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Article

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A Diffuse Analysis Based on Analytical Processes to Prioritize Barriers in the Development of Renewable Energy Technologies in Alignment with the United Nations Sustainable Development Goals: Evidence from Guajira/Colombia

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ABSTRACT

Colombia is a country that is characterized by having potential in many renewable and sustainable energy sources such as solar, wind, hydroelectric, biomass, etc., in this country the growth value of renewable energy (ER) has not yet reached a benchmark, this due to the existence of several barriers or limitations that have hindered the path of research and implementation. It is difficult to identify and prioritize the impact of these barriers that mostly hinder growth or improvement in the quality of life of a specific population. For this research, a systematic structure has been developed to identify and prioritize the barriers and manage to find a solution path to the aforementioned. This study aims to recognize and classify the barriers according to their impact on the development of renewable energy technologies, as well as demonstrate the non-relationship that may exist between a territory rich in energy potential and the good quality of life of its inhabitants, the study consists of four phases; (1) A study area was taken for its characterization in renewable energy potential and compared with the current quality of its inhabitants, (2) The barriers were recognized from the available literature studies, project reports and interactions with 6 experts from academia and industries, (3) for the final selection, the FAHP decision method was used, then, 24 were selected and classified into five groups: social and economic barriers, political and, administrative and market barriers and geographical and environmental barriers and (4) the FAHP method was used to obtain the priority weight and the hierarchy between these barriers. The results showed first that there is no relationship indicating that a potential area in renewable energy source has a positive impact on people's quality of life, also that politics and political barriers occupies the first place among the main barriers, besides that corruption and nepotism is the most relevant sub-criterion according to the experts' results. Sensitivity analysis is used to confirm the stability of all prioritized barriers.

Keywords: Decision Methods, Fuzzy Logic, Renewable Energies, Limitations of Renewable Energies, Energy Potential, Solar Energy, Wind Energy
JEL Classifications: C44, C45, C46, C65

1. INTRODUCTION

When talking about barriers or limitations in the research and implementation of renewable energies, the literature usually shows only some base factors which are defined as follows (Haykir et al., 2023).

1.1. Scarcity of Renewable Resources

Renewable energy sources are inherently unstable, which is the main reason why they are not widely used, existing renewable electricity distribution networks compensate for this situation with fossil fuel or uranium-based installations and implementation to secure and guarantee supply (Isah et al., 2023). As long as the share of renewables in an electricity market represents around 20-30% of the total, the additional costs of the system to compensate for consumption are generally acceptable, especially to avoid energy cuts and thus favour CO2 reduction and fuel imports are considered uneconomic (Nasirov et al., 2023). However, if renewables contribute most of the energy to the grid, other measures are needed to ensure supply when there is no wind and on cloudy days when there is no solar radiation, to give these two examples (Bax et al., 2023) Considering the above situation, the countries of the European Community usually use the exchange of electricity between countries to balance the difference in resources and renewable generation between localities or regions; For example, in the particular case of Spain, this choice is very limited due to the size of its energy links with France, which makes it a true energy island (Carolli et al., 2022).

1.2. Low Density and Environmental Impacts

An essential problem is that most renewable energy flows are by nature diffuse, i.e. they are accompanied by a low energy density, so the capture of significant amounts of energy implies the occupation of large areas of land, especially in the case of photovoltaic and wind solar energy (Haykir et al., 2023). To give an example, in relation to wind energy, several of the problems caused by the massive use of this energy source are derived from its operating principles, for a better understanding of this idea regarding wind energy, high ground is ideal to install this technology (Nuñez-Jimenez et al., 2023), but they are highly criticized from the point of view of the environment, since large equipment causes great visual impacts, in addition to sometimes altering in a very appreciable way the life of the local fauna. Therefore, the use of renewable energies is a measure that benefits the environment and society, since it contributes to the fight against climate change and the protection of the planet (Ejeh et al., 2023). The development of renewable energy is a priority for most countries, but the challenge is to make these technologies sustainable in the long term. The key to achieving this goal is the research and development of new technologies that allow a better use of natural resources and a lower environmental impact (Prokopenko et al., 2023). However, the impacts caused by modern renewable technologies (wind and solar) are much smaller than those of the continued use of fossil fuels to produce energy, which are very evident in terms of greenhouse gas emissions and, consequently, climate change (Kell et al., 2023).

1.3. Value of the kW/h of the Energy Obtained from Renewable Sources

A final note on the cost of renewable energy sources, with the exception of hydroelectric technology, most renewable technologies are relatively new and therefore technologically immature and, like any other new energy source, take a long time to develop and mature to produce energy at a competitive price (Sarker et al., 2023). Prices for the use of renewable sources (Hartvigsson et al., 2023). This translates into high unit costs per kWh of energy produced, although this phenomenon is rapidly decreasing as the use of these technologies spreads and different modern technologies are developed (Poshnath et al., 2023). In fact, in some geographies characterized by sunny and/or very windy conditions, solar and wind technologies have competed on cost with fossil fuel-based technologies and, in some cases, even cheaper than the latter technology (Yao et al., 2023).

The objective of public policies is to promote the use of renewable sources to improve energy security, reduce environmental impact and increase industrial competitiveness. As a result, governments have introduced a range of tax incentives, both directly and indirectly (e.g., subsidies) (Manuel et al., 2022). Since unit costs are high and because they are becoming lower and lower due to technological advancement and increasing production volume (Fournier et al., 2023). However, this research will show that there is a set of criteria and that each of these criteria are composed of a number of subcriteria that make up a whole theme of barriers or limitations in the research and/or implementation of renewable energies (Jesus et al., 2021).

In the case of electricity generation specifically in Colombia, which is the sixth cleanest matrix in the world, 68% of the installed capacity comes from renewable sources, broken down as follows: solar 0.1%, cogeneration 0.9%, wind 0.1%, thermal energy 30.7% and hydraulic 68.3% (Moreno et al., 2022). The country can become a major producer of solar energy if it wishes, as "exposure to solar energy lasts up to 12 h a day, registering even the highest rates in the world" (Hernández et al., 2021). This particular phenomenon allows the country to develop solar solutions and farms or solar parks that produce energy year-round more efficiently than countries experiencing different seasons (Opperman et al., 2023). In second place the country depends on the exploitation and transformation of fossil fuels (oil, gas and coal), however, thanks to its natural wealth and privileged location, the country can become a key player in the development and application of alternative technologies to solve the global energy crisis and, at the same time, address the national energy crisis and help protect the environment (Restrepo-Herrera et al., 2023). In the policy developed by the Colombian government for the national production of renewable energies, solutions such as the automatic exclusion of the "VAT" tax on solar infrastructure; Deduction of income tax of 50% for 15 years for investments in infrastructure to finance and obligation of marketers to acquire this energy from 8 to 10%. In Colombia, renewable energies have been a priority for sustainable development (Río et al., 2023). The Colombian government has made a great effort in recent years to promote the use of clean and green energy sources, such as wind, solar, geothermal and biomass. These technologies represent a great opportunity to reduce carbon emissions and improve air quality (Pereira et al., 2023).

In addition to promoting the use of these energy sources, Colombia has also invested in innovative projects that save electricity, these projects include strategies to store renewable energy, such as solar batteries, hybrid systems between renewable and non-renewable energy, as well as technologies that optimize electricity consumption and reduce total cost (Garces et al., 2023). Another important part of the commitment to renewable energies is their use in productive activities. To promote its use, subsidies have been made to Colombian companies dedicated to the development of ecological projects to produce renewable energy (Guignard et al., 2022) On the other hand, the installation of solar panels has also been encouraged to supply homes and commercial premises with clean and environmentally friendly electricity. Finally, Colombia has become a regional leader in the field of renewable energies thanks to government support through the financing of innovative projects that contribute to generating a more sustainable future (Barbosa-Granados et al., 2022). This vision has allowed Colombia to move towards an energy model based on clean and reliable sources that reduce polluting emissions and significantly improve air quality, it is projected that in 2023 the installed capacity in this area will increase by more than 100 times compared to 2018. This capacity is currently 725.38 megawatts (MW), which corresponds to the consumption of 547,402 homes and allows CO2 emissions to be reduced by 921,333 tons/year (Maestre-gongora et al., 2022).

On the other hand, solar radiation is one of the emerging energy sources, it is part of the main way to develop renewable energy, despite its abundance, with an available and low-tech intervention (Barbosa-Granados et al., 2022). This technology still presents significant barriers to research, development, and implementation in areas where energy is a fairy (Santos, 2022). Renewable energy sources have been at the center of the world in recent decades, trying to use natural sources to meet energy needs with traditional sources and the smallest pollution it can, Colombia, Colombia has participated in the development of air development -trad capable of regenerating (González, 2015). Energy in 2014, along with the enforcement of Law 1715. In order for the action to be widely accepted socially, the State, through the Ministry of Mining and Energy, has offered tax incentives to those who meet the corresponding requirements and procedures (Shadman et al., 2023).

Even so, not in all regions of this country can take full advantage of the development of these projects, this due to different barriers or limitations that do not help renewable energies to be part of the solution to an already known problem, as is the case of the department of La Guajira, located in the northeast of the country in the Caribbean region, this region consists of a great solar and wind potential as explained by the professor of the University of the coast Juan Jose Cabello Eras in his article "A look to the Electricity Generation from Non-Conventional Renewable Energy Sources in Colombia" where he states that the solar potential is at least 6.8 kWh/m^2/d being one of the main areas of wind potential of the region (Angel-Sanint et al., 2023). The energy potential and reliability of solar radiation depends on the number of days in which they are available in high luminosity values. Being the north coast of Colombia which has the privilege of having high values of solar energy luminosity throughout the year, with the department of La Guajira (229–240 month day) that has the highest values, while the departments of Valledupar, Cesar and part of Magdalena decrease in the range of 229–207 month day (Younis et al, 2022). As for solar radiation, the departments of Guajira and Atlántico showed global solar radiation values of up to 6,015 W/m2. The departments of Cesar, Magdalena and part of Bolívar showed values close to 5,259 W/m2; while Sucre, and Córdoba showed low solar radiation values of 4,502 W/m2 (Robles-algarín et al., 2022).

If the non-conventional renewable resources of this country are properly exploited, in addition to mitigating the barriers that prevent the research and implementation of technologies with renewable sources, it could be expected that by 2050 we would not only have met the national demand, but we would also exceed it by 40% (Rosso-Cerón et al., 2017). Given the previous idea, the Colombian state has begun to realize this potential, so it carried out in 2014 with the implementation of Law 1715 for the promotion and development of non-conventional renewable energies, as expressed above; which would entail taking advantage of these resources so a series of projects have been drawn up around the different regions that make up this country. All the strategies already generated and the next ones that are generated, have the need to explore new ways to use this source of energy to support clean and affordable energy, and climate action, as indicated in the United Nations Declaration on Sustainable Development through the Sustainable Development Goals established in 2015 (Pereira et al., 2023).

This document is based on a process of research, collection and interpretation based on the collection of data on the development of technologies in a specific area having as a point of focus one of the most impoverished departments and with the greatest potential such as La Guajira. This work aims to review the evidence that supports the generation of energy using solar radiation, and its impact on this community, identifying and hierarchizing those barriers and/or limitations that do not allow the wise exploitation and implementation of renewable energy sources.

Table 1 shows the future projects of wind generation in the department of La Guajira, where you can see the generation power that is expected to be a total of 4126.8 MW by half of 2025, only in wind energy, while Table 2 shows the generation capacity of future projects in solar generation that is estimated to be for the beginning of 2026 of has a total generation of 1225 MW, thus evidencing the high potential in renewable sources of the study area.

According to the literature consulted such as, scientific literature, databases such as Dialnet, Scielo, Google Scholar, Scopus, WOS, IEE, university repository, books, foundation reports and reports of the National Administrative Department of Statistics of Colombia "Dane", it was possible to establish some criteria and subcriteria of great national and international relevance acting as limiters and/or barriers in the research and implementation of renewable energies, For better understanding see Table 3.

On the other hand, this research seeks to contribute and simplify decision-making processes, becoming a powerful tool for future research where you want to find the best solution or option against a group of alternatives regarding the mitigation or elimination of barriers in the implementation of renewable energy sources. Inherent in this research the following questions were addressed, which these answers were used to capture the objectives addressed, the concerns were:

What are the most appropriate criteria to evaluate the limitations in the research and implementation of renewable energy sources in a territory?

What sustainability criteria and which are relevant to the evaluation structure? What is the relative importance of the criteria and/or sub-criteria identified?

Table 1: New wind generation projects in La Guajira (SIEL, 2021) Author elaboration

Municipality	Number	Capacity (MW)	Operation input
Uribia	Kappa wind power generation project	500	31/12/2024
Maicao	Guajira II Wind Farm	414	1/06/2024
Uribia	Andre Jusayu (before cerrito)	378	30/06/2025
Maicao	Omega wind power generation project	300	31/12/2023
Maicao	Elipse wind power generation project	200	31/12/2023
Uribia	Wakuaipa Wind Project	200	1/01/2024
Uribia	Carrizal Wind Farm	195	28/02/2023
Manaure	Musichi wind farm	194	31/12/2022
Uribia	Wind farm Electric house	180	28/02/2023
Uribia	Jouttalein SAS	150	1/07/2026
Foster	San Juan Wind	103	31/07/2022
Uribia	Irraipa wind farm	99	28/02/2023
Uribia	Apotolorru wind farm	75	28/02/2023
Rioacha	El Ahumado Wind Farm	50	1/04/2022
Maicao	NOE wind farm	9,9	30/12/2023
Maicao	Manita Wind Farm	9	31/12/2023
Maicao	Jehovah Wind Farm	9,9	1/01/2024
Uribia	Jotomana wind farm - Apotolorru II	99	28/02/2023
Maicao	Beta	280	1/12/2022
Uribia	Wind Camellias	268	27/12/2023
Maicao	Alpha	212	1/11/2022
Uribia	EO200i	201	28/02/2023

Table 2: New solar generation projects in La Guajira (SIEL, 2021) Author elaboration

Municipality	Number	capacity (MW)	Operation input
The Mill	Guardientera solar photovoltaic plant	181	6/03/2023
Uribia	Trupillo Wind Farm	100	31/12/2025
Maicao	Cuestecitas Solar Park	600	1/10/2024
San Juan del Cesar	San Juan Solar	100	31/12/2021
San Juan del Cesar	WIMKE photovoltaic solar plant	76	31/12/2023
The Mill	PSFV Potreritos	168	31/12/2023

Table 3: Classification of criteria according to their subcriteria

Social and Economic Barriers (BSE)	Lack of social awareness BSE1
	Lack of social acceptance BSE2
	High cost of capital BSE3
	Lack of access to BSE4 credit/funds
Policy and Political Barriers (BPP)	Lack of a transparent BPP1 decision-making process
	Lack of a BPP2 renewable energy policy
	BPP3 corruption and nepotism
	BPP4 political instability
	Insecurity and/or BPP5 Terrorism
Technical barriers (BT)	Lack of qualified personnel BT1
	Shortage of BT2 training institutes
	Lack of BT3 research facilities
	Lack of entrepreneurs and innovations BT4
	Use of technologies that are not suitable and/or not updated BT5
Administrative and market barriers (BAM)	Lack of institutional capacity BAM1
	Lack of coordination between BAM2 institutions
	Insufficient market size BAM3
	Lack of competition in the BAM4 market
	Lack of BAM5 international treaties and/or conventions
Geographical and Environmental Barriers (BGA)	Availability of renewable energy BGA1
	Geographical climatic conditions BGA2
	BGA3 Land Requirement
	Need for BGA4 waste disposal
	Occupation of BGA5 indigenous lands

Which sub-criterion has more or less absolute and relative importance in each criterion?

These questions were answered through a statistical study approach that involved experts in the field of renewable energies, to validate and consolidate the criteria identified for identification and hierarchy, coming from the existing literature. Finally, this research makes a double tribute to the planning in the research and implementation of the different sources of renewable energies that could be used in a specific area by addressing the research questions embodied above, first, it provides an evaluation structure to evaluate the feasibility of different measures, which allows the study areas whatever the power to identify aspects in which they are required. changes or select an optimal measure in this case for the implementation of electric vehicles. Secondly, it presents equally important criteria and sub-criteria that are often not taken into account in the planning of renewable energy policy measures.

2. METHODOLOGY

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 governmental and research databases were consulted.

It happens that the characterizations of population nature manages to obtain as results information on the structure and large number of identity attributes of various groups of people with evolutionary continuity in time, which according to their differences configure particular ways of being and being in a territory, in this research 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 (Moreno Rocha et al., 2022). These studies characterizing a population vs. its energy potentials also make it possible to focus attention on guaranteeing or re-establishing the effective enjoyment of rights of population groups, the recognition of their diversity and multiculturalism as a social wealth, the particularities and inequalities that hinder or enable their access to the dynamics and benefits of social and territorial development (Thomasi et al., 2022). The importance of correctly directing the appropriate forms of population characterization exercises lies in the fact that they allow to base the design, adjustment and implementation of public policies with a view to transforming situations considered as problematic, and offering goods and services that respond satisfactorily to the needs and interests of population groups (Zhu et al., 2022).

On the other hand, we proceeded with the implementation of the hierarchical analytical method with fuzzy logic with the aim of prioritizing the barriers that may arise in the implementation of energies with renewable sources, in the aforementioned study area (Moreno Rocha et al., 2022), for the explanation of this methodology they were separated by sections for better understanding.

2.1. Fuzzy Assembly Operations

- The complementary set of a fuzzy set $\overline{A}$ A is one whose characteristic function is defined by (Díaz et al., 2022):

$$m_{A} = (x) - m_{A}(x)$$

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

$$m_{A \cup B}(x) = máx\ m_{A}(x), m_{B}(x)$$

- The intersection of two fuzzy sets A and B is a fuzzy set $A \circ B$ in U

With characteristic function:

$$m_{A \cap B}(x) = mín\ m_{A}(x), m_{B}(x)$$

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

$$m_{A \cup B}(x) = m_{A}(x) + m_{B}(x) - m_{A}(x) m_{B}(x)$$

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

$$m_{A \cap B}(x) = m_{A}(x) m_{B}(x)$$

2.2. Fuzzy Relationships

$$R(U,V) = ((x,y), m_{R}(x,y))\,(x,y) \epsilon\, UxV$$

Suppose

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

They are relations in the same product space $U\,x\,V$ The intersection or union between R and S, which are compositions between the two relations, are defined as (Yang et al., 2022):

$$m_{R \cap S}(x,y) = m_{R}(x,y) * m_{S}(x)$$

$$m_{R \cup S}(x) = m_{R}(x,y) \oplus m_{S}(x,y)$$

If R ° S, R and S belong to discrete universes of discourse. It is defined as a fuzzy relation in U x W whose membership function is given by:

$$m_{R \circ S}(x,z) = sup_{y \varepsilon V}[\mu_{R}(x,y) * \mu_{s}(y,z)]$$

Where the SUP operator is the maximum and the * operator can be any T-norm. Depending on the t-norm chosen we can obtain different compositions; The two most used compositions are max-min composition and max-product composition:

- The max-min composition of the fuzzy relationships R(U, V) and S(V, W), is a fuzzy relation R ◦ S in UxW defined by the membership function

$$\mu_{R\circ S}(x,z) = máx_{y\varepsilon V}\, min[\mu_R(x,y) * \mu_s(y,z)]$$

Where $(x,z) \epsilon\, UxW$

- The max-product composition of the fuzzy relations R(U,V) and S(V,W), is a fuzzy relation to R ◦ Sin UxW defined by characteristic function

$$\mu_{R\circ S}(x,z) = máx_{y\varepsilon V}[\mu_R(x,y) * \mu_s(y,z)]$$

Where $(x,z) \epsilon\, UxW$

2.3. Fuzzy Implication

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

$m_{A\to B} = (x,y)$ (Maity et al., 2022):

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

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

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

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 u is A THEN v is B"

Consequence: "v is B*"

Where the fuzzy set A* need not necessarily be the same as the fuzzy set A of the rule antecedent and the fuzzy set B* need not necessarily be the same as the fuzzy set B that appears in the consequent of the rule.

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

$$\mu_{B*}(y) = sup_{x\varepsilon A*1}\, [\mu_{A*}(x) * \mu_{A\to B}(x,y)]$$

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:

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

$$\mu_{A\to B}(x,y) = \mu_A(x).\mu_B(y)$$

2.4. Methods of Syndication

- Maximum method: the output variable is chosen for which the characteristic function of the fuzzy output set is maximum. In general it is not an optimal method, since this maximum value can be reached by several outputs.
- Centroid method: Uses the center of gravity of the output characteristic function as the system output. Mathematically (Kabir et al., 2022):

$$y = (\int y\mu_A(y)dy) / (\int y\mu_B(y)dy)$$

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

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

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

2.5. Analysis with Fuzzy Logic

If is a set of objects and a set of objectives, according to the extended analysis method of Chang (1996), the extended analysis is developed for each of the values of the objects; in this way they can be obtained for each objective $X = \{x_1, x_2, x_3, \ldots x_n\}$ $U = \{u_1, u_2, u_3, \ldots u_n\}$ (Manuel et al., 2022). Therefore, extended analysis values of m can be obtained with the following notation (He et al., 2022):

$M^1_{gi}, M^2_{gi}, \ldots, M^m_{gi} = 1,2,3, \ldots n.$

Where everything is triangular fuzzy numbers.

$$M^1_{gi}(j = 1,2,3, \ldots m)$$

Key steps of the model proposed by Chang (1996) (Moreno Rocha et al., 2022):

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

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

To obtain, the operation of fuzzy addition of m values of the extended analysis is performed for a particular matrix, such that:

$$\sum_{j=1}^{m} M^j_g$$

$$\sum_{j=1}^{m} M^j_{gi} = \left(\sum_{j=1}^{m} l_j \sum_{j=1}^{m} m_j \sum_{j=1}^{m} u_j\right)$$

To get, perform the operation of blurred addition of values, so that:

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

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

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

Step 2: The degree of chances of it is defined as:

$$M_2 = (l_2, m_2, u_2) \geq M_1 = (l_1, m_1, u_1)$$

$$V\ (M_2 \geq M_1) = sup_{y \geq x}[min(\mu_{M1}(x), \mu_{M2}(y))]$$

And it can be expressed equivalently as follows:

$$V\ (M_2 \geq M_1) = hgt(M_1 \cap M_2) = \mu_{M2}(d) = f\ (d)$$

Yes $m_2 \geq m_1$

$$\text{Yes } l_1 \geq u_2 = \begin{cases} 1, \\ 0, \\ \dfrac{l_1 - u_2}{(m_2 - u_{2)} - (m_1 - l_1)} \end{cases}$$

Where d is the ordinate of the highest intersection point D between and μ_{M1}. To compare and the values of y are required $\mu_{M2} M_1 M_2$.

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

Step 3: The degree of possibility that a diffuse convex number is greater than k

Convex numbers are defined as:

$$V\ (M \geq M_1, M_2, \ldots, M_k) = V[(M \geq M_1)\, y\ (M \geq M_2)$$
$$y\ (M \geq M_k)] = min V(M \geq M_i), i = 1, 23, \ldots, k$$

So, assuming that:

$$d'(A_i))\ min V\ (S_i \geq S_k)$$

For. The weight of the vector is given by:

$$k = 1, 2, 3, \ldots, n;\ k \neq i\ \ W' = (d'(A_1),\ d'(A_2), \ldots, d'(A_n))^T$$

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

Step 4: The normalization of the vector presented as follows:

$$W = (d\ (A_1),\ d\ (A_2),\ \ldots,\ d\ (A_n))^T$$

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

For this case it should be borne in mind that W are now not fuzzy numbers, but vectors with the final weights. Table 4 represents the values used in the conversion of the linguistic syntax used by the experts and their respective valuation into fuzzy triangular and triangular numbers. Finally, Figure 1 presents a scheme as an explanation of 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.

3. RESULTS

3.1. Characterization of Study Area

The characterization of the study area had a range of data obtained from 2010 to 2019, it is important to clarify that, during the years 2020, 2021 and 2022 it was not possible to carry out censuses in favor of obtaining data, this due to the presence of the sars Covid-19 virus worldwide. However, the data obtained allow a diagnosis and identification of specific variables that help in the approach of possible solutions to the difficulties encountered in the area, despite being a territory of installation and implementation of different sources of renewable energy. In Figure 2 it is possible to appreciate how in the period of established range of study, the consumption of energy has presented a downward trend, perhaps it is thought that this is due to a decrease in the population, but it is not so since Figure 3 shows that the opposite happens the population presents a tendency to increase which belies the hypothesis mentioned above. This decrease in energy consumption is basically due to the great slowdown in trade and industry in this area of Colombia as can be seen in Figure 4 and is that many companies and commercial and industrial enterprises have decided to migrate from this area due to the lack of possibility of success, while others have ultimately decided to close.

Table 4: Triangular fuzzy conversion scale (Mendonça & Haddad, 2022)

Linguistic scale	Triangular fuzzy	
	Fuzzy scale	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)

Figure 1: FAHP implementation schema

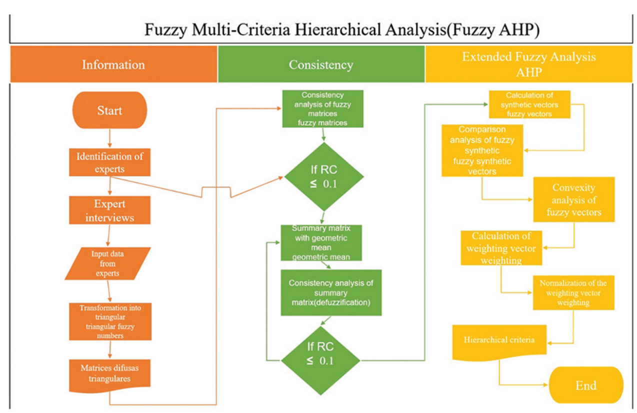


Figure 2: Evolution of energy consumption (kW)

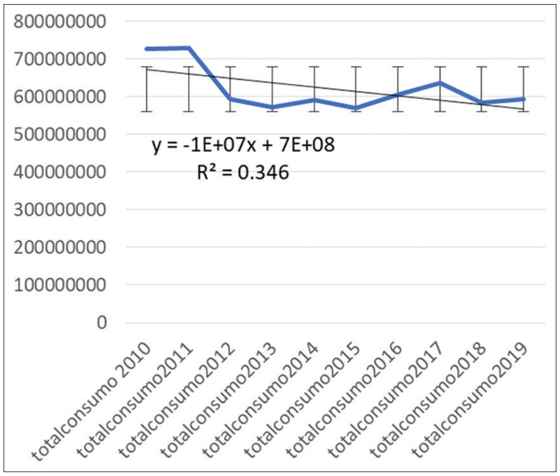


Figure 3: Evolution of population growth

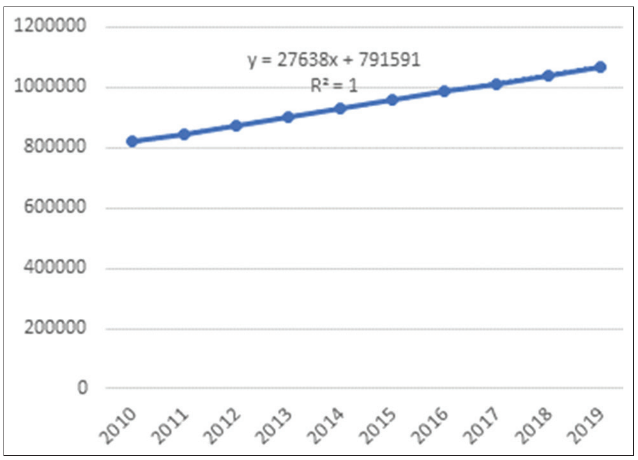
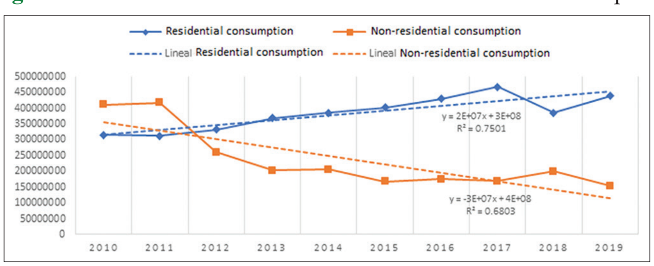


Figure 4: Evolution of residential versus non-residential consumption



This study area presents a very marked heterogeneous form in the consumption of electrical energy as shown in Figure 5, the municipalities that consume the most energy are directly those that offer the best quality of life to their inhabitants, municipalities such as Riohacha, Maicao and Albania register a historical average of consumption above 20% of everything consumed in the department of La Guajira, these municipalities are where the largest percentage of commerce and industry of the entire department is concentrated, perhaps the best known industry internationally is the largest open-pit coal mine in the world, its name is El Cerrejón, on the other hand it is important to note that this Colombian department has a potential of approximately 15,000 MW only in wind and solar energy, which would represent on average 90% of the total that is currently generated between all types of sources and that includes water resources and that Colombia has an average solar radiation of 4.5 KW per square meter, with some areas of the Caribbean such as La Guajira reaching 6 KW, which is 66% higher than the world average.

On the other hand, the average wind speeds are close to or greater than nine meters per second in a range of 80 m high, according to a study by the Association of Renewable Energies of Colombia that would boost almost doubling the generation of the national electricity system. This is how La Guajira has one of the greatest potentials at national and continental level because "it concentrates the largest volume of trade winds that the country receives, which, together with solar radiation, make it an area of great attraction for investments.

Social stratification corresponds to the way in which households are classified according to different criteria that do not depend on the income of the individual or the family, but on the condition of the dwelling in which the family group lives and the school or local environment. By social class, the cost of domestic services, certain taxes and the provision of some economic assistance to certain households is determined. According to the Department of National Planning of Colombia, there are six socioeconomic classes into which housing or property can be divided: Stratum 1 means low-low, Stratum 2 means low, Stratum 3 means medium-low, Stratum 4 means medium, Stratum 5 means medium-high, Stratum 6 means high. Levels 1, 2 and 3 correspond to those with fewer resources that receive subsidies from the national government for housing and public services; Levels 5 and 6 correspond to higher incomes with large economic resources that incur additional costs (contributions) for household utility costs. While tier 4 is not a concessionaire and does not pay the excessive costs, it pays exactly what the utility identifies as the cost of performing the service. In accordance with what has been explained and the results obtained, it can be seen in Figure 6 that for this study area there are only 3 socioeconomic strata of level 1, 2 and 3, this gives to talk about the conditions and quality of life of the population as such. Likewise, it is possible to appreciate the significant increase of the population in level one step from 20% in 2010 to 43% of the total population for the year 2019 and a slight increase in the population in socioeconomic level 2, going from 20% in 2010 to 27% in 2019.

It should be noted that although this area of Colombia is the cradle of great energy potential as mentioned above, this does not imply that its inhabitants enjoy a good quality of life, in fact there are some criteria and subcriteria that strongly mark the non-implementation of energy sources or projects in this study area, The lack of a good quality of life is reflected if this department is compared with the other departments of the Colombian Caribbean region, in coherence with the above, Figures 7-9 are reflections that the lack, partial or total absence of an electric fluid strongly influences factors associated with human development such as infant mortality, child mortality and life expectancy. It should be clear that the variable electric fluid is not proportional to the different variables that mark human development, but it is a variable that impacts on it, as can be seen in the figures mentioned above. It is important to clarify that the human development index

Figure 5: General visualization of the percentage of consumption by municipality per year in the department of La Guajira

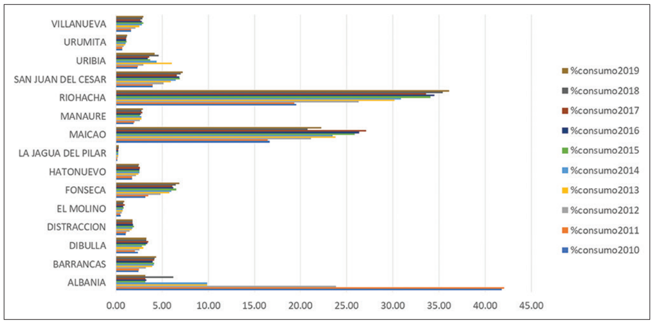


Figure 6: Consumption by socioeconomic strata

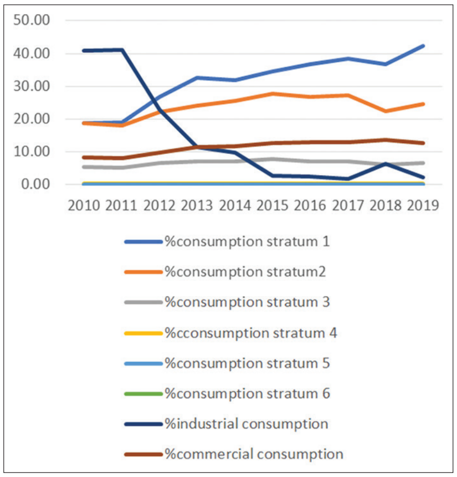


Figure 7: Percentage of infant mortality under 1 year

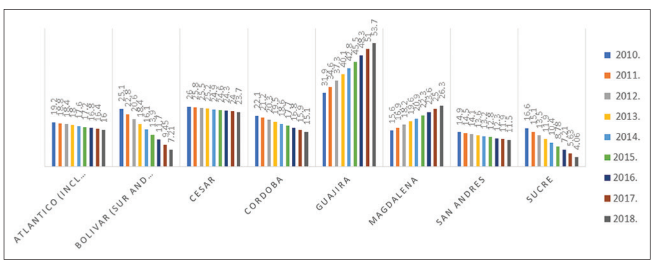
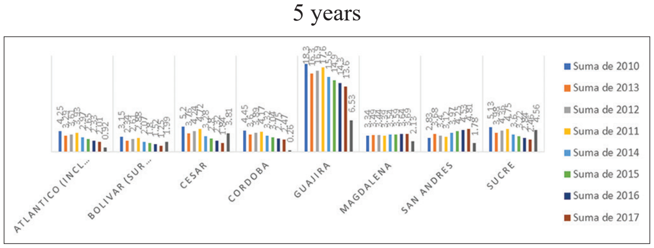


Figure 8: Percentage infant mortality in children between 1 and 5 years



is an indicator developed by the United Nations Development Program, it is used to classify regions into three levels of human development, this is composed of life expectancy, education (literacy rate, gross enrolment rate at different levels and net attendance and per capita income indicators, the study area presents the lowest HDI of all the departments that make up the Caribbean region of Colombia as shown in Figure 10, this shows

Figure 9: Life expectancy at birth

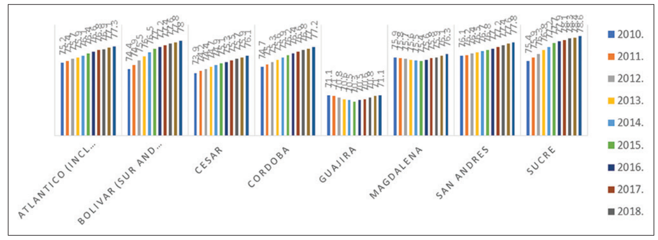
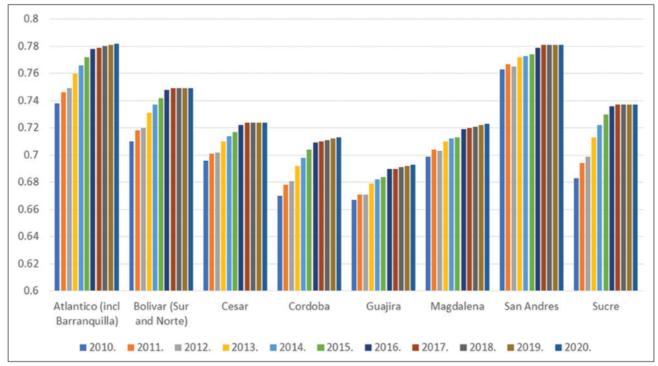


Figure 10: Human development indices



that despite being a potential area in renewable energies and it would be expected that the inhabitants maintain a good quality of life on average, however the inhabitants of this area lack a good quality of life, It is true that there are barriers or limitations that prevent the installation and implementation of renewable energy sources that perhaps with the installation and implementation of these energy projects the variables seen so far may be different from those shown in this research.

3.2. Is There Enough Potential in this Area to Meet Current and Future Demand?

Taking into account the information provided by the different media, the daily average of energy consumption in the study area, on the 3rd day of May 2022 presented a peak of 27,900,000,000.00 Wh (27.9 GWh). In addition, according to the information presented above, a base power of 5,391,300,000.00 W (5,391.3 GW) is presented, only in solar energy, in this research the renewable energy potential was not characterized with other energy sources. With this information present, the following question can be answered: Could energy production meet current demand?

First the base power generated on the day is calculated, for this the following operation is carried out

$$\frac{27,9\ GWh}{24\ h} = 1.162.500.000,00\ W$$

This subtracted from the generation projection for 2026 could deduce that demand could be met and with a reserve margin of 78.43% in an ideal case.

With respect to future projections in the article of the Energy Mining Planning Unit "UPME" demand projections the growth rate of energy demand will be between 2.22% and 3.35%. Therefore, the behavior of energy consumption would be represented in the following Figure 11:

Looking at Figure 12, it is evident the average percentage of population growth which is 2.98870178% with this approximate value can be predicted to some extent population growth, since 2010 to 2019.

The previous Figure 13 shows the progressive population growth of the department, which is evident that the consumption of electricity would also increase as there are more people. With the above clarified, a comparison is made between the demand estimates and the summaries of the electrical power capacities of the different projects with respect to each year.

For Figure 14 it is evident that by 2023 it would theoretically be meeting the demand in addition to having sufficient capacity for possible new projects and a better development in the infrastructures and quality of life of La Guajira, all this would be possible if there was a true will to energy transition overcoming the limitations and/or barriers in the research and installation of new energy sources. In addition to achieving improvement in the living conditions of this study area.

3.3. Suggestions to the Study Area

It could also be said that, despite the high energy potential, and the high expectations that are kept with the projects (if they all work);

Figure 11: Estimation of energy demand growth

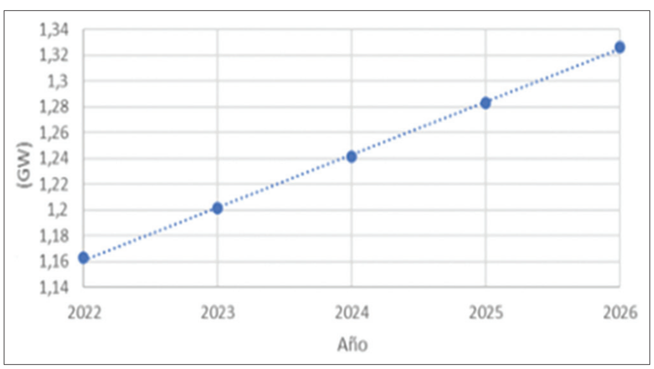
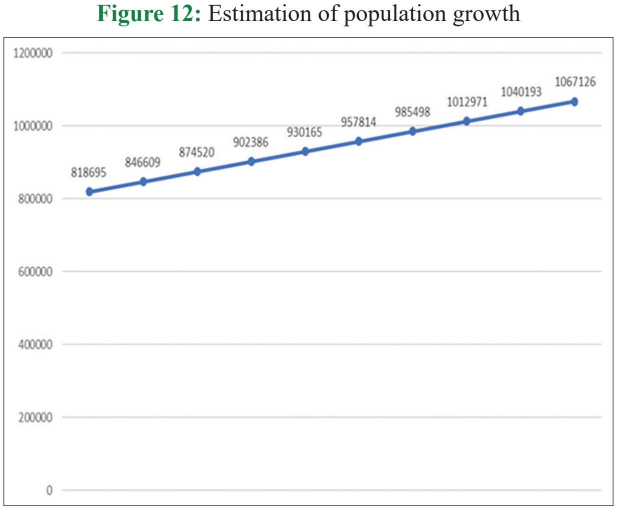


Figure 12: Estimation of population growth



A setback in energy storage could be evident, since especially solar energy would only be in operation for a certain number of hours a day and could become a limitation.

One of the objectives of this research is to demonstrate but also quantify what has been happening for a long time in a rich area with great potential for emerging energy, is the department of La Guajira-Colombia the land where in recent years the eyes of an entire country have rested in favor of the implementation of large energy projects, This territory throughout the history of Colombia has been one of the populations most affected by poverty and extreme poverty, this has happened and continues to happen to think that in this area it has the energy potential to greatly alleviate the challenges that Colombian society requires in terms of energization. Although in the department of La Guajira some energy projects based on renewable sources have been implemented, these projects have not had the desired impact, an example of this can be seen that in Figure 4 a decline in energy consumption and not precisely because of an increase in efficiency or good energy habits of the population, This decline refers to the closure of industries and massive displacement of its population to other areas, however the consumption of this area is marked by 3 main cities as shown in Figure 5, the economic activities of these cities are commerce in general, coal exploitation and rest area of the population that works in the coal mines. It is also striking to observe that while in Figure 6 there is a decrease in energy consumption, in Figure 6 the upward trend of its population can be evidenced, at first glance it is very contradictory since the first thing that is thought is that the more people the more energy consumption, that would be the logic. This leads us to ask initially, what is

Figure 13: Estimation of population growth

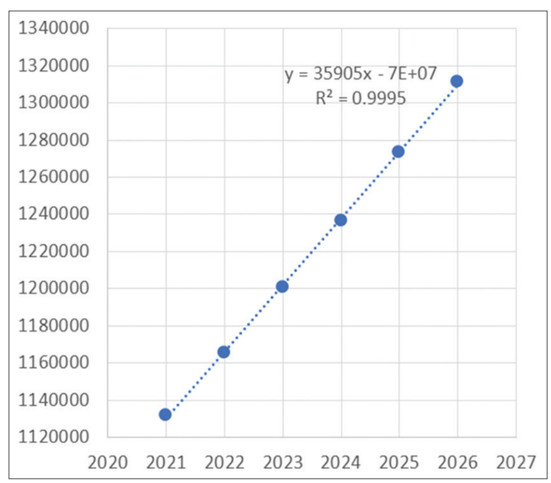
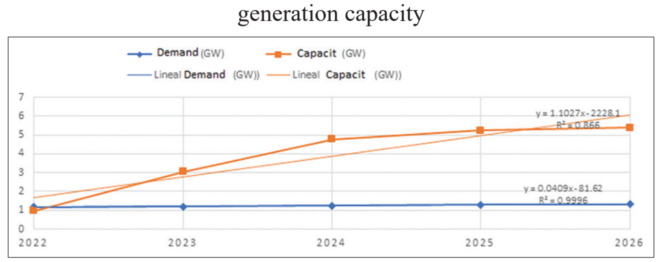


Figure 14: Comparison of demand estimation vs power generation capacity



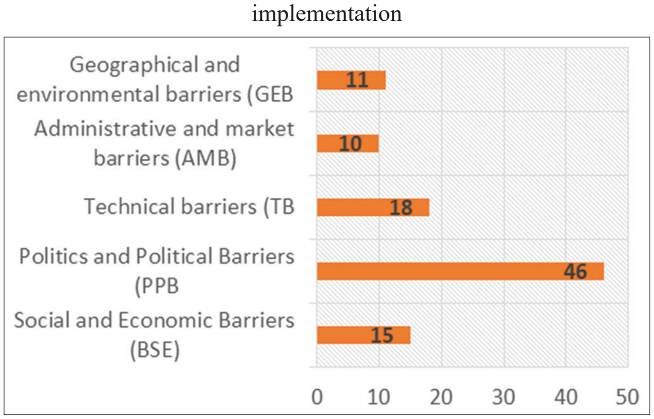
happening in this area so rich and act for the implementation of energy projects.

3.4. FAHP Results

Although the results on the characterization of the study area showed a rich area and record for the development of new sources of renewable energy, however there are some barriers or limitations that are not allowing this, these barriers or limitations were hierarchized and the results obtained in the implementation of the hierarchical analytical method with fuzzy logic were obtained the following results; in the first instance, the criteria that can cause barriers or limitations in the research or implementation of renewable energy sources were hierarchized, in Figure 15 it is possible to appreciate that according to the group of experts consulted they consider that the greatest barrier or limitation against renewable energies is the political criterion with a degree of importance equivalent to 46%, followed in second place with 18% of importance the barriers derived from the technical criterion and in a third place is the criterion referring to social and economic barriers with 15% of importance. these results show that the greatest limitation to the research and implementation of renewable energy sources in a territory is the political will of a government, although there are many international agreements and commitments that each country has acquired according to the fulfillment of the sustainable development goals, some countries despite these commitments are few actions that in practice have taken.

Although the criterion of political barriers was the most important according to the experts consulted, this criterion has 5 subcriteria that were also submitted to judgment and hierarchy, in Figure 16 it is evident that the largest predominant sub-criterion in the criterion of political barriers refers to corruption and nepotism with 38% importance, in this hierarchy the sub-criterion lack of a transparent decision-making process occupies the second place with 22% of importance and for a third place the sub-criterion insecurity and/or terrorism with 17%, this shows that bad actions and the little or almost no commitment of a government for the research or implementation of renewable energy sources are the greatest obstacles to the advancement of the same, likewise, the actions of insecurity and/or terrorism that may occur in an area, are causes of non-investment in research or implementation of renewable energy sources.

Figure 15: Percentage of criteria barriers in renewable energy implementation



Likewise, the criterion of technical barriers occupied the second place in the degree of importance, however it is striking that for this criterion the subcriterion of greater weighting was the lack of research facilities with 58% according to the group of experts consulted as shown in Figure 17, this is something that is experienced in developing countries such as Colombia, I am very few or almost null research centers that are for the implementation or innovation in renewable energy sources, always causing dependence on first world countries, which apart from providing the material must also provide knowledge for future maintenance, that is, you must have qualified personnel of whatever the technology to be applied, In turn, this causes an inflation in the implementation since it must be acquired abroad and make a whole process for entry and implementation within the territory.

Figure 18 shows the hierarchical behavior of the subcriteria associated with social and economic barriers, for this research the subcriterion of greater weighting was that corresponding to the lack of social awareness with 48%, this result reveals that perhaps within the policies that a government to fulfill its commitments to sustainable development goals or simply wants to meet the needs of a population, Provide the right tools, provide the opportunities that are required, but all these tools and opportunities are lost because perhaps there is no interest in the affected population or population in general in the study, in research, in the implementation of alternative energy sources, that is, there is a lack of a social conscience that helps in the mitigation of a problem situation such as the lack of energy service on your territory. On the other hand another limitation in the implementation or research of renewable energy sources is the

Figure 16: Percentage importance in political barriers

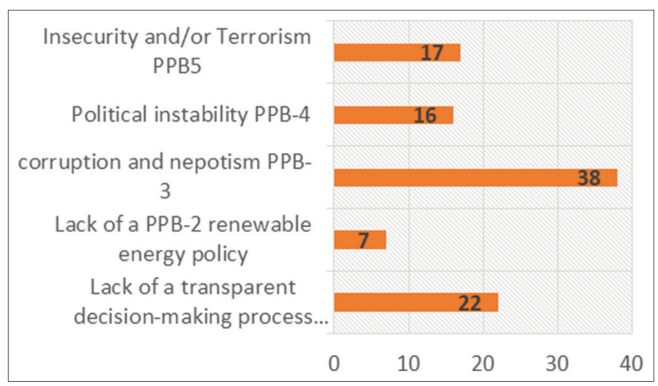


Figure 17: Percentage importance in technical barriers

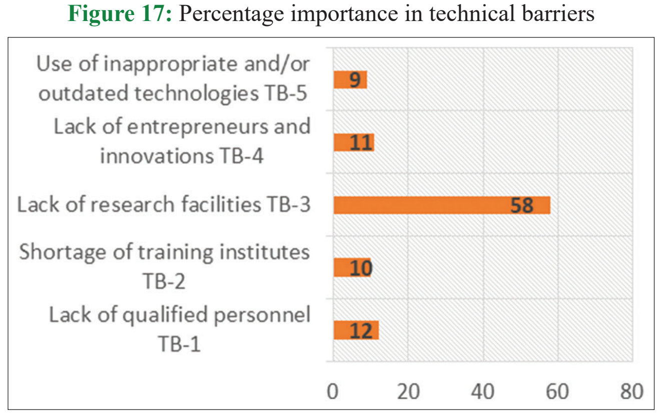


Figure 18: Percentage importance of social and economic barriers sub-criteria

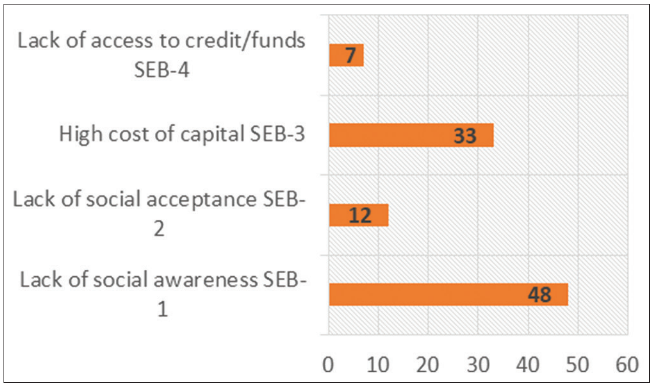
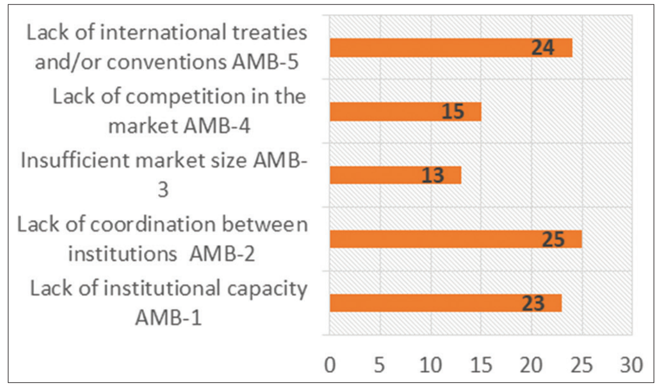


Figure 19: Percentage of importance in administrative and market barriers



high cost of their initial capital, this happens more frequently in countries that depend on the purchase of material abroad and not only on the purchase, but there is also a chain of dependence in the installation process, start-up and training of local personnel, all this set of factors end up affecting and increasing the value of a project or research. The lack of coordination between the institutions of a government and the lack of international treaties and/or agreements as shown in Figures 19 and 20, are also subcriteria that already feed the list of barriers or limitations in the execution of research or implementation of renewable energy sources and is that in the absence of good communication and a common objective by all the institutions of a government, If not that each one has a different policy on the subject of renewable energies causes it to be impossible to achieve progress against this policy of national and international interest, in addition governments especially those of emerging countries must ensure the signing of agreements with large companies or international laboratories regarding the issue of alternative energy sources, This in order to reach agreements that enable some type of discount on the purchase of products, training for personnel in order to have qualified personnel, follow-up to projects in execution, etc.

Regarding geographical and environmental barriers, perhaps the most relevant sub-criterion was the land requirement, it is not a secret that whatever the renewable energy source technology to be implemented in an area, this project requires the use of large amounts of land, some of these lands are indigenous reserves which hinders the implementation of the project, Other lands are private or are in protected reserves which causes the government processes to be able to use them, another difficulty regarding the lands is that large extensions are required and these lands could be implemented for other projects such as agriculture, livestock or construction of family homes, for these reasons as shown in Figure 21 the experts considered this subcriterion as the most important.

Although in this research the criteria and subcriteria associated with each criterion were hierarchized, it was also possible to weigh which of all the subcriteria was the most relevant to the group of experts consulted, in Figure 16 it is shown that the three subcriteria of greater relevance were Corruption and nepotism, Lack of investigation facilities and Lack of a transparent decision process with 17.48%, 10.44% and 10.12% respectively, demonstrating that definitely the greatest driver in a nation in the research and

Figure 20: Percentage importance in geographical and environmental barriers

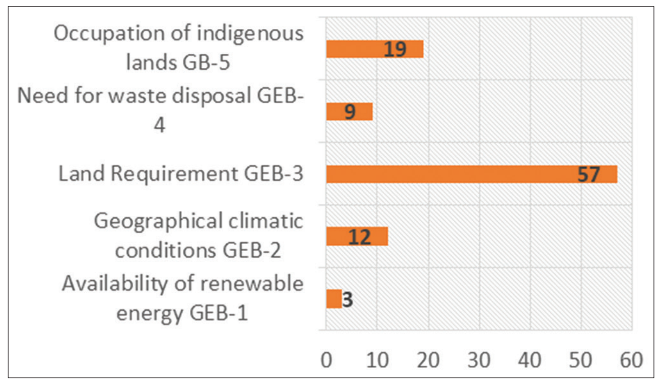
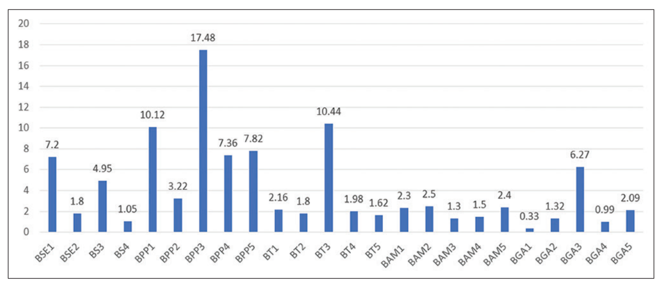


Figure 21: Percentage of the overall importance of the sub-criteria



implementation of renewable energy sources are the commitments and actions taken by the government of the day.

It is important to know the barriers or limitations in the research and implementations of renewable energies because this allows to identify the challenges and opportunities to improve and expand the use of these energy sources in the future. It can be concluded that among the most common barriers are installation and maintenance costs, lack of favorable policies and regulations, limited energy storage capacity, dependence on climatic and environmental conditions, lack of adequate infrastructure and resistance to change by some sectors.

Knowing these barriers allows researchers, engineers and planners to develop innovative and practical solutions to overcome these challenges and improve the efficiency and profitability of renewable energy. In addition, it can help encourage the adoption of more favorable policies and regulations that allow for greater investment and development of renewable energy in the future. In summary, understanding the barriers and limitations in renewable energy research and implementations is essential to drive sustainable development and promote a transition to a cleaner and more sustainable future.

4. CONCLUSIONS

Colombia is a country that thrives in the field of renewable energy sources such as solar, wind, biomass and hydroelectric, many of these energy sources offer important employment opportunities in the future and are prepared to build or assemble most of the equipment locally in the future, however, to achieve this objective, several barriers must be eliminated to improve the adoption and acceptance in the market of all or part of the clean energy technology, this study identified and prioritized the barriers to the deployment of renewable energy.

Taking into account the results obtained from the FAHP, it is proposed to create a government agency whose sole purpose is to regulate and promote renewable energies, facilitate the granting of licenses and develop new or updated policies according to the international market and finally update existing policies. On the other hand, financial and research support should be provided to facilitate access to credit/financing for both technology developers and end users, in addition, the government should ensure a balance between renewable and conventional energy sources through subsidies for renewable energy sources. The creation and delivery of vocational courses/training to develop skills is proposed. To create a social cognitive system that was flexible enough to cope with any new barriers that might arise over time. Ultimately, this study provides an analytical and theoretical framework for many legislators/politicians and stakeholders to better understand the barriers to the development of renewable energy, in addition it opens new horizons to overcome the impact of the barriers that limit the development of renewable energy technologies in any study area.

In the world and in Colombia as an emerging nation, there are some obstacles to the research and development of renewable energies, in Colombia this phenomenon occurs with greater intensity due to political mismanagement, high corruption, high production costs, lack of market size, lack of public awareness and lack of research centers, however these obstacles must be overcome to be able to grow quickly and widely use these technologies especially in the territories that most require it due to the conditions their inhabitants are. The fact of overcoming or perhaps mitigating these barriers or limitations will help to develop local renewable energy markets and limit the traditional use of non-renewable energy, which will bring as a consequence the improvement in the quality of life of each of the territories, in addition to the fulfillment of the international commitments acquired such as the sustainable development goals, some proposals that will help the fulfillment of the previous idea are mentioned below.

4.1. Greater Support for Research and Development

Strengthening research and development capacity in the field of clean energy, this is extremely important to help renewable energy companies with a high innovation potential, expand the amount of renewable energy financing and increase R&D financing for private renewable energy companies.

4.2. Corruption Mitigation

The draft policy or action plan for the exponential growth of the renewable market covers all the key aspects. The action plans will be developed in consultation with different government entities associated solely with renewable energies. Objectives and action plans should be realistic and measurable they should be useful tools to help policymakers focus action and improve the efficiency of their implementation.

4.3. Funding Bank

Appropriate financial institutions are essential as lack of easy access to capital expenditure is a serious problem for the lower classes. The financial mechanism in Colombia needs to be changed/improved to encourage the development of renewable energy and not depend so much on the outside.

4.4. Mitigate International Purchases and Encourage Local Construction

By reducing the initial investment costs of renewable projects, companies and academic institutions are expected to improve their R&D capabilities, this is also feasible if financing policies are in place.

4.5. Clear Renewable Energy Policies

This includes the recognition of urban planning and approaches through specific energy-based growth strategies that create an enabling environment for the application of renewable energy technologies. Solving problems requires planning tools, laws, regulations and rules, public knowledge, as well as choosing decision methods and city practices.

4.6. Social Work

Field presentations, conferences, courses, education and training programs in order to inspire people to implement renewable energy technologies in Colombia. People will be encouraged to install solar lights in government offices, parks and sidewalks, as well as in other areas related to renewable energy.

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