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Methodology to Assess the Implementation of Solar Power Projects in Rural Areas Using AHP: a Case Study of Colombia

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ABSTRACT

Selection of a location for a solar power projects is critical factor in energy planning due to conflicting objectives. The objective of this paper is to develop a methodology to assess the implementation of solar power projects in rural areas applied in Colombia using an Analytic Hierarchy Process (AHP). In order to assess potential locations of solar power projects in Colombia. This study takes into consideration techno-economic, social, and environmental-risk criteria based on data from the National Survey on Living Conditions in Colombia (NSLCC) and The Institute of Hydrology, Meteorology and Environmental Studies (IDEAM). Finally, eight departments were chosen representing different regions of the country, with differing levels of irradiation as well as distinct social, economic and environmental living conditions. The methodology presented here can be applied as a design tool for energy policy by utilities companies, providers, investors and academic researchers in the selection of locations for solar power projects. The application of proposed methodology shows that the Caribbean region presents the highest energy needs and the best environmental for the development of rural solar power projects in Colombia with overall priority of 72.4%.

Keywords

Solar power projects;
Analytic Hierarchy Process (AHP);
Rural areas;
Colombia;

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1. Introduction

In 2015 most countries in the world adopted the Sustainable Development Goals (SDGs) enumerated in the 2030 Agenda for Sustainability [1]. The seventh of these goals is ”*Affordable and Clean Energy*” (United Nations, 2015), which stipulates foremost a universal access to energy. At present almost 13% of the global population lacks access to modern electricity [2]. In Colombia, the government has addressed this issue with a strategy of long and short-term energy planning favoring electric power through on-grid and off-grid projects. These two schemes for expanding the electrification are based on: first, auctions for long-term electricity supply using renewables resources (on-grid); and second for short-term generating incentives for non-conventional energy resources mainly focused on small and medium projects (on-grid and off-grid) [3].

The funds related to electrification in rural areas off-grid in Colombia are provided by Financial Support Fund for the Energization of non-interconnected Areas, known as “*Fondo de apoyo financiero para la energización de las zonas no interconectadas* (FAZNI)” [4].

The resources of FAZNI are sponsored by generating agents of the wholesale Colombian energy market and international electrification programs.

With respect to auctions 2,200 MW of installed capacity was approved on 22^{nd} October 2019 [5]. Related to incentives 71 MW were approved, where 78 projects correspond to solar resources on 31^{st} January 2020 [6]. Furthermore, the government of Colombia agreed in the

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World Summit on Climate Change in Paris (COP21): increase the use of renewable energy resources; reduce greenhouse gas emissions by 20%; ensure the resilience of the electricity generation matrix against climate change; and mitigate the effects of climate variability [7].

Colombia is considered as Latin America's fourth largest economy measured by Gross Domestic Product (GDP) at Purchasing Power Parity (PPP) in 2019 of International Monetary Fund estimated in 791,9 billion USD [36], with an approximate population of 49.1 million according to the National Administrative Department of Statistics (DANE) [3]. In 2017, the total of energy produced by Colombia was 5,170.9 PJ (123.5 MToe), the exports reached 4,258.1 PJ (101.7 MToe), being an exporting country mainly oil and coal. The consumption was 1,231.8 PJ (29.42 MToe) divided into: industry 28.11%; transport 36.02%; others 34.67%; and non-energy use 1.18% [8]. The CO_2 emissions of Colombia represents 0.22% of the world and the electricity consumption was 73.5 TWh in 2017 [8].

Colombia's electric power generation capacity is roughly 16,750 MW. Hydro-power accounts for 10,960 MW (about 66%) and thermal generation units for 4,850 MW (about 29%), of which 3,509 MW come from gas power plants and 1,340 MW from coal-fired power plants [9]. The remainder is produced by smaller power plants.

Table 1 presents the main energy and socioeconomic indicators for Colombia, including: GDP (PPP); rural population; rural poverty gap; access to electricity in rural areas; and forest area.

1.1. Brief review of state of art

There is an extensive literature on planning renewable energies and in particular on using solar applications. This brief review of state of art is focused on: sustainable indicators; access and affordable energy using solar systems; and solar decision-making methods.

Currently indicators are a powerful tool for sustainable assessment. Narula [11] built a multidimensional index known as Sustainable Energy Security which was applied for various energy sources for residential sector in India. Razmjoo and Sumper [12] investigated on Sustainable Energy Development Index applied for developing countries. A paper developed by Jaroszewska et al. [13] explores the relations between energy efficiency systems and sustainable energy management the results correspond to tourism sector in polish. SDGs and specifically goal 7, "*Affordable and Clean Energy,*" energy management will play an important role in developing countries.

Ogundari et al. [14] evaluates the energy lighting adequate on off-grid between Photovoltaic (PV) solar and diesel generation, the results show that the PV system is four times less expensive. Nigeria has a very strong dependence on fossil resources, this condition imposes barriers to the entry of renewable energy specially PV systems, this solution allows reduce or eliminate fuel fraud, more cost competitive and technological learning. Groth [15] basically compares on-grid with off-grid households and found huge differences in Tanzania, PV systems can be an important link to reduce socio-economic impacts.

Regarding to studies using the AHP approach focused on renewable applications the literature is diverse [16–18]. In Iran, where geographical conditions produce an especially high level of solar radiance, Azizkhani et al. [19] elaborated an AHP based on technical features, economic parameters, geographical location and solar radiance on the Earth's surface. Algarin et al. [20] built

Table 1: Energy and socioeconomic indicators in Colombia, data from [10]

Variable	2014	2015	2016	2017	2018
GDP, (Billion-PPP) (Current International- USD)	348.48	359.45	366.45	372.93	381.88
GDP per capita (Constant-LCU)	16,640.4	16,933.5	17,053.4	17,026	17,200,4
Rural population (% of total population)	20.58	20.23	19.89	19.5	19.22
Poverty gap at $1.90 a day (2011 PPP) (%)	2.0	1.8	1.8	1.6	1.7
Access to rural electricity (% of total population, on interconnected areas)	89.89	91.79	92.76	92.74	99.6
Forest area (% of land area)	52.75	52.72	52.70	–	–

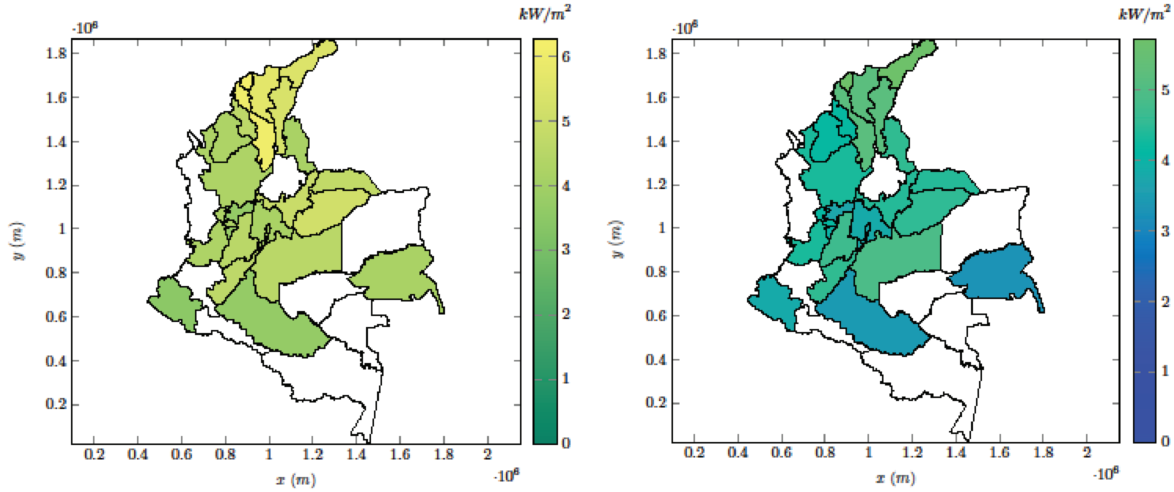

Figure 1: Daily horizontal global irradiation in Colombia, annual average. Developed from IDEAM available data [23]

a decision-making procedure for selecting different renewable resources in Colombia based on multi-criteria decision analysis. One of the most interesting aspects of the latter work is that it includes techno-economic, social, and environmental-risk criteria. Ayag [31] developed a decision-making method for evaluating solar plants locations based on geographical, economic and social factors.

Also there is another approaches specially developed for non-expert decision making [21]. This work presents a method to compare the electric power production from renewable and non-renewable sources using a Multi-Stage Qualification for Micro-Level Decision-Makin . Likewise, Ozdemir and Sahin [17] developed an applied work at Igdir University to determine the best location for a solar photovoltaic plant between three alternatives using measurements of solar radiance and geographical information. Pellegrini et al. [22] aim to identify technological and non-technological barriers in district heating systems using an AHP classification.

1.2 The potential of solar energy in Colombia

Colombia is located in northwestern South America and covers 1,038,700 square km^2 of land. It is a rich country in natural resources suited to the production of electricity, such as: solar, wind, hydro, and biomass. The average solar irradiation of the country is approximately 4.5 kWh/m^2/day [23], in comparison with the average irradiation of the world, 3.9 kWh/m^2/day [24]. Colombia experiences two seasonal periods: summer, from December 1st to April 30th, and winter, from May 1st to November 30th [25]. Figure 1 illustrates the annual average for daily horizontal global irradiation in Colombia in 2014.

Table 2: Average irradiation by regions of Colombia [23]

Region	Average irradiation (kWh/m^2/day)
Pacific	3.5 – 4.0
Amazon	3.5 – 4.0
Andean	4.0 – 4.5
Orinoquía	4.5 – 5.0
Caribbean	4.5 – 5.0

Colombia is divided into 31 departments comprised in 5 regions known as: Pacific; Amazon; Andean; Orinoquía and Caribbean, each with different levels of solar irradiation as shown in Table 2. Nevertheless, there are some departments with a great potential. Are the case of the departments of La Guajira and Cesar with an average irradiation between 5.0 – 6.0 kWh/m^2/day.

1.3 Aim of the study

This article aims to assess the implementation of solar power projects in rural areas of Colombia that can be applied on small and medium projects (on-grid and off-grid). The goals are: *(i)* to develop a methodology to assess new criteria in developing countries such as: technical-economic factors, social factors, and environmental risk; *(ii)* to determine criteria and sub-criteria based on data from the NSLCC and IDEAM; and *(iii)* to find and assess the best alternatives for localization of solar energy projects in Colombia. This paper is divided into three main parts: section two presents the materials and methods for the AHP theoretical framework, a description of the data, and the proposed methodology. Section three provides the descriptive analysis and the selection of criteria and sub-criteria, along with the results of the application of the AHP method. Section four presents the discussion and conclusions.

2. Methods and Data

Many problems related to engineering, economics, health and education need solutions that may have different interests. This hierarchical analysis technique allows addressing these differences in a rational and numerical way. The method of AHP was introduced by Saaty [26] as a tool for dealing with complex decision-making. This methodology can be applied in the selection of renewable energy projects [17] [34] [35]. This section related to the methodology is divided into: theoretical framework; data; and flowchart of methodology.

2.1. Theoretical Framework

One of the most important characteristics of AHP is that it allows for the measurement of subjective aspects of a decision. Furthermore, the model quantifies the consistency of decision maker's assessment, Figure 2 illustrates the general diagram related to AHP process. In general terms an AHP contains the following steps:

(i) Developing a model: An AHP analysis consists of building hierarchy and can be divided into: goals; criteria; sub-criteria; and alternatives. Using the scale proposed by Saaty [26] according to Table 3, establishes Saaty's pairwise comparison scale. The importance of two criteria can be calculated, where the *jth* criterion is equally or more important than the *kth* criterion. This approach allows to compare different alternatives, which can be very useful in renewables decision-making [27] [28].

(ii) Determining weights matrix for the criteria and sub-criteria: decision makers must establish in the AHP process the relative priorities (weights) for the criteria. These weights are relative because depends of the relationship with pairwise comparison. Hence, the criteria should not have the same importance [29]. In this step the weights for the criteria and sub-criteria are derived Eq. (1), according to Table 2.

$$A = \begin{bmatrix} 1 & a_{1,2} & \cdots a_{1,k} \\ \frac{1}{a_{2,k}} & 1 & \cdots a_{2,k} \\ \frac{1}{a_{j,k}} & \frac{1}{a_{i,2}} & \cdots 1 \end{bmatrix} \tag{1}$$

Table 3: Pairwise comparison between criterion according to Saaty's

Value of $a_{j,k}$	Interpretation
1	*j* and *k* are equally important
3	*j* is slightly more important than *k*
5	*j* is more important than *k*
7	*j* is strongly more important than *k*
9	*j* is absolutely more important than *k*

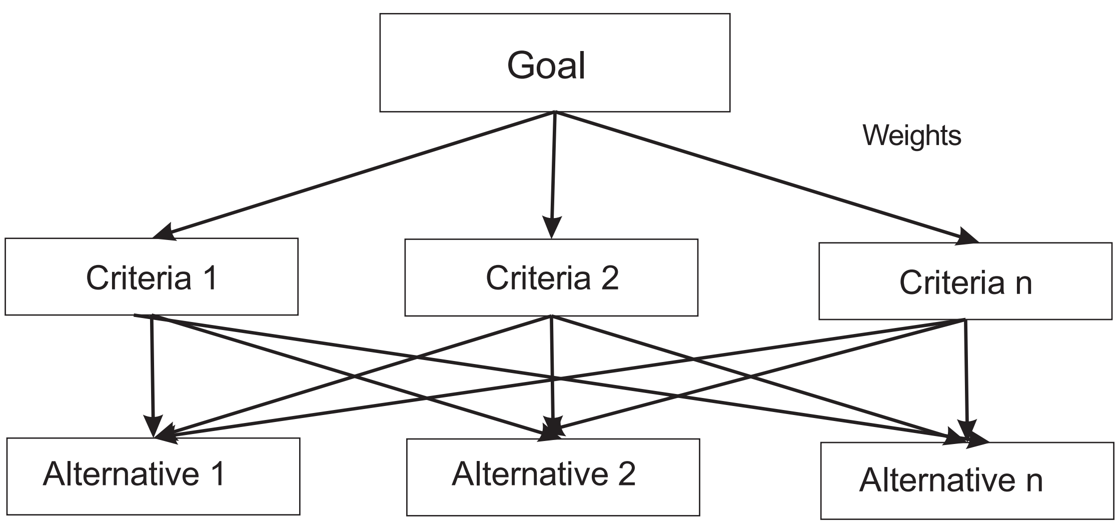

Figure 2: General diagram of AHP process

Where A corresponds to matrix of priorities (weights) and $a_{j,k}$ relative priorities between criteria. And *j*, *k* refers to pairwise comparison criteria. The matrix must have *nxn* dimensions (n represents order de matrix).

(iii) Computing the vector of priorities: the next step consists to derive the normalized pairwise comparison matrix *Anorm* from matrix *A*, set the sum of the entries on each column equal to 1. The criteria weight vector W is composed of the average of the entries in each row, according to Eq. (2) and (3):

$$\bar{a}_{j,k} = \frac{a_{j,k}}{\sum_{l}^{n} a_{j,k}} \tag{2}$$

$$w_j = \frac{\sum_{l}^{n} a_{j,l}}{n} \tag{3}$$

Where $\bar{a}_{j,k}$ is the matrix A_{norm}; and is the weight of the *jth* criterion.

(iv) Checking the consistency of judgments: in order to achieve consistency in the AHP process, is necessary to apply the Consistency Index (CI) and the Consistency Ratio (CR) as is presented in the Eq. (4) and (5). If CR Eq. (4) is smaller than 0.1, the result is acceptable [31-32].

$$CI = \frac{(\lambda_{max} - n)}{n-1} \tag{4}$$

Where,

λ_{max}: is obtained by summing the priorities and dividing by the number of criteria.

n= number of criteria.

The consistency ratio is defined in Eq. (5) as follows:

$$CR = \frac{CI}{RI} \tag{5}$$

Where,

CI: consistency index

RI: index of a quasi-random matrix.

(v) Making a final decision: the goal is to calculate the overall priority for each alternative. This procedure consists on the global weight values of the criterions. And sum of the global weights of the alternatives, evaluating all alternatives.

2.2. Data

In the 1990s, Colombia developed national standards of life surveys sponsored initially by United Nations and National Planning Department. The design and execution of the survey considers the methodology called the Living Standards Measurement Study [30] which was promoted by the WB.

This survey was conducted in 2016 by the DANE and measures living standards and to characterize the population in urban areas, intermediate cities and rural areas of Colombia, thus covering a nationally representative sample. The NSLCC 2016 sample contains information from questionnaire interviews of 14,800 households divided into: urban (8,974 households), intermediate cities (2,154 households), and rural areas. (3,673 households).

The present study is developed exclusively in rural areas, therefore the NSLCC data used in this paper includes rural sample that corresponds to 3,673 households and data available at IDEAM. The data used related to NSLCC are: energy use (cooking and electrification); monthly income; potable water; flood overflows; landslides; garbage collection; and violent acts. With respect to IDEAM the data used corresponds to include solar irradiation.

The data are divided into: binary; category; and continuous as described as follows:

(i) binary: electrification; potable water; flood overflows; landslides; garbage collection; and violent acts.

(ii) category: energy use for cooking.

(iii) continuous: monthly income and solar irradiation.

The database was pre-processed, eliminating missing values, and cleaning empty data for a proper handling of the data.

2.3. Flowchart of methodology

This methodology makes it possible to assess the localization of solar power projects in rural areas of Colombia and to select the departments best suited for this type of project. Figure 3 presents the proposed methodology using an AHP approach based on NSLCC survey and IDEAM data. Figure 3 illustrates the methodology for determining the location of the alternatives for solar projects in Colombia. The methodology hierarchically presents main criteria, criteria, sub-criteria and alternatives.

Table 4 presents the criteria and sub-criteria based on techno-economic, social and environmental risk. Therefore, the parameters of the sub-criteria are presented in detail as follows as:

(i) Techno-economic Criteria: include solar irradiation, energy poverty, and income of the rural areas.

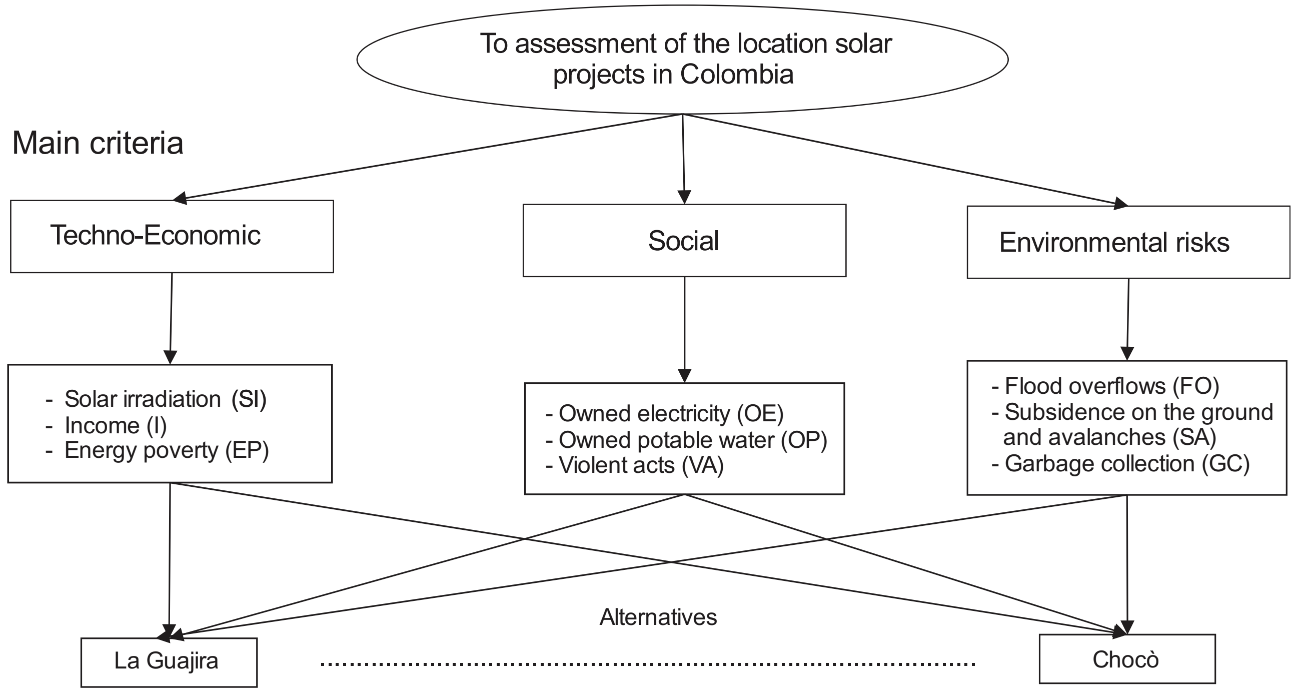

Figure 3: Flowchart methodology assessment of location solar projects in Colombia

Table 4 Definitions of criteria and sub-criteria

Factor (Criteria and sub-criteria)	Definition
	Techno-economic
Solar irradiation (SI)	Solar radiation is radiant energy emitted by the sun, particularly electromagnetic energy in kWh/m^2/day in each department
Income (I)	Average monthly income of households in the departments in USD (year 2016 USD)
Energy Poverty (EP)	Type of fuel used by households for cooking (Solid; transition and modern fuels)
	Social
Owned electricity (OE)	The household has electricity
Owned potable water (OP)	The household has potable water
Violent acts (VA)	The household is vulnerable to armed conflict or violent acts
	Environmental Risks
Floods (FO)	The area suffered flood or over floods
Subsidence of the ground and avalanches and avalanches (SA)	The area suffered subsidence of the ground
Garbage collection (GC)	The area has garbage collection

(*ii*) Social Criteria: include owned electricity, owned potable water, and violent acts.

(iii) Environmental Risk Criteria: include flood overflows, landslides, and garbage collection.

3. Results

The application of the proposed methodology was carried out in Colombia, according to the implemented criteria and sub-criteria with NSLCC and IDEAM data.

3.1. Prioritization and Selected data

This subsection presents a prioritization and selected data according to the data available in the NLSCC. Due to the fact that in the NSLCC many departments there is no data, were selected several departments belonging to different regions of Colombia. The departments selected were: Antioquìa (ANT), Atlàntico (ATL), Bolìvar (BOL), Boyacà (BOY), Caldas (CAL), Caquetà (CAQ), Cauca (CAU), Cesar (CES), Còrdoba (COR), Cundinamarca (CUN), Chocò (CHO), Huila (HUI), La Guajira (GUA), Magdalena (MAG), Meta (MET), Nariño (NAR), Norte de Santander (NSD), Quindío (QUI), Risaralda (RIS), Santander (SAN), Sucre (SUC), Tolima (TOL), and Valle del Cauca (VAL). The NSLCC does not include information about the following departments in rural areas: Arauca (ARA), Casanare (CAS), Putumayo (PUT), Amazonas (AMA), Guainìa (GUA), Guaviare (GUV), Vapuès (VAU) and Vichada (VIC). The prioritization of data is presented in Table 5 and the departments chosen for each region are in italics.

3.2. Consistency and alternatives obtained

The weights given for each sub-criteria take into account the prioritization as follows as:

(i) Techno-economic criteria. A higher priority is given to departments with higher solar irradiation, lower income, and lower use of cooking fuel.

(ii) Social criteria. The priority is given to departments with lower levels of electrification and potable water, and that have experienced violent acts.

(iii) Environmental risk criteria. The preference is for areas with lower frequency of floods and ground subsidence and higher levels of garbage collection.

Table 6 illustrates the result of the priorities. The CI and CR were calculated using equations (4) and (5). The values obtained are 0.0742 and 0.0512, respectively. The consistency ratio is adequate and appropriate [17] [32–33]. Nevertheless, when there is inconsistency the process should be reviewed again. For this case, the AHP model is consistent. Table 7 presents the overall priorities derived, taking into account each one of the sub-criteria analyzed for each alternative.

The results of each alternative are presented in Table 6. According with the proposed methodology and applying AHP approach, the first overall priority is GUA with a value of 35.5%; the second alternative is CES with 20.4%; and the third alternative is COR at 16.5%. These departments all belong to the Caribbean region further, have high levels of solar irradiation and energy poverty. The next department is ANT, one of the most

Table 5: Results of criteria and sub-criteria by selected departments

Department	SI (kWh/m^2/day)	I (Monthly-USD)	EP (%)	OE (%)	OP (%)	VA (%)	FO (%)	SA (%)	GC (%)
GUA	*2,007.50*	*261.85*	*88.6*	*0.0*	*37.1*	*37.1*	*0.0*	*2.9*	*5.7*
ATL	1,916.25	457.41	59.5	39.2	76.0	34.2	0.0	5.1	0.0
CES	*1,916.25*	*566.35*	*46.0*	*46.8*	*83.9*	*15.3*	*0.0*	*4.0*	*7.3*
MAG	1,916.25	270.15	71.2	25.4	89.8	25.4	3.4	3.4	0.0
BOL	1,733.75	266.98	66.7	33.3	69.2	41.0	0.0	12.8	12.8
COR	1,733.75	291.66	77.0	20.7	91.4	13.8	0.0	1.7	1.7
SUC	1,733.75	489.60	52.4	35.7	95.2	66.7	0.0	4.8	2.4
ANT	1,642.50	380.86	30.5	67.7	98.9	59.3	0.9	6.7	3.1
BOY	1,642.50	495.78	70.9	26.0	95.9	70.1	1.0	3.1	6.7
HUI	1,642.50	297.20	44.3	54.0	98.3	58.3	1.3	10.6	18.3
MET	*1,642.50*	*497.17*	*17.2*	*79.1*	*89.6*	*35.1*	*0.0*	*13.4*	*14.9*
VAL	*1,642.50*	*469.55*	*14.8*	*82.8*	*94.5*	*68.6*	*2.5*	*5.5*	*6.1*
CAL	*1,551.25*	*392.39*	*37.5*	*60.8*	*98.9*	*40.9*	*1.7*	*0.6*	*4.5*
RIS	1,551.25	312.47	66.7	32.3	97.0	63.6	0.0	0.0	3.0
TOL	1,551.25	346.03	54.6	43.5	94.9	27.3	1.1	4.1	2.2
CUN	*1,460.00*	*529.13*	*34.3*	*62.9*	*96.9*	*55.4*	*0.3*	*3.8*	*5.7*
SAN	1,460.00	351.56	41.7	57.7	100.0	50.0	0.6	1.3	5.1
NSD	1,387.00	381.25	62.9	35.3	94.1	35.3	1.2	1.8	11.2
CAQ	1,368.75	534.40	62.6	36.6	44.3	0.8	0.8	1.5	2.3
CAU	*1,368.75*	*360.98*	*60.6*	*38.2*	*96.2*	*78.7*	*0.6*	*6.4*	*12.1*
NAR	1,368.75	232.84	54.1	44.2	96.4	76.8	2.3	11.3	24.4
QUI	1,368.75	535.55	31.0	69.0	100.0	99.0	0.0	3.0	1.0
CHO	*1,277.50*	*343.45*	*18.5*	*81.5*	*81.5*	*32.3*	*1.5*	*50.8*	*3.1*

Table 6: Consistency of the criteria selected

Sub-criteria	SI	I	EP	OE	OP	VA	FO	SA	GC	Overall Priority
SI	0.369	0.576	0.370	0.234	0.277	0.233	0.154	0.151	0.170	0.282
I	0.123	0.192	0.370	0.390	0.277	0.181	0.198	0.194	0.170	0.233
EP	0.123	0.064	0.123	0.234	0.166	0.233	0.198	0.194	0.170	0.167
OE	0.123	0.038	0.041	0.078	0.166	0.181	0.198	0.194	0.170	0.132
OP	0.074	0.038	0.041	0.026	0.055	0.130	0.110	0.065	0.057	0.066
VA	0.041	0.027	0.014	0.011	0.011	0.026	0.110	0.108	0.094	0.049
FO	0.053	0.021	0.014	0.009	0.011	0.005	0.022	0.065	0.094	0.033
SA	0.053	0.021	0.014	0.009	0.018	0.005	0.007	0.022	0.057	0.023
GC	0.041	0.021	0.014	0.009	0.018	0.005	0.004	0.007	0.019	0.015

Table 7: List of alternatives ordered by overall result

	SI	I	EP	OE	OP	VA	FO	SA	GC	Overall Priority
Criteria Weights	0.282	0.233	0.167	0.132	0.066	0.049	0.033	0.023	0.015	
GUA	0.109	0.075	0.059	0.065	0.020	0.009	0.007	0.005	0.004	35.4%
CES	0.064	0.053	0.033	0.018	0.013	0.009	0.006	0.004	0.004	20.4%
COR	0.043	0.043	0.034	0.012	0.011	0.009	0.006	0.004	0.003	16.5%
ANT	0.019	0.024	0.012	0.009	0.006	0.008	0.003	0.003	0.001	8.6%
MET	0.015	0.014	0.010	0.012	0.008	0.007	0.004	0.003	0.001	7.4%
VAL	0.017	0.011	0.010	0.008	0.003	0.003	0.003	0.002	0.001	5.6%
CAL	0.010	0.009	0.004	0.004	0.003	0.002	0.002	0.001	0.001	3.6%
CUN	0.005	0.004	0.005	0.004	0.001	0.002	0.002	0.001	0.000	2.5%

important departments in terms of commercial and industrial development, was 8.6%. Located in the central northwestern part of Colombia with a narrow section that borders the Caribbean Sea.

The next is MET a department that belongs to Orinoquía, as known as eastern plains, the next border to Venezuela. This department is an important agricultural and livestock center of the country, with a result of 7.4%. VAL is an important industrial and commercial department. Therefore, a large sugar cane producer, had a result of 5.6%. Regarding these latter results (ANT, MET, VAL) there are no significant differences.

Finally, in the Andean region the departments of CAL and CUN represent 3.6% and 2.5% respectively. CUN is located in the center of Colombia and in general terms is the most developed department in the country. CAL and CUN do not have high levels of solar irradiation. Furthermore, these departments have high levels of income and electrification in comparison with the departments of the Caribbean and Orinoquía regions.

4. Discussion and conclusions

The selection of solar power projects is a complex task due to diverse interests. Decision makers are forced to choose the location of solar power projects under uncertain conditions, and incorrect decisions can have consequences in the development of renewable generation projects for developing countries. For this reason, the main goal of this work is to develop a methodology based on several criteria and sub-criteria divided into technical-economic, social, and environmental-risk for assess the implementation of solar projects in rural areas using an AHP approach.

Decision makers, local authorities, and researchers need to choose investments not only based on levels of irradiation, therefore considering social and environmental criteria that prioritize developing communities and provide electrical coverage under safe and reliable conditions.

This methodology should act as a feasible and practical tool to be applied in developing countries. The methodology was applied in Colombia, nevertheless, can be applied in other developing countries.

The data was ordered corresponding to twenty-three departments starting from of solar irradiation and selected eight departments that belong to different regions of the country; the data is from the NSLCC conducted in 2016 and the IDEAM irradiation measure. In the aim of finding the suitable and possible location, were selected the following sub-criteria: solar irradiation; energy poverty; income; owned electricity; owned; potable water; violent acts; floods; landslides; and garbage collection.

In our study, the results of the alternatives give the highest priority to the Caribbean region and, to the departments the GUA, CES and COR which make up 72.4% (overall priority). Other departments with development potential for solar power plants are ANT, MET, and VAL (belonging to the Andean, Orinoquía and Pacific regions respectively). Nonetheless, between these departments the percentage of the alternatives are not comparable with the departments of the Caribbean region.

Currently the government of Colombia is employing an aggressive strategy for long-term energy planning that looks to implement electric power projects focused on renewable energy. The government's stated objectives are: (i) to strengthen the resilience of the power matrix against larger shocks associated with climate change (like the El Niño event); (ii) to promote competition and increase price efficiency through long-term energy contracts; (iii) to mitigate the effects of climate change by harnessing renewable energy resources; and (iv) to reduce GHG from the power sector in order to achieve the countries commitments signed at COP21.

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