and qualitative criteria and allows verifying the consistency index by making corrections if necessary.

The hierarchical analysis process developed by (Kabir et al., 2022) is based on the conception of a complex problem with multiple criteria that can be solved by classifying the problems posed, for which subjective evaluations are required on the relative importance of each of the criteria and also their preference for each of the decision alternatives. With the result of applying the AHP method, it is possible to generate a ranking with the priorities of each of the decision alternatives (Savino et al., 2017). The AHP method tries to break down a problem and then unite all the solutions of the subproblems into a conclusion and is divided into 4 fundamental stages:

Stage 1. Modeling: In this stage the hierarchical order of the problem is carried out, the objectives, criteria and alternatives to be implemented are defined. The objective of the process is defined according to the criteria of experts. Then the alternatives

Figure 1: AHP hierarchical analytical process modeling



through which we want to achieve our objective are defined and consequently, the criteria to be evaluated are determined. These criteria must take into account the problem and must identify the attributes that contribute to a good decision. These criteria must be measured and quantified in order to use a comparison scale (Maity et al., 2022). The solution of the problem passes 3 levels, the first level is the fundamental objective that we must achieve to solve the problem, in the second level the criteria would be located according to a descending hierarchical structure of one or more specific objectives, which will allow evaluating the alternatives for each of the criteria. In the third and last level would be the alternatives in the decision-making of (Zhang et al., 2022).

Stage 1. Modeling: In this stage the hierarchical order of the problem is carried out, the objectives, criteria and alternatives to be implemented are defined. The objective of the process is defined according to the criteria of experts. Then the alternatives through which we want to achieve our objective are defined and consequently, the criteria to be evaluated are determined. These criteria must take into account the problem and must identify the attributes that contribute to a good decision. These criteria must be measured and quantified in order to use a comparison scale (He et al., 2022).

The solution of the problem passes 3 levels, the first level is the fundamental objective that we must achieve to solve the problem, in the second level the criteria would be located according to a descending hierarchical structure of one or more specific objectives, which will allow evaluating the alternatives for each of the criteria. In the third and last level would be the alternatives in the decision-making of (Mendonça and Haddad, 2022; Moradi et al., 2020).

Stage 2. In this research the Fuzzy AHP method was used, the procedure of the Fuzzy AHP method can be explained as follows. For this explanation it is important to know that a diffuse scale was used as shown in Table 1.

Table 1: Triangular fuzzy coversion scale

Linguistic scale	Triangular fuzzy scale	Triangular fuzzy reciprocal scale
Just equal	(0,0,0)	(0,0,0)
Weakly important	(0,1,3)	(−3,−1,0)
Important	(1,3,5)	(−5,−3,−1)
Strongly more important	(3,5,7)	(−7,−5,−3)
Very strongly more important	(5,7,9)	(−9,−7,−5)
Absolutely more important	(7,9,9)	(−9,−9,−7)

The FAHP method for its acronym in English, was proposed in 1996, this method for its development incorporates the so-called diffuse numbers to the AHP methodology proposed by Saaty in 1994, then, this incorporation will be shown.(Studi et al., 2013).

Is $X = x_1, x_2, x_3, \ldots, x_n$ a set of several objects, y $Z = z_1, z_2, z_3, \ldots, z_n$ a set of objectives. According to the method proposed by Chang, each objective is taken and the analysis is performed for each objective respectively. As shown in Equation (1) extended analysis values "m" can be obtained for each of the objects with the following notation (Zhou, 2012):

$$M_{gi}^{1}, M_{gi}^{1}, \ldots, M_{gi}^{1} i = 1, 2, \ldots, n \tag{1}$$

Where all the $M_{gr}^{1}, i = 1, 2, \ldots, m$ they're fuzzy triangular numbers.

For a better understanding of the methodology proposed by Chang in this research the steps proposed by (Moreno Rocha et al., 2022) will be explained (2014).

Step 1: There exists a value of which results from the extended analysis with respect to the i-th object, it is defined in Equation (2) as:

$$S_i = \sum_{j=1}^{m} M_{gi}^{j} \otimes \left[\sum_{i=1}^{m} \sum_{j=1}^{m} M_{gi}^{j} \right]^{-1} \tag{2}$$

If it is desired to obtain $\sum_{j=1}^{m} M_{gi}^{j}$, the fuzzy number addition operation of the extended analysis values for m should be developed for a particular matrix as shown in Equation (3):

$$\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j} = \sum_{j=1}^{m} li \sum_{j=1}^{m} mi\ ,\ \sum_{j=1}^{m} ui \quad (3)$$

Then to get $\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}\right]^{-1}$, the fuzzy number addition operation is developed $M_{gi}^{j}(j = 1,2,\ldots,m)$ such that:

$$\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j} = \sum_{j=1}^{m} li \sum_{j=1}^{m} mi, \sum_{j=1}^{m} ui \quad (4)$$

To obtain the inverse of Equation (5) is done as follows:

$$\left(\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}\right)^{-1} = \frac{1}{\sum_{j=1}^{m} ui}, \frac{1}{\sum_{j=1}^{m} mi}, \frac{1}{\sum_{j=1}^{m} li} \quad (5)$$

Step 2: This step determines the degree of possibility that $M_2 \geq M_1$ and this can be detonated as seen in Equation (6):

$$V(M_2 \geq M_1) = \sup(\min(u_{M1}(x), u_{M1}(y)) \quad (6)$$

Now, there are a couple of points (x, y) such that $y \geq xy\ u_{M1}(x) = u_{M2}(y)$ then you have to $V(M_2 \geq M_1) = 1$, además $M_1 = 1_{1,\ m1}$, $u_1\ y\ M_2 = l_2, m_2, u_2$ they are convex diffuse numbers as shown in Equation (7) and observed in Table 1:

$$V(M_2 \geq M_1) = hgt(M_1 \cap M_2) = u_{M2}(d) = \begin{Bmatrix} 1 & m_2 \geq m_1 \\ 0 & l_2 \geq l_1 \\ \multicolumn{2}{c}{\frac{l_1 - l_2}{(m_2 - u_2) - (m_1 - l_1)}} \end{Bmatrix} \quad (7)$$

Where d will be the ordinate of the highest intersection point D between u_{M1} and u_{M2}

Step 3: There is a degree of possibility for a diffuse number M_j (i=1,2…,k) to be greater than K convex diffuse numbers defined as follows, shown in Equation (8):

$$V(M \geq M_1, M_2, \ldots, M_k) = V(M \geq M_1)\ y\ M \geq M_2\ y \ldots y\ M \geq M_k = \min V\ M \geq M_i \quad (8)$$

If so, then assume Equation (9):

$$d'(A_i) = \min s_i \geq s_k \quad (9)$$

So that $k = 1, 2, \ldots, n$; $k \neq i$ therefore, the weights of the vectors are given by Equation (10):

$$W' = d'(A_i), d'(A_2), \ldots d'(A_n)^T \quad (10)$$

Step 4: For this step we must normalize the weights of the vectors as shown in Equation (11):

$$W' = d'(A_i), d'(A_2), \ldots d'(A_n)^T \quad (11)$$

For this case it should be borne in mind that W are now not fuzzy numbers, but vectors with the final weights.

The rating of each alternative is multiplied by the weights of the subcriteria and aggregated to obtain local ratings with respect to each criterion. Local grades are multiplied by the weights of the criteria and aggregated to obtain global grades (Zhou et al., 2019).

2.2.1. Fuzzy modeling

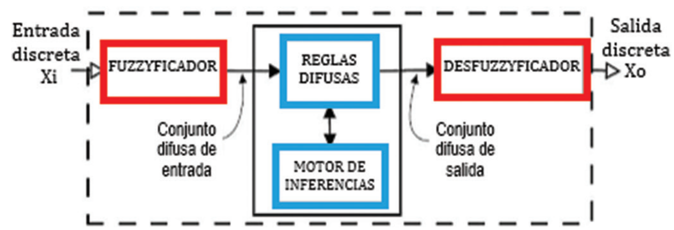
It is the application of fuzzy logic and fuzzy set theory to model phenomena through fuzzy rules. For example, fuzzy systems could be applied in control and decision-making processes see Figure 2. A fuzzy system consists of four phases: Fuzification, fuzzy rule bases, inference, and defuzification. Fuzification is the first phase where a function is set from X to all fuzzy sets in X. In other words, a real number ∈ is assigned a degree of belonging to a fuzzy set A. Then there are the fuzzy rules which is a collection of rules that describes the relationship between actions and system states. The rules are expressed in the form if (A1) and/or (A2). (An) then (Cn) where (An) and (Cn) are the actions and the states of the system respectively for n ∈ N (Zeng et al., 2020) Thirdly, there is inference which is a deduction rule to determine a fuzzy output based on an arbitrary set in X, and, finally, defuzification which is an operator that transforms fuzzy sets to real numbers. There are several methods of defuzification being one of the most used the center of gravity (Olabanji and Mpofu, 2020).

The fuzzyfier block is the block in which each input variable is assigned a degree of belonging to each of the fuzzy sets that can be considered, this is achieved thanks to the characteristic functions associated with these fuzzy sets. The inputs to this block are concrete values of the input variables to the outputs are degrees of belonging to the fuzzy sets that are considered.

The inference block, using what is called the inference engine, has the function of relating the input and output fuzzy sets that represent the rules that define the system. It should be clear that the inputs of this block are fuzzy sets and the outputs are also fuzzy sets associated with the output variable.

The defuzzyf block is the one in which, from a fuzzy set obtained previously in the inference mechanism and applying the mathematical methods of defusing, a specific value of the output

Figure 2: Diffuse system



variable is obtained, that is, the expected value must be obtained (Aristóteles, 2015).

Stage 4. Consistency analysis: This analysis takes into account the subjectivity of the decision maker. When performing the paired matrix comparison procedure, subjectivity is sought to be as real and objective as possible since the different elements of the matrix are successively compared to form another matrix.

There is a procedure to calculate it. If it is acceptable, the decision process can continue, but if it is unacceptable, a new analysis will be necessary because it is likely to modify the judgments about the paired comparisons (Hernández et al., 2021). The consistency relationship is calculated using Equation (12) obtaining the normalized matrix A:

$$Anormalized\left[\frac{a_y}{\sum_{k-1}^{n} a_{kj}}\right] \tag{12}$$

The sum of rows is obtained from Equation (13):

$$\begin{aligned}
\frac{a_{11}}{\sum_{n-1}^{n} a_{n1}} + \frac{a_{12}}{\sum_{n-1}^{n} a_{n2}} + \ldots\ldots\ldots\ldots\ldots + \frac{a_{1n}}{\sum_{n-1}^{n} a_{nn}} = b_1 \\
\frac{a_{11}}{\sum_{n-1}^{n} a_{n1}} + \frac{a_{12}}{\sum_{n-1}^{n} a_{n2}} + \ldots\ldots\ldots\ldots\ldots + \frac{a_{1n}}{\sum_{n-1}^{n} a_{nn}} = b_2 \\
\frac{a_{11}}{\sum_{n-1}^{n} a_{n1}} + \frac{a_{12}}{\sum_{n-1}^{n} a_{n2}} + \ldots\ldots\ldots\ldots\ldots + \frac{a_{1n}}{\sum_{n-1}^{n} a_{nn}} = b_n
\end{aligned} \tag{13}$$

The priority vector B that is formed is given by Equation (14):

$$\left[\frac{b_1}{n}, \frac{b_2}{n}, \ldots\ldots \frac{b_n}{n},\right]^T \tag{14}$$

The product of the original matrix A and the priority vector B forms a column C matrix, Equation (15):

$$A*B=C = [c_1, c_2 \ldots\ldots\ldots, c_n]^T \tag{15}$$

We proceed to calculate the quotient between the matrix column C and the vector of priorities B, obtaining another column vector D, Equation (16):

$$\frac{C}{B} = D \tag{16}$$

Adding and averaging its elements, the value of the consistency index (CI) is obtained, Equation (17):

$$CI = \frac{\lambda_{max-n}}{n-1} \tag{17}$$

Subsequently, the CI obtained is compared with the random CI in Table 2:

The random consistency (CI) value as a function of the size of the matrix represents the value that the CI should obtain if the numerical judgments with the scale of (Bepary and Kabir, 2022) had been completely randomly introduced into the comparison matrix.

Therefore, the CI is divided by the random consistency, thus obtaining the Inconsistency Ratio (IR), Equation (18):

$$IR = \frac{CI}{\text{Random consistency}} \tag{18}$$

Finally, a consistent matrix will be considered when the following values stipulated for the size of each matrix are not exceeded, Table 3.

If any matrix exceeds the consistency ratio, the valuations made by the decision-maker are reviewed and modified to reduce this consistency ratio to admissible values (Robles Algarín et al., 2017).

2.3. Criteria and Sub-criteria Approach

In the selection of criteria and sub-criteria, a set of qualitative criteria was established that are considered as a means of comparison between the different alternatives. These parameters influence multi-criteria decision making for the selection of technologies to be used. The criteria considered in the analysis are based on the study of different articles and/or publications from different databases (Carpitella et al., 2018; Savino et al., 2017; Zhou, 2012). Table 4 shows the classification of the sub-criteria according to the Social (C1), Economic (C2), Environmental (C3) and Technical (C4) criteria.

Next, a general explanation of each of the sub-criteria will be made, for a better understanding:

2.3.1. Social acceptance (C1.1)

The visual impact that the implementation of renewable energy could cause in an area could displease or please a large part of the population. This sub-criterion is key when evaluating technologies, since it considers the degree of acceptability that the population has in the installation of renewable technologies.

2.3.2.Generation of work (C1.2)

Carrying out a clean, renewable energy generation project requires the intervention of a diverse staff. The intervention of the workforce is essential to complete each phase of the project, from the planning of the work, to then continue to the execution and finally reach the operation, it is recommended that this qualified workforce be from the population and areas close.

2.3.3.Obstacles in Zones (C1.3)

The extraction of energy from a renewable resource is not an easy task, many technologies require large or large areas. The

Table 2: Comparison between the CI obtained and the random CI

Array 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

Table 3: Consistency limits (Díaz et al., 2022)

Matrix size (n)	Consistency ratio
3	5%
4	9%
5 or more than 5	10%

Table 4: Classification of sub-criteria according to criteria (Moreno Rocha et al., 2022)

Criteria	Sub-criteria
Social (C1)	Social acceptance (C 1.1) Generation of work (C 1.2) Obstacles in Zones (C 1.3) Disponibilidad de zona (C 1.4) Vandalism and/or terrorism (C 1.5)
Economical (C2)	Initial Capital (C 2.1) Operation and maintenance cost (C 2.2) Net present value (C 2.3) Electricity generation cost (C 2.4)
Environmental (C3)	Renewable faction (C 3.1) Carbon footprint (C 3.2) Ecosystem impact (C 3.3)
Technicians (C4)	Efficiency (C 4.1) Reliability (C 4.2) Source availability (C 4.3) Technology maturity (C 4.4)

availability of land is necessary to implement a technology, managing to be applied within an urban or rural area without major problem.

2.3.4. Zone availability (C1.4)

It should be understood that each region is a totally independent geographic area. Each region of our territory has isolated locations or zones, known as Availability Zones. These zones provide the ability to place resources, develop projects, in various locations closer to your end users.

2.3.5. Vandalism and/or terrorism (C1.5)

This sub-criterion is decisive on many occasions when developing a civil project in our national territory, the presence of armed groups outside the law and the impact that this may have on the development and presence of the project in the area should be studied.

2.3.6. Initial Capital (C2.1)

To carry out any project, it is necessary to consider the investment or the initial capital, due to the cost of the equipment and machinery necessary to start the project. On the other hand, any investor or interested party will analyze the expenses that could be generated by the installation of a technology.

2.3.7. Operation and maintenance cost (C2.2)

At the time of any energy transformation, it depends directly on a large number of machinery and equipment directly dependent on periodic maintenance, in order to extend their useful life. Generating additional costs, which must be considered and analyzed in detail.

2.3.8. Net present value (C2.3)

Net present value is a financial indicator used to determine the viability of a project. After measuring the flows of future income and expenses and discounting the initial investment, some profit remains, then it is determined that the project is viable.

2.3.9. Electricity generation cost (C2.4)

In any energy project it is of vital importance to evaluate how much the cost of the generated kW will be, this data will determine the valuation of the project in the future, any variable that manages to increase the cost of generation must be mitigated.

2.3.10. Renewable faction (C3.1)

It refers to the amount of energy, equipment or products that once used can be reused again in some other activity, or also any equipment, product or activity that comes from the use of a renewable source.

2.3.11. Carbon footprint (C3.2)

The carbon footprint is defined as the totality of greenhouse gases emitted by direct or indirect effect by an individual, organization, event or product.

2.3.12. Ecosystem impact (C3.3)

It is a change or an alteration in the environment, being a cause or an effect due to human activity and intervention. This impact on the ecosystem can be positive or negative, the negative represents a break in the ecological balance, causing serious damage and harm to the environment, as well as to the health of people and other living beings.

2.3.13. Efficiency (C4.1)

It is the relationship between the useful energy and the energy that is invested. If it is taken in a qualitative way, in this case the efficiency will be higher, as a greater amount of available energy is presented.

2.3.14. Reliability (C4.2)

The word reliable is used to refer to something being reliable and that it will always give the same result, it is an important sub-criterion when it comes to any project, continuity must be guaranteed at the best possible performance over time.

2.3.15. Source availability (C4.3)

If it is necessary to produce electrical energy, a primary source is necessary from which it is obtained, this will depend on your locality to take advantage of its capacity. The availability of primary source defines whether or not a resource can be used to the maximum to transform it into energy, depending on its area of application.

2.3.16. Technology matures (C4.4)

The technological maturity of renewable technologies has prevailed when opting for the inclusion of a renewable resource. It is vital to have a mature technology that ensures better performance in order to capture great economic and environmental benefits.

Once the final list of criteria has been obtained, the interrelationships between the elements are determined in order to make pairwise comparisons. The theoretical definitions of the elements were carefully examined and the literature reviewed to establish *precise interrelationships. The initial relationships were decided based on information obtained from the literature. On the other hand, the participation of experts from the energy sector plays a very important role. In our study, and taking into account the multidisciplinary nature of energy investments, a team of experts of 16 people was assembled. The experts have a minimum of 2 years of experience and know about the topics of investments in renewable energy sources. The experts were asked to review the interrelationships obtained from the literature and complete the interrelationship matrix. The set of scales suggested by (Ramirez* et al.*, 2005) was used in the pairwise comparison matrices and the numbers 1-9 are used to indicate the relative importance of the items. In the next step, the relative importance indices of the clusters were determined and the items were determined. The set of scales suggested by (Zeng* et al.*, 2020) was used in the pairwise comparison matrices. The profile of the experts is shown in Table 5.*

The objective of this methodology is to be able to analyze the criteria, sub-criteria and alternatives of a hierarchical structure in order to obtain the judgments issued by each of the experts consulted. In the method, the comparison is made in pairs, where it is necessary to generate the evaluation issued by one or more experts; success at this stage will depend on the knowledge and expertise of the group of decision makers. The evaluated criteria are assigned the Satty scale to obtain the weightings of each one of them.

To validate the reliability of the results obtained in the weightings and ranking of criteria and sub-criteria, the experts consulted calculate the consistency index and the consistency radius of each of the decision matrices. The paired comparison matrix reflects the importance of one attribute with respect to another, however, it is always necessary to validate the consistency of the judgments provided by the experts to obtain a valid and accurate comparison matrix in their responses. Table 6 shows the decision matrix of some of the experts, where the comparison between the criteria is observed (Khan et al., 2020).

Table 7 shows the normalization of the decision matrix of some of the experts, which is an important step in determining the consistency index and the consistency radius.

Table 8 shows the consistency index and the consistency radius of the obtained values, it is noted that the consistency radius is <0.1, allowing us to determine the validity and precision of the values reflected in the matrix.

3. RESULTS AND DISCUSSION

The decision matrix consists of the grouping of all the values obtained in the application of fuzzy logic and the hierarchical analytical process, in this matrix are the current values of the weights that each criterion evaluated has, it also shows the values of importance of each of the subcriteria according to the evaluation made by each of the experts. It is from this decision matrix as the one observed in Table 9 where through a weighted sum it will be found or determined which is the best alternative energy source for the study area.

Table 5*: *Categorization of the group of experts

Expert number	Occupation	Academic training	Years of experiences
1	Professor	Magister	2
2	Professor	Magister	2
3	Professor	Magister	2
4	Professor	Magister	2
5	Professor	Magister	4
6	Professor	Magister	4
7	Professor	Magister	4
8	Lawyer	Magister	4
9	Lawyer	Magister	6
10	Field engineer	Magister	6
11	Field engineer	Magister	6
12	Administrative	Magister	6
13	Administrative	Magister	8
14	Professor	Doctor	More than 10
15	Professor	Doctor	More than 10
16	Professor	Doctor	More than 10

Table 6: Comparison matrix between criteria

	Economic	Social	Environmental	Technicians
Economic	1	3	7	5
Social	1/3	1	1/7	1/3
Environmental	0.14	7	1	9
Technicians	1/5	3	1/9	1
Sum	1.68	14.00	8.25	15.33

Table 7: Matrix of normalized values

	Economic	Social	Environmental	Technicians
Economic	0.60	0.21	0.85	0.33
Social	0.20	0.07	0.02	0.02
Environmental	0.09	0.50	0.12	0.59
Technicians	0.12	0.21	0.01	0.07
Sum	1.00	1.00	1.00	1.00

Table 8: Determination of the consistency index and consistency radius

ʎ max	Consistency Index (C.I)	Consistency radius
4.1005	0.0335	0.0338

The growth of renewable energies worldwide is increasing according to data provided annually by the IEA. According to IEA forecasts, the share of renewable energy in global electricity supply will go from 26% in 2018 to 44% in 2040 and contribute 2/3 of the increase in electricity demand in that period, mainly through the use of wind and photovoltaic technologies.

According to the IEA, global electricity demand will increase by 70% by 2040, which will allow an increase in the proportion of energy consumption from 18% to 24%, mainly in emerging regions such as India, China, Africa, the Middle East and East and Southeast Asia.

The development and use of clean energy is essential to reverse the serious environmental situation and mitigate the effects of climate change. For example, 2019 was the second warmest year on record, behind 2016. The average temperature recorded the last 5 years have been about 1.2°C higher than the pre-industrial years, according to the Copernicus climate change service. In addition,

Table 9: Decision matrix

C1 (14%)					C2 (40%)				C3 (31%)			C4 (15%)			
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
0.17	0.36	0.10	0.24	0.13	0.28	0.35	0.09	0.28	0.62	0.13	0.25	0.34	0.35	0.12	0.19
0.03	0.06	0.02	0.04	0.02	0.11	0.14	0.04	0.11	0.18	0.04	0.07	0.05	0.05	0.02	0.03
0.35	0.25	0.25	0.28	0.25	0.26	0.05	0.06	0.05	0.13	0.08	0.34	0.45	0.47	0.31	0.31
0.26	0.19	0.16	0.14	0.22	0.23	0.06	0.13	0.11	0.23	0.08	0.22	0.10	0.15	0.24	0.20
0.09	0.14	0.12	0.14	0.13	0.11	0.11	0.33	0.29	0.14	0.31	0.13	0.18	0.15	0.10	0.11
0.10	0.13	0.12	0.14	0.14	0.17	0.20	0.19	0.27	0.17	0.26	0.13	0.13	0.10	0.09	0.12
0.08	0.11	0.11	0.08	0.09	0.04	0.33	0.07	0.18	0.22	0.12	0.06	0.06	0.05	0.07	0.07
0.12	0.18	0.24	0.22	0.17	0.18	0.24	0.22	0.10	0.11	0.16	0.13	0.08	0.08	0.20	0.19

approximately 860 million people in the world did not have access to electricity in 2018, which requires a lot of additional effort in the deployment of clean energy to achieve universal access to electricity by 2030.

In accordance with the opinion and assessment of the experts in each of the decision matrices, and with the help of the methodology of the FAHP is possible to set, as shown in Figure 3, the weighting of the criteria used in the study area, achieving determine the weighting and ranking of the economic criteria are the most ideoneos for this research. The Figure 3 shows the percentages obtained in the assessment of the criteria to have in mind when you are making a project for the installation of renewable energy, in this figure reflects the fact that the following being the economic criterion of greater impact at the time of making the investment and/or installation of renewable energy sources, however in this study was accomplished to determine that the group of experts consulted, and bearing in mind the area of application, the environmental criterion also plays an important role when investing and/or installing energy projects associated with renewable energy sources, is that the implementation of different energy alternatives, generate environmental impacts already known for such technologies. Within this identification, those impacts, direct or indirect, derived from the installation, operation and maintenance phases, that had an impact on the biotic and/or abiotic environment, were considered for each of the electricity generation scenarios.

In order to determine the overall weight of each of the criteria, related to the selection methodology, the sub-criteria derived from the review were related and evaluated with each of the technologies. Thus highlighting which of the technologies contemplated has a better performance against each of the criteria selected in this research, before making the selection of the technology. In Figure 4 it is clear that the sub-criterion of greater impact was the criterion of fraction renewable C3.1 this is because each day it takes greater importance to the implementation of materials and renewable processes in the different projects executed in the industry in order to mitigate the environmental impact, so the other subctiterio of greater importance was the cost of operation and maintenance C2.2, remains the economic in general the most important factor at the time of executing projects associated with renewable energy, the final value of the operation cost and the maintenance cost of the same play a decisive role when starting a renewable energy project.

The weighting part of the criteria generally do not have a behavior homogeno in the different energy alternatives that is why in Figure 5 shows the behavior heterogenogeno of such ctiretios in the presence of each of the energy sources alternative, so for example, if we compare the energy alternatives PV and wind, it turns out that for the first criterion of a greater percentage weighting, or importance, according to the experts consulted is the technical criteria, followed by the social criteria, while for the second alternative energy source the criterion of greatest importance at the time of its installation and/or execution according to the expert group is the social criterion followed by the technical criterion. This behavior of non-homogeneity of the criteria for each of the alternative energy sources is marked by the very nature in the structural anatomy and general impacts of each of them.

Finally, Figure 6 shows in order of importance, what would be the best source of energy alternative to install and run in island areas of

Figure 3: Weighting of criteria

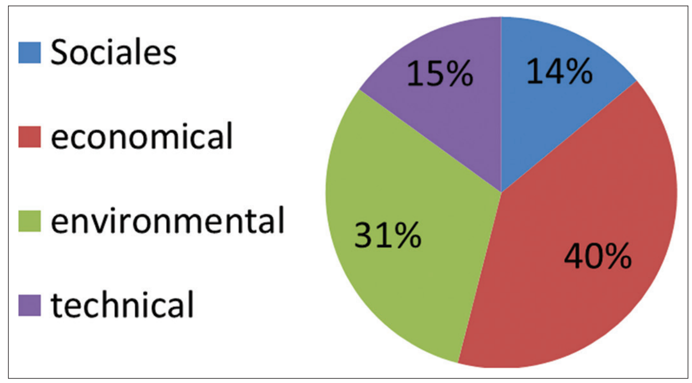


Figure 4: Weighting of sub-criteria

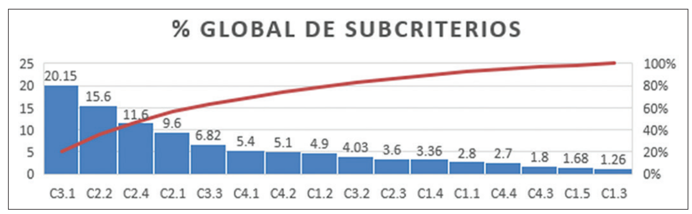


Figure 5: Weight of criteria versus energy alternatives

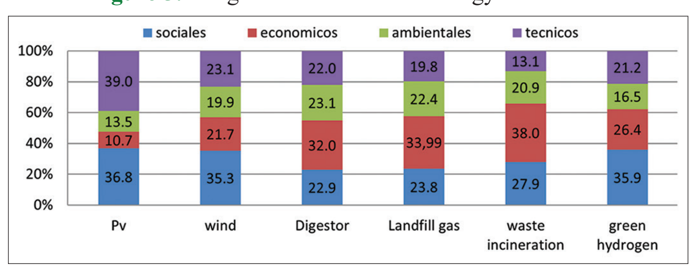
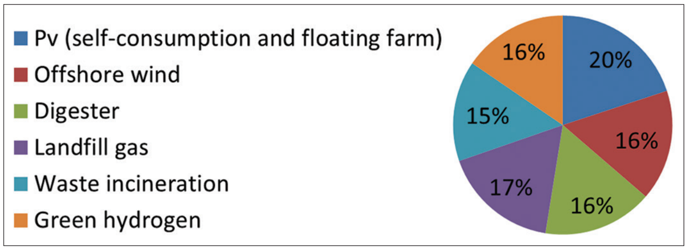


Figure 6: Weight of energy alternatives



Colombia, it must be clear and understand very well that if it shows the source of greater weighting according to the group of expert consultation at no time should you think that it is the only source to use as it also can be implemented hybrid systems implementing 2 or more sources of energy referred to in this research.

The decision to choose a renewable energy that has the potential and resources available in an area of application generates great losses of time and money. The methodology described in this research help to make better decisions that can converge in public policies aimed at making use of the energy resources available in a given area. The methodology selected in this study was FAHP, which provides the hierarchical analysis process with improved application of fuzzy logic.

The calculation of the consistency index and the consistency radius was made of great importance since it was possible to measure the level of relevance and reliability of each of the decision matrices by the experts.

The selected sub-criteria allowed the exhaustive evaluation of energy planning projects that take into account technical, economic, social and environmental criteria, as well as each of the 16 sub-criteria that were used in the insular region of the Colombian territory.

In addition, it is concluded that the environmental criterion, as as well as the sub-criteria assigned to it in energy planning, its percentage value has increased, which shows a greater concern for the conservation and decadent use of each of the energy sources that are currently used, it is also a reflection of the improvement of the policies implemented by the Colombian government in recent years.

The proposed methodology allowed the consolidation of 4 criteria and 16 sub-criteria that, according to the experts, are relevant for energy planning projects in insular areas and interconnected networks throughout the Colombian territory.

These results are not absolute due to the fact that the percentage values (level of importance) of each criterion and subcriterium evaluated may change according to national and international situations, likewise the presence of energy potentials in the area may be affected as consequences of climate change.

4. CONCLUSION

To conclude, the application of the proposed FAHP method allowed the participation of a group of experts for the weighting and hierarchization of the 4 criteria and the 16 subcriteria used, which can be generalized in energy planning projects in rural areas and insular areas using renewable energy sources as high impact alternatives.

On the other hand, the calculation of the consistency index and the consistency radius made it possible to measure the level of relevance and reliability of each of the decision matrices by the experts.

The selected sub-criteria enabled the comprehensive evaluation of energy planning projects taking into account technical, economic, social and environmental criteria, as well as each of the 16 sub-criteria used in the island areas.

In addition, it was concluded that the economic and environmental criteria influenced decision-making, as well as the sub-criteria assigned to it in energy planning, have increased their percentage value, which shows a greater concern for the conservation and appropriate use of each of the energy sources that are currently used.

The proposed methodology allowed the consolidation of 4 criteria and 16 sub-criteria that, in the opinion of the experts, are relevant for energy planning projects in rural areas, island areas and the implementation of the best renewable energy alternative.

Having said the above, it can be concluded that the development of a multicriteria methodology requires a previous study of the associated parameters, without mentioning that each development case may suppose new criteria involved depending on the objectives and the limitations of each context. This means that the results presented in this document are not of universal application, since the particularities of the non-interconnected areas, the availability of resources and the technological viability would establish a different framework of consideration in which the reference parameters and priorities, regardless of the quantity and nature of the criteria addressed, would be different from those chosen for their development within the conditions.

REFERENCES

Aberilla, J.M., Gallego-Schmid, A., Stamford, L., Azapagic, A. (2020), Design and environmental sustainability assessment of small-scale off-grid energy systems for remote rural communities. Applied Energy, 258(1), 114004.

Ajayan, J., Nirmal, D., Mohankumar, P., Saravanan, M., Jagadesh, M., Arivazhagan, L. (2020), A review of photovoltaic performance of organic/inorganic solar cells for future renewable and sustainable energy technologies. Superlattices and Microstructures, 143(1), 106549.

Alptekin, S.E. (2012), A fuzzy decision support system for digital camera selection based on user preferences. Expert Systems with Applications, 39(3), 3037-3047.

Aragonés-Beltrán, P., Chaparro-González, F., Pastor-Ferrando, J.P., Pla-Rubio, A. (2014), An AHP (Analytic Hierarchy Process)/ANP (Analytic Network Process)-based multi-criteria decision approach for the selection of solar-thermal power plant investment projects. Energy, 66, 222-238.

Aristóteles, C. (2015), AHP y AHP Difuso en la selección de la mejor tecnología para la producción de energía eléctrica a partir del carbón mineral. Scientia et Technica, 20(3), 255-260.

Baloch, Z.A., Tan, Q., Kamran, H.W., Nawaz, M.A., Albashar, G., Hameed, J. (2022), A multi-perspective assessment approach of renewable energy production: policy perspective analysis. Environment, Development and Sustainability, 24(2), 2164-2192.

Bepary, B., Kabir, G. (2022), Occupational risk assessment of wind turbines in Bangladesh. Applied System Innovation, 5(2), 34.

Carpitella, S., Ocaña-Levario, S.J., Benítez, J., Certa, A., Izquierdo, J. (2018), A hybrid multi-criteria approach to GPR image mining applied to water supply system maintenance. Journal of Applied Geophysics, 159, 754-764.

Castro, A., García, J.L., Sifuentes, E., Linares, M.V. (2010), Estudio del Estado del arte de las aplicaciones de analytic hierarchy process. Culcyt//Tecnología, 51, 144-164.

Deveci, K., Güler, Ö. (2020), A CMOPSO based multi-objective optimization of renewable energy planning: Case of Turkey. Renewable Energy, 155(5686), 578-590.

Díaz, H., Teixeira, A.P., Soares, C.G. (2022), Application of Monte Carlo and Fuzzy Analytic Hierarchy Processes for ranking floating wind farm locations. Ocean Engineering, 245(1), 110453.

DNP. (2016), Instalación de sistemas solares fotovoltaicos individuales en zonas no interconectadas. Journal of Chemical Information and Modeling, 53(9), 1689-1699.

Díaz, H., Teixeira, A.P., Guedes Soares, C. (2022), Application of Monte Carlo and Fuzzy Analytic Hierarchy Processes for ranking floating wind farm locations. Ocean Engineering, 245, 110453.

García, H., Correodor, A., Calderón, L., Gómez, M. (2013), Análisis Costo Beneficio de Energías Renovables no Convencionales en Colombia, No. 90. Available from: http://www.fedesarrollo.org.co/wp-content/uploads/2011/08/WWF_Analisis-costo-beneficio-energias-renovables-no-convencionales-en-Colombia.pdf

González. (2015), Integración de las Energías Renovables No Convencionales en Colombia. In Unidad de Planeación Minero Energética. Available from: http://www1.upme.gov.co/DemandaEnergetica/INTEGRACION_ENERGIAS_RENOVANLES_WEB.pdf

He, S., Lu, Y., Li, M. (2022), Probabilistic risk analysis for coal mine gas overrun based on FAHP and BN: A case study. Environmental Science and Pollution Research, 29, 28458-28468.

Hernández, J.C.B., Moreno, C., Ospino-Castro, A., Robles-Algarin, C.A., Tobón-Perez, J. (2021), A hybrid energy solution for the sustainable electricity supply of an irrigation system in a rural area of Zona Bananera, Colombia. International Journal of Energy Economics and Policy, 11(4), 521-528.

Jamal, T., Urmee, T., Shafiullah, G.M. (2020), Planning of off-grid power supply systems in remote areas using multi-criteria decision analysis. Energy, 201, 117580.

Kabir, G., Ahmed, S.K., Aalirezaei, A., Ng, K.T.W. (2022), Benchmarking Canadian solid waste management system integrating fuzzy analytic hierarchy process (FAHP) with efficacy methods. Environmental Science and Pollution Research, In press, https://doi.org/10.1007/s11356-022-19492-5

Khan, A.M., Gupta, M.K., Hegab, H., Jamil, M., Mia, M., He, N., Song, Q., Liu, Z., Pruncu, C.I. (2020), Energy-based cost integrated modelling and sustainability assessment of Al-GnP hybrid nanofluid assisted turning of AISI52100 steel. Journal of Cleaner Production, 257, 120502.

Kim, B.C., Kim, J., Kim, J. (2019), Evaluation model for investment in solar photovoltaic power generation using fuzzy analytic hierarchy process. Sustainability (Switzerland), 11(10), 2905.

Krejčí, J. (2018), Pairwise comparison matrices and their fuzzy extension: Multi-criteria decision making with a new fuzzy approach. In: Studies in Fuzziness and Soft Computing Vol. 366. ???: ???. AQ3

Maity, B., Mallick, S.K., Das, P., Rudra, S. (2022), Comparative analysis of groundwater potentiality zone using fuzzy AHP, frequency ratio and Bayesian weights of evidence methods. Applied Water Science, 12(4), 1-16.

Manuel, C., Rocha, M. (2022), Implementación de un sistema de adquisición de datos, Convertidor Análogo Digital (CAD) de 16 Bits a bajo ruido. Revista Agunkuyâa, 11(2), 39-58.

Manuel, C., Rocha, M., Alfredo, A., Guzman, M., Patricia, A., Pérez, H. (2022), Implementación de un sistema para la medición de fuerza basado en el efecto piezoresistivo. Revista Agunkuyâa, 11(2), 76-92.

Mayor, J., Botero, S., González-Ruiz, J.D. (2016), Modelo de decisión multicriterio difuso para la selección de contratistas en proyectos de infraestructura: caso Colombia. Obras y Proyectos, 20, 56-74.

Mehrjerdi, H. (2020), Modeling, integration, and optimal selection of the turbine technology in the hybrid wind-photovoltaic renewable energy system design. Energy Conversion and Management, 205(1), 112350.

Mendonça, M.B., Haddad, A.N. (2022), Sustainability assessment of a low-income building : A BIM-LCSA-FAHP-based analysis. Buildings, 12(2), 181.

Moradi, S., Yousefi, H., Noorollahi, Y., Rosso, D. (2020), Multi-criteria decision support system for wind farm site selection and sensitivity analysis: Case study of Alborz Province, Iran. Energy Strategy Reviews, 29(1), 100478.

Moreno, C., Milanes, C.B., Arguello, W., Fontalvo, A., Alvarez, R.N. (2022), Challenges and perspectives of the use of photovoltaic solar energy in Colombia. International Journal of Electrical and Computer Engineering, 12(5), 4521-28.

Moreno Rocha, C.M., Alvarez, J.R.N., Castillo, D.A.D., Domingue, E.D.F., Hernandez, J.C.B. (2022), Implementation of the hierarchical analytical process in the selection of the best source of renewable energy in the Colombian Caribbean Region. International Journal of Energy Economics and Policy, 12(2), 111-119.

Ochoa Ramón, J.L. (2009), Criterios de Evaluación y Análisis de Alternativas Para el Diseño de Proyectos de Electrificación Rural con Energía Eólica y Solar en Países En Desarrollo, No. 52. Available from: https://core.ac.uk/download/pdf/41799448.pdf%0Ahttp://upcommons.upc.edu/bitstream/handle/2099.1/11564/Memoria.pdf?sequence=1&isAllowed=y

Olabanji, O.M., Mpofu, K. (2020), Hybridized fuzzy analytic hierarchy process and fuzzy weighted average for identifying optimal design concept. Heliyon, 6(1), e03182.

Ong, M.S., Chang, M.Y., Foong, M.J., Chiew, J.J., Teh, K.C., Tan, J., Lim, S.S., Foo, D.C.Y. (2020), An integrated approach for sustainability assessment with hybrid AHP-LCA-PI techniques for chitosan-based TiO_2 nanotubes production. Sustainable Production and Consumption, 21, 170-181.

Ozorhon, B., Batmaz, A., Caglayan, S. (2018), Generating a framework to facilitate decision making in renewable energy investments. Renewable and Sustainable Energy Reviews, 95(1), 217-226.

Pinto, F. (2004), Energías renovables y desarrollo sostenible en zonas rurales de Colombia. El caso de la vereda Carrizal en Sutamarchán. Cuadernos de Desarrollo Rural, 1(53), 103-132.

Ramirez, A., Barriga, A., Baturone, I., Solano, S.S. (2005), Logica difusa conceptos fundamentales. In: Libro Electrónico Sobre Lógica Difusa. Ch. 2. Sevilla, Spain: Instituto de Microelectrónica de Sevilla Avda. p35-59. Available from: http://catarina.udlap.mx/u_dl_a/tales/documentos/lmt/ramirez_r_o/capitulo3.pdf

Robles Algarín, C., Llanos, A.P., Castro, A.O. (2017), An analytic hierarchy process based approach for evaluating renewable energy sources. International Journal of Energy Economics and Policy, 7(4), 38-47.

Robles-Algarín, C.A., Taborda-Giraldo, J.A., Ospino-Castro, A.J. (2018), A procedure for criteria selection in the energy planning of Colombian rural areas. Informacion Tecnologica, 29(3), 71-80.

Rosso Cerón, A.M., Kafarov, V., Latorre-Bayona, G. (2017), A fuzzy logic decision support system for assessing sustainable alternative for power generation in non-interconnected areas of Colombia-case of study. Chemical Engineering Transactions, 57, 421-426.

Savino, M.M., Manzini, R., Selva, V.D., Accorsi, R. (2017), A new model for environmental and economic evaluation of renewable energy systems: The case of wind turbines. Applied Energy, 189, 739-752.

Şengül, Ü., Eren, M., Shiraz, SE., Gezder, V., Sengül, A.B. (2015), Fuzzy TOPSIS method for ranking renewable energy supply systems in Turkey. Renewable Energy, 75, 617-625.

Srinivasan, C.S., Zanello, G., Nkegbe, P., Cherukuri, R., Picchioni, F., Gowdru, N., Webb, P. (2020), Drudgery reduction, physical activity and energy requirements in rural livelihoods. Economics and Human Biology, 37, 100846.

Yang, M., Ji, Z., Zhang, L., Zhang, A., Xia, Y. (2022), A hybrid comprehensive performance evaluation approach of cutter holder for tunnel boring machine. Advanced Engineering Informatics, 52(1), 101546.

Zeng, Y., Guo, W., Wang, H., Zhang, F. (2020), A two-stage evaluation and optimization method for renewable energy development based on data envelopment analysis. Applied Energy, 262(1), 114363.

Zhang, J., Qu, Q., Chen, X.B. (2022), Assessing the sustainable safety practices based on human behavior factors: an application to Chinese petrochemical industry. Environmental Science and Pollution Research, 2022, 0123456789.

Zhou, J., Wu, Y., Wu, C., Deng, Z., Xu, C., Hu, Y. (2019), A hybrid fuzzy multi-criteria decision-making approach for performance analysis and evaluation of park-level integrated energy system. Energy Conversion and Management, 201(1), 112134.

Zhou, X. (2012), Fuzzy analytical network process implementation with Matlab. In: MATLAB a Fundamental Tool for Scientific Computing and Engineering Applications. Norderstedt: BoD Books on Demand.

Zhu, Y., Tan, J., Cao, Y., Liu, Y., Liu, Y., Zhang, Q., Liu, Q. (2022), Application of Fuzzy analytic hierarchy process in environmental economics education: Under the online and offline blended teaching mode. Sustainability, 14(4), 2414.