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Multi-Criteria Decision Making for energy planning in Democratic Republic of Congo: Case study of Idjwi island

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ABSTRACT: Energy planning involves multiple actors (authorities, community, investors, and operators) and multiple objectives most of the time in perpetual conflict. The Analysis Hierarchy Process (AHP) which consists of a Multi-Criteria Decision Analysis method (MCDA) theory of measurement through pairwise comparisons and relies on the judgments of experts to derive priority scales was used to evaluate the energy resources of Idjwi island in the Democratic Republic of Congo (DRC). The weights obtained from AHP analysis were used to rank the seven alternative energy resources for the island using the Technique of Order Preferences to Similarity to Ideal Solution (TOPSIS). The combination of the two MCDA methods reduces the uncertainty and reinforce the reliability of the decision by combining the advantages of both methods. Two surveys were conducted in this research, one for the rural community in Idjwi, in order to determine their preferences, priority, economic situation for an energy project. The second survey was conducted for the energy experts in the region was to analyze the importance of the criteria. This thesis aims at ranking the different energy resources for rural electrification in the Island. Energy planning in many developing countries is still not well-handled and depend mostly on the priorities of actual authorities. To minimize the risk of investing in wrong sources of energy, energy planning is needed which includes many actors and factors. For example, the exclusion of the local communities in the process of electrification projects can lead to failures of many mini-grid projects in villages. Based on the preferences and priorities of the community, the small hydropower and solar photovoltaic sources were the first alternatives to power Idjwi Island. An assessment of the renewable energy resources of the DRC is also included.

KEYWORDS: Energy planning, AHP, TOPSIS, rural electrification, energy alternatives.

1 INTRODUCTION

Energy access has been proved in the information age to be inevitable to all kind of development. It has also proven that the 17 Sustainable Developments Goals are interconnected, many scholars agree that the 7th SDG which consists of access to clean energy for all. It can accelerate the other goals such as education, zero hunger, gender equality.

According to the Energy Access Outlook 2017, 1.1 billion people live without access to electricity although remarkable efforts have been made in the past bringing electricity to 1.2 billion people since 2000. The same report showed still 14% of the world population lives without electricity where 84% are in rural areas [1].

In Sub-Saharan Africa, more than 580 million live without electricity compared to 2000 (510 million) [1]. Tremendous efforts have been made to power African countries, for that decentralized and mini-grids have played a key role in electrification of rural areas where the grid solution is expensive [2].

More than 71 million of Congolese from DRC live without access to electricity, and this represents 12% of the African population [3]. Moreover, according to the national Institute of Statistics (INS), 42 million (60% of the DRC population) of the habitants of DRC living without electricity are living in the rural areas [4].

The Idjwi Island, located in the East of the DRC in the middle of the Kivu lake, has 250 000 habitants living without electricity. Less than 10% of this population own very small Solar Home Systems (SHS) for lighting. A mini-grid is a low voltage electrical grid in which loads, generators and micro sources are operating to supply electricity to rural areas. The mini-grids most of the time use a primary source of renewable energy (solar, hydropower, biogas, biomass, wind, and/or hybrid sources with storage system or diesel generators). These mini-grids can operate autonomously or tied to the main electrical grid [5], [2].

To meet the goals of the initiative of clean energy for all, the 60% of new access to electricity by 2030 will come from renewable energy. Mini-grid using hydro is leading following by solar PV mini-grid technology. The trends need to be scaled up in most African countries [1], [2]. This requires technological, economic solid arguments to attract the investors and advise the policymakers in the national energy plans.

Special attention is required to the mini-grid systems as proved solution to rural communities most of the time with low incomes. Where in another hand the mini-grid imply high investment costs, the high levelized cost of electricity, long payback time, etc. A model including technical, and economic aspects need to be developed from local data collections on existing mini-grids, or in order to design new model.

During the past decades, many countries have deployed projects of mini-grids to assure rural electrification [2]. The viability of such a project differs from one country to another and from a region to another.

DRC has made progress in the liberalization of the Energy sector by promulgating in 2014, the law which regulates the electricity production [6]. This liberalization followed by the work of assessment and mapping of energy resources by experts of the ministry of energy in one document to support investors in their decision in order to achieve sustainable energy for all [3]. An optimum power generation mix for rural electrification has not yet been tapped in the current research in DRC. Many options are offering to the country to power the rural community such as the extension of the national grid of National electricity company (SNEL), the large-scale deployment of mini-grids with multiplies options like solar mini-grids, hydro mini-grids, biomass mini-grids, hybrid systems mini-grids.

An assessment of resources, technological review and economic analysis on Solar, hydro, biogas, and biomass and hybrid systems were undertaken in this study for the Idjwi Island in DRC, two Multi-Criteria Decision-Making methods were selected to choose the best energy alternative for idjwi island.

In many African countries, DRC included have limited resources for proper planning in the domain of energy. Investors and young entrepreneurs lack results for energy planning. In order to meet the agenda 2030 and the objectives of SE4ALL independent researches in the domain of energy planning and optimization power generation systems to assist decision-makers at all levels are crucial.

Moreover, in order not to violate the inclusivity characteristics of the SGDs (*leave nobody behind*), rural electrification is a key sector that has attracted many researchers in power, energy engineering. In addition, in most politically unstable countries such as DRC, the priority for electrification of different regions can be biased by the political appurtenance, regionalism of leaders, etc. Thus, research in energy planning for rural electrification for a sustainable development based on the actual situation and future scenarios is important for both strategic and operational level. The rural community in DRC represent 69,5% in 2005 and 61,1% in 2012 [9], however, the planning and priority are given to urban population leaving a huge amount of the population behind without access to electricity.

The population of DRC is growing fast more than 80 million in 2017 [7]. More than 60% living in rural area [4]. In another hand, the electricity access rate still low it has increased from 6.48% in 2001 to 9% in 2011 [3]. With exception of the capital city with an electrification rate of 59.5%, the provinces have electrification access below 5% (1% as a national average) [3].

This work is structured in the following sections. Section I, present the actual renewable resources of DRC, especially for Idjwi Island. The second section describes the multicriteria decision aids method for selecting the suitable energy alternative for Idjwi Island, the MCDM hybrid method using the AHP to determine the weights of the criteria to use in the TOPSIS method [8]. The last section presents the results from the two MCDM methods used with preferences of experts for electrification of Idjwi Island as an example of the testing the robustness of the framework methodology used in the research.

2 METHODOLOGY

In order to address the problem of this research and to meet its objectives the following steps were undertaken

- Data Collection and Data Analysis: Through surveys, interviews, workshops onsite at Idjwi Island, Data was collected to determine the profile load of Idjwi Island, community criteria priority and experts' prioritization of different criteria of selection of the best option among different alternatives of primary energy source.
- Among the Multi-criteria Decision-Making Methods, two methods AHP and TOPSIS were selected for raking of different options of rural electrification of Idjwi Island.
- The results from the previous analyses were used to make a recommendation on the future energy projects at Idjwi Island.

Technical assessment of different aspects of the energy sector in Idjwi was analyzed. This assessment implied costs and labors intervention such as guides, local community involvement, group discussions and workshops.

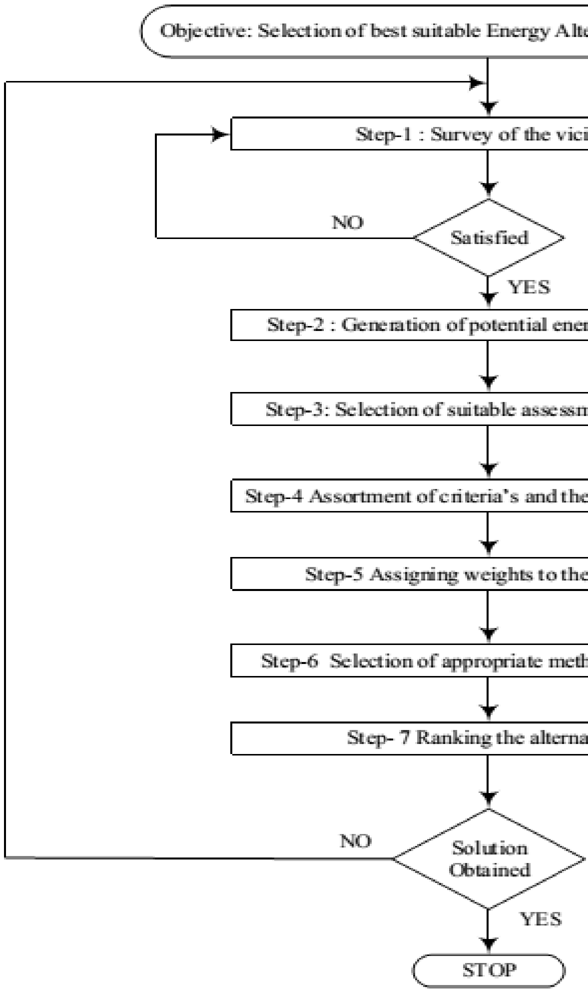

Fig. 1. Methodological Framework for selection of energy alternative

To achieve the objectives of this research, selection of suitable energy alternative for powering Idjwi Island, the following steps were used as developed by Kumar et al. in [10], [11]. As illustrated in the figure 1, the generalized framework for selecting a suitable and reliable rural energy source for developing countries. From the results of two surveys, one for the rural community and another one for experts in the energy sector, we used this methodological framework of seven different steps as shown in the figure 1 to meet the objective of selecting a suitable solution for energy projects in Idjwi. Step 1 is a series of survey to determine the preferences of local community and experts. This was done using surveys. Step 2 of generation of potential energy alternatives of available energy resources of Idjwi. Step 3 is based on the results of the step 1 in order to fix criteria based on judgement and views of decision-makers and experts. This was done using another survey to specify which criteria and sub-criteria to use for evaluation of the different alternatives. The following step was handling by AHP method in order to assign weight to different criteria and sub-criteria. This process reported in the section of results and discuss for every criteria and sub-criteria. The last step ranked the different alternatives using TOPSIS method. This step used the available data from Idjwi and in the literature to analyse the different alternatives to power Idjwi.

2.1 Survey Design

A door to door survey of a targeted 67 households with a questionnaire was carried out in the rural community of Idjwi. A set of meetings and workshops were also conducted with local authorities, academics, experts in the energy sector of the region. The purpose of these initiatives during this research was based on the recommendations of similar researches [10] in the same domains in order to convince the local community to be part of an electrification project of the Island. More objectives were to:

1. Understand the community's support towards the energy project
2. The energy demand assessment of the Idjwi Island
3. The financial situation of the community to get the average income of a household per month to pay for the electricity bill
4. Evaluate the availability of the resources which can be utilized and possible sites for implementing the project

Another survey was distributed to the experts in the energy sector in order to select different criteria and sub-criteria to use in the AHP and TOPSIS methods. This survey was also conducted to question the preferences of the experts on the criteria considering the social and economic situation of the inhabitants of Idjwi.

Energy planning is a field that involves many aspects, actors and multiple attributes both qualitative and quantitative which cannot evaluate by a single-phase evaluation indicator such as Cost to Benefit Analysis (CBA) or Net Present Value (NPV). Planning in energy technologies involves a multidimensional problem with multiple objectives and many traits [11], [8], [12]. This involvement of multiple stakeholders, benchmarks, and more energy alternatives (renewable and non-renewable) sources in rural electrification system has made the design process more complex. Various MCDM models have been developed for energy planning for electrification purpose to reach sustainability. A detailed review of such models and their application has been elaborated by authors as reported above in the literature review of this thesis and in [13]. Scientific methods such as MCDM which involve the evaluation of both qualitative and quantitative attributes to rank different types of energy resources over a long period (time) dimensions have become popular [8]. Many actors including groups of people in the local community, institutions and administration authorities, potential investors, academic institutions, environmental agencies are stakeholders in MCDM and define the main criteria to be considered.

This study involved four criteria proposed by the experts in the energy sector with carefully selected sub-criteria (both qualitative and quantitative) under different dimension units to facilitate the ranking of energy technologies in Republic Democratic of Congo through MCDM techniques. Researchers have recommended to combine or compare two methods in order to reduce uncertainty and to increase the reliability of the methods [14]. That is the reason why AHP was used in order to determine different weights of the criteria and sub-criteria. It was followed by a TOPSIS method for evaluating the best solution to power Idjwi Island. Figure 2 indicates different steps that were taken during this thesis by developing a hybrid method of Multi-criteria decision making AHP-TOPSIS to rank different alternatives for energy resources.

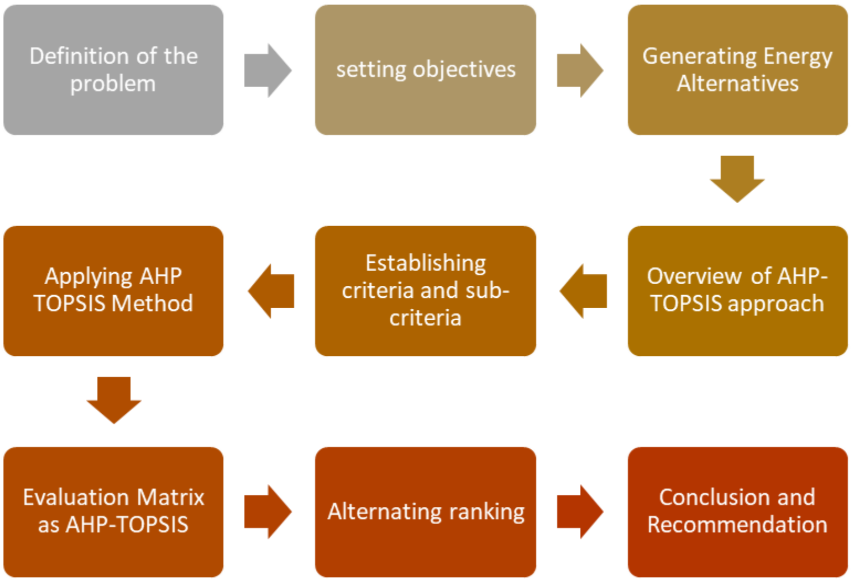

Fig. 2. A proposed methodology using AHP-TOPSIS in MCDM for DRC

2.2 Overview Of Ahp-Topsis Approach

The aim of selecting the AHP-TOPSIS method is because AHP determines the weights of the criteria, and the alternatives are ranked using TOPSIS [15]. AHP-TOPSIS methods follows the following procedures as explained by the number of researches conducted in Multicriteria Decision Making Method [16], [10], [17], [18]. "The main weaknesses of TOPSIS are that it does not deliver for weight elicitation, and consistency checking for judgments; on the other hand, the use of AHP has been significantly restrained by the human capacity for the information process" [18].

2.2.1 Ahp Method

AHP involves the decision architects to provide judgments and specify preferences on the relative importance of each criterion and each alternative considering all criteria. In AHP, the problem is created as a hierarchy breaking down the decision top to bottom. "The goal is at the top level, criteria and sub-criteria are in middle levels, and the alternatives are at the bottom layer of the hierarchy [19]. The following are the essential steps to be followed in AHP model:

2.2.1.1 CONSTRUCT A COMPARISON MATRIX

Construct a matrix from a pairwise comparison of criteria using a well-defined scale of relative importance as proposed by Saaty in table 1 [20]. The scale presented was proposed and its effectiveness has been approved by numerous scholars. Obtained pairs of criteria Ai and Aj are represented by an n×n single-value comparison matrix A:

$$A = a_{ij} = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ 1/a_{12} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/a_{1n} & 1/a_{2n} & \cdots & 1 \end{bmatrix}$$

Where, a_{ij} is the relative importance of criteria A_i and A_j [19].

Table 1. The fundamental scale of absolute numbers [20]

Intensity of importance	Definition	Explanation
1	Equal Importance	Two activities contribute equally to the objective
2	Weak or slight	
3	Moderate importance	Experience and judgment slightly favor one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgment strongly favor one activity over another
6	Strong plus	
7	Very strong or demonstrated importance	An activity is favored very strongly over another; its dominance demonstrated in practice
8	Very, very strong	
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
Reciprocals of above	If activity i has one of the above non-zero numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i	A reasonable assumption
1.1-1.9	If the activities are very close	May be difficult to assign the best value but when compared with other contrasting activities the size of the small numbers would not be too noticeable, yet they can still indicate the relative importance of the activities

2.2.1.2 CALCULATE THE IMPORTANCE DEGREE OF EACH ELEMENT

Set priorities for criteria, a numerical value must be assigned to all criteria according to the preferences of the DM.

The weighting vector of a specific element k can be calculated through the following Equation:

$$\mathrm{W}_k = \frac{1}{n}\sum_{j=1}^{n}\left(\mathrm{a}_{kj}/\sum_{i=1}^{n} a_{ij}\right)\ (k = 1,2,\ldots\ldots,n)\ (1)$$

Where, a_{ij} is the entry of row i and column j in a comparison matrix of order n, and W_k is the weighting vector of a specific element k in the pairwise comparison matrix.

2.2.1.3 CONSISTENCY TEST

Check the consistency of the matrix before the results. The comparisons is considered reasonable only if the consistency ratio is equal to or less than 0.10 [21], [22], [23]. An approximation of the ratio can be obtained using the following equation;

$$CR = \frac{CI}{RI} \ (2)$$

While

$$CI = \frac{\lambda_{max} - n}{n - 1} \ (3)$$

Where CR is the consistency ratio, RI is the random index, λmax is the maximum weighting value of an n×n comparison matrix. shows the random Index value for different matrices sizes as identified by Daim, Oliver and Kim [19].

Table 2. Average Random Index (RI) values [19]

Matrix size (n)	2	3	4	5	6	7	8	9	10
RI	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

2.2.2 TOPSIS METHOD

TOPSIS refers to Technique of Order Preference by Similarity to Ideal Solution, this method considers three types of attributes or criteria which are; Qualitative benefit attributes or criteria, quantitative benefit attributes and Cost attributes or criteria. The key idea of TOPSIS is to assess the alternatives by concurrently measuring how far are they from the Positive Ideal Solution (PIS) and to the Negative Ideal Solution (NIS) i.e. through distance measure [25], [24]. TOPSIS assumes that we have m alternatives (options) and n attributes/criteria and we have the score of each option with respect to each criterion. Let x_{ij} be the score of option i with respect to criterion j, we have a matrix X = (x_{ij}), m × n matrix. Let J be the set of benefit attributes or criteria (more is better) and let J' be the set of negative attributes or criteria (less is better). The following are the procedures to be followed when performing TOPSIS.

The matrix X that consists of the original information is shown as equation (4).

$$X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \dots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \ (4)$$

2.2.2.1 CONSTRUCT NORMALIZED DECISION MATRIX.

This step aims at transforming various attribute dimensions into dimensionless attributes to allow comparisons across criteria from different sources. This is carried out as follows where r_{ij} are the normalized values;

$$r_{ij} = \frac{X_{ij}}{\sqrt{\left(\sum X_{ij}^2\right)}} \ (5)$$

For i =1, …, m; j=1, …, n.

2.2.2.2 CONSTRUCT THE WEIGHTED NORMALIZED DECISION MATRIX.

Assume we have a set of weights for each criteria wj for j = 1, …, n. Multiply each column of the normalized decision matrix by its associated weight.

An element of the new matrix is:

$$v_{ij} = w_j * r_{ij} \ (6)$$

2.2.2.3 DETERMINE THE IDEAL AND NEGATIVE IDEAL SOLUTIONS.

Assume J the set of benefit attributes or criteria more is better and let J' be the set of cost attributes or criteria less is better.

Positive Ideal solution

$$A^+ = \{v_1^+, \dots, v_n^+\} \ (7)$$

Where

$$v_i^+ = \left\{\max_i \ (v_{ij}) \ if \ j \in J; \ \min_i \ (v_{ij}) \ if \ j \in J'\right\}$$

Negative ideal solution

$$\boldsymbol{A}^{-} = \{\boldsymbol{v}_1^-, \dots, \boldsymbol{v}_n^-\} \ (\mathbf{8})$$

Where

$$\boldsymbol{v}_i^- = \left\{\min_i (\boldsymbol{v}_{ij}) \ \boldsymbol{if} \ \boldsymbol{j} \in \boldsymbol{J}; \ \max_i (\boldsymbol{v}_{ij}) \ \boldsymbol{if} \ \boldsymbol{j} \in \boldsymbol{J}'\right\}$$

2.2.2.4 Calculate The Separation Measures For Each Alternative.

The separation from the ideal alternative is

$$\boldsymbol{S}_i^+ = \left[\sum_i (\boldsymbol{v}_j^+ - \boldsymbol{v}_{ij})^2\right]^{1/2} \ (\mathbf{9})$$

i = 1, …, m

Similarly, the separation from the negative ideal alternative is:

$$S_i^- = \left[\sum_i (v_j^- - v_{ij})^2\right]^{1/2} \ (10)$$

i = 1, …, m

2.2.2.5 Calculate The Relative Closeness To The Ideal Solution Ci

$$C_i = \frac{S_i^-}{(S_i^- + S_i^+)} \ (11)$$

Whereby 0 <Ci < 1. Select the option with Ci closest to 1

The best option among the alternatives is the one with the highest value of Ci.

3 Results Analysis And Discussion

3.1 Weights Of Criteria

The AHP method was first used to determine the weights of all criteria and sub-criteria established by the results of the surveys, interviews, meetings and workshops. The main reasons for selecting AHP was its simplicity, flexibility and its ability to handle both quantitative and qualitative criteria in the same framework [26].

The scenario considered in this work comes from the survey's results and is presented as follows

- Social criteria were the most important in the four criteria considered because the community is living in a condition of extreme poverty with an average of one America Dollar per day. For this reason, in the scale of pairwise comparison proposed by Saaty [27],
- The technical criteria come after the social criteria because for the sustainability of the project, a trained team for maintenance and operating the micro-grid.
- The economic and environmental criteria follow to have the scenario below:

Social Criteria > Technical Criteria > Economic Criteria > Environmental Criteria

Table 3 reports the different weights of main criteria, with Social representing 52.56%, Technical 27.28%, Economic 12.42% and Environmental 7.73%.

An excel sheet was developed following step by step of the AHP method as described previously using equations (1), (2) and (3) respectively to calculate weights of criteria, checking the consistency of the matrix of decision.

Table 3. Pairwise comparison of criteria and their weights

	Technical	Environmental	Economic	Social	Weights
Technical	1	4	3	1/5	27.28%
Environmental	1/4	1	1/2	1/9	7.73%
Economic	1/3	2	1	1/7	12.42%
Social	3	5	4	1	52.56%%

3.2 Sub-Criteria Weights

A compilation of all 17 sub-criteria weights used in this work is given in the figure below:

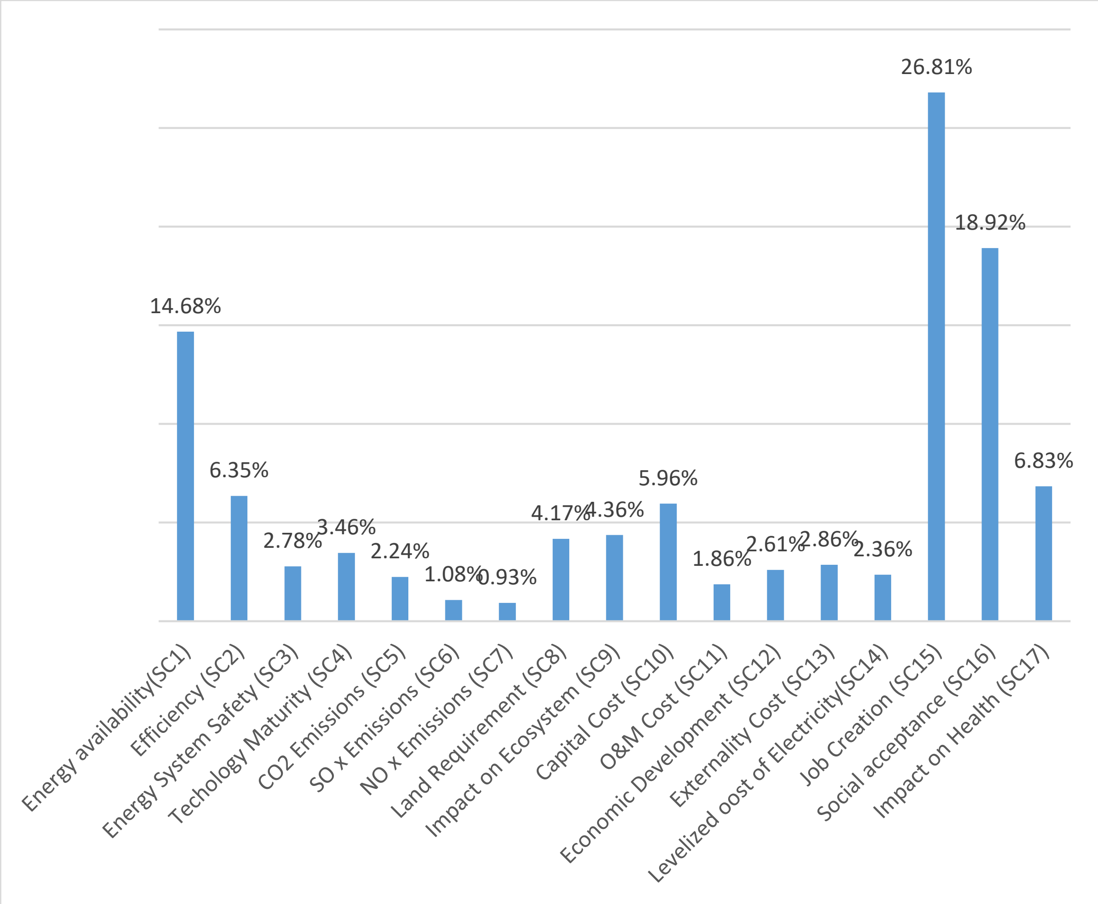

Fig. 3. Weights of the sub-criteria

3.3 Discussion Of The Results

The energy planning was done on the surveys' results from the local community, experts in energy field, local authorities, NGO of the region. Out of these surveys, social criteria were highly weighted compare to other criteria such as technical, economic and environment. The respondents consulted showed the importance of job creation for rural community by an electrification project and the acceptance of the community of any project as their priority. Another aspect was the land requirement for the project, and the survey shows that land is essential for the villagers, thus a good source of energy which requires less land for implementation was the most welcome.

The MCDM hybrid method AHP and TOPSIS were used to evaluate the suitable energy resource to power Idjwi Island in this study.

The seven energy alternatives (Solar PV, Small Hydro Power Plant, Biomass, Geothermal, Diesel and Natural Gas) were compared through a TOPSIS method, concerning each of the 17 established criteria grouped in 4 main criteria (technical, economic, social, environmental).

The weights obtained by the AHP method according to the experts' choices and preferences. The two first places of relevance were for Small Hydro mini-grid and Solar PV energy. This result shows how renewable energies can meet the energy needs of Idjwi Island and improve the social life of the community.

The third and fourth preference was alternated between Diesel and Natural Gas as illustrated in the table 4. From this result, we can confirm that for the case of Idjwi, Diesel Generator can be used as back up in combination with Hydro or Solar PV in order to meet the peak demand of the island.

The natural gas in the Kivu lake seems to be an alternative that can be exploited and remaining in the preferences of the local community.

Table 4. Raking of different energy alternatives from TOPSIS calculation

	Si+	Si-	Ci	Rank
Solar PV	0.098	0.109	0.5259	2
Small Hydro	0.089	0.1048	0.5395	1
Biomass	0.104	0.06088	0.3689	5
Wind	0.11	0.04983	0.3115	7
Geothermal	0.122	0.06112	0.33706	6
Diesel	0.9388	0.10069	0.5174	3
Natural Gas	0.077	0.07705	0.5078	4

Energy projects accompanied by sophisticated technologies and promise affordable electricity even tend to fail many times, due to ignorance or less importance of social factors. For that, the methodology used in this study can assist decision-makers in the policy sector, investors, and energy's project developers of the country to properly plan for future energy project for rural electrification.

4 Conclusion

Based on the available energy resources of the Idjwi island in the Democratic Republic of Congo, this study has been devoted to select the best source of energy to electrify the Idjwi Island. A step by step methodological framework for selecting energy alternative was formulated in this work using two Multi-Criteria Decision-Making methods. To meet the objectives of this study, the Analysis Hierarchy Process (AHP) was used to weight all the 17 criteria maintained for the analysis of the problems. According to the preferences of the community and the experts, the social criteria such as Job creation and social acceptance were highly weighted respectively 26.8% and 19.8%. All weights of criteria obtained were used on the Technique of Order Preferences by Similarity to Ideal Solution (TOPSIS) to rank the seven alternatives of available energy resources on the Idjwi island (Solar PV, Small hydro, Biomass, Geothermal, Wind, Diesel and Natural Gas). One scenario was developed which consist of the fact that Social aspects of the project were the priority followed by technical, economic and environmental aspects meet sustainability of any energy project at Idjwi. Throughout of this research, the small hydropower plant system and solar photovoltaic were ranked the two first alternatives in which investment could meet the need and the preferences of the local community of Idjwi. The small hydro has a closeness parameter to an ideal solution of 0.5395 and solar PV of 0.5259. They were followed by the Diesel and Methane Gas projects as third and fourth preferences to power the Island, the biomass, Geothermal and wind were the last on the list according to the scenario developed. These results clarify which type of hybrid system can be developed on the Island to power the Island. The results proved that the Democratic Republic of Congo which has huge amount of energy resources is facing a situation of energy poverty in the rural areas and a good energy planning involving the local community can reinforce the ownership of the project by the community and assure its sustainability. Energy projects accompanied by sophisticated technologies and promise affordable electricity even tend to fail many times, due to ignorance or less importance of social factors. For that, the methodology used in this study can assist decision-makers in the policy sector, investors, and energy's project developers of the country to properly plan for future energy project for rural electrification. Further research can be oriented on the sizing of the energy mini-grid systems based on the results of this project to meet the energy needs of the local community. This mini-grid can be either hybrid systems such as Small Hydropower system combined to Solar Photovoltaic with a back-up of Diesel Generator for peak loads. A comparison of more than one scenario can reinforce the reliability of the methodological framework. In this regard, further research should consider multiple scenarios.

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