Decentralized Energy Planning Using Multicriteria Methods

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ABSTRACT

Traditionally, the planning of rural electrification in the developing countries has taken into account technical and economic criteria. So far, the environmental and social aspects have been considered very little. Consequently, a coherent and appropriate power supply planning is required to facilitate the access to electricity. Multi-criteria Decision Making (MCDM) approaches emerge as well suited options for such purposes. This work applies Analytical Hierarchy Process (AHP) and a comprehensive VIKOR method for evaluate the best compromise solution that satisfies the electricity requirements from a rural-remote population located in the Venezuelan Andean region (35 houses, one school and a medical dispensary). The work considers 19 alternatives for electricity supply; the first nine alternatives are associated with Dispersed Decentralized Generation (DDG); other nine relates to Compact Decentralized Generation (CDG); and the latter alternative (in the comparative form) considers the network extension or Centralized Generation (CG). The criteria and sub-criteria weighting has been assigned through expert group assessment. The results indicate that DDG represents the best model for electricity supply, consisting on the combination of an integrated hybrid system with solar photovoltaic (SPV), small hydropower (SHP) and sustainable hydrogen fuel cell (FC).

Key words: Decentralized energy planning; Decentralized generation and multicriteria decision making; Power supply planning in rural and remote areas.

1. INTRODUCTION

Currently, 1600 million people worldwide have no access to electricity, of which 80% live in rural areas. The world's population and electricity demand will grow. If rural electrification does not increase, the number of people without access to electricity will remain almost unchanged [1]. According to the International Energy Agency (IEA) [2] in the last 15 years, the number of people without electricity has been reduced from 2000 million in 1990 to 1600 million in 2005, with China registering the fastest progress. Excluding China, the number of people without electricity has increased steadily over the last 15 years. Due to the constant growth of population, if the countries do not put in practical on new policies, it will continue existing 1400 million persons without access to the electricity in 2030.

The electrification of rural areas has gone through various stages or moments. Different factors, including political, economic, social and environmental concerns have influenced the shape, type, method and model to promote or facilitate the power supply.

The first formal development of energizing rural areas was realized using the model of urban areas [3]. Indeed, the extension of distribution networks has remained as the dominant model bring up electricity to rural and remote areas. Both technical and economic criteria [4] [5] have been the dominant features in growth of power systems to rural areas-and therefore, enables a considerable number of villages to benefit from the availability of energy. In contrast, centralized distribution in rural and remotes areas have shown some drawbacks as the partial or total blackout, the cost of energy, network's maintenance lack, social and environmental impacts, high costs of investment in new facilities, non-availability of enough financial resources and competition with new power technologies such as *distributed generation* (DG) [3] [6] [7].

The emergence of DG has brought a new vision of on-site generating power for applications as an affordable, secure and the minimal impact both social and environmentally (regarding the extension of distribution networks); such aspects should be taken into account in the planning of future power supply systems from rural and remote areas.

In general, the process of rural energy decision-making has neglected certain factors influencing rural electrification [8] (for example, considering of the population needs). Hence, there are important consideration on identifying a consistent and comprehensive energy planning in order to improve access to electricity taking into account the populations needs and the local environmental conditions. For this reason, this paper proposes a method of multicriterio decision that uses the combination of two techniques: Analytic Hierarchical Process (AHP) and VIKOR.

2. MULTICRITERIA METHODS FOR DECENTRALIZED ENERGY PLANNING

Most of problems are complex fundamentally due to the unknown aspects related to decision making process, as it is the consideration of vagueness and uncertainty. Although occasionally it is possible to solve them based on experience or intuition, it has been proven several times to complex problems can lead to misguided solutions. For this reason, it is convenient to use models and methods to achieve a better quality decisions.

Rojas et al. [10] determined some considerations based in single criterion decision models, one-dimensional optimization using linear programming with applications to electricity supply in rural and remotes areas. The consideration of few criteria in the modeling of energy supply problems makes the context of planning unrealistic and very simplified. In contrast, energy planning problems are complex, and generally, require multiple decision-makers, criteria and restriction, which requires the use of more complete and robust methods. In this context, and given that the energy supply planning represent a multidimensional problem, its mathematical expression is of nature multicriterion-multiobjective or vice versa. Therefore, the multicriteria decision making (MCDM) emerge as well suited options for such purposes.

On the other hand, Alanne and Saari [7] explained that the choice of a distributed generation system from renewable sources is a good choice with regard to sustainable development throughout its life cycle. However, there are some implications of generation distributed in some aspects of sustainability. There on, Karger and Hennings [11] suggest the need for multicriteria methods for distributed generation decision making. Likewise, Pohekar and Ramachandran [12] consider that the Multicriteria methods are gaining popularity in sustainable energy management, since these techniques provide solutions to the problems involving multiple objectives; that may be conflicting or contradictory among them. Alarcon et al. [4] also explain that multicriteria methods are appropriate to solve multidimensional problems. In addition, Loken [13] proposes that the MCDM are suitable in situations of multiple decision-makers.

Based on these reviews, the MCDM methods are suitable for the treatment of problems that require the selection of a power supply systems under the sustainability consideration.

3. PROPOSED METHOD: AN INTEGRATION OF AHP – VIKOR

The decision-making problem intended to solve is: *given the need of electrical power in rural and remote areas of developing countries, a finite set of alternatives (discreet) associated with three modalities of power supply are presented, where several makers (multi-expert) must participate in the selection of the best alternative, taking into account different criteria or points of view in conflict (Multicriteria).*

Currently, there is a wide range of discrete multicriteria methods. Such diversity is the result of the incredible practical interest which these methods provide.

In reference to value measurement methods, the hierarchical analytical process (AHP), is one of the most popular MCDM methods. The ease to deal with complex problems, simplicity, transparency and a wide field of application has contributed to its widespread popularity.

Preference level methods are associated to certain features that favor its implementation such as their relative ease of management, flexibility, transparency and interactivity with decision makers, broad application and the speed to get a result. Of these methods, VIKOR, one of the most recent, in addition incorporates a concept of stability in the compromise solutions classification, which helps to improve the decisions quality.

3.1 Analytical Hierarchical Process (AHP)

The hierarchical analytical process was proposed by Thomas L. Saaty (1980, 1994, 1996 y 2000). AHP is a powerful tool that can be used to decompose a complex problem in a hierarchical model [14]. The purpose of the method is to allow that the decision-maker can structure a multicriteria problem in visual form, through the construction of a hierarchical model which basically contains three levels: goal or objective, criteria and alternatives [15]. Once built the hierarchical model, policy-makers carry out comparisons of pairs between these elements (criteria - sub-criteria and alternatives) and numeric values are attributed to the preferences expressed by them, delivering a synthesis through the aggregation of these partial judgments. This comparison is carried out using the Saaty scale, which is shown in table 1.

AHP enables decision making group by adding opinions, then take the geometric or arithmetic average of the opinions.

Table 1. Saaty scale

Value	Definition	Comment
1	Equally important	The criterion A is of equal importance that B
3	Moderate importance	The experience and the judgment favors slightly criterion A over B
5	High importance	The experience and the judgment are strongly favorable from criterion A over B
7	Very high importance	The criterion A is much more important than B
9	Extreme importance	The importance of the criterion A over B is indisputable
2,4,6,8	Intermediate values	

According to Saaty [16], once the corresponding trials in the matrix of comparisons have been introduced, the problem is reduced to the calculation of eigenvalues and eigenvectors, which represent the priorities and the consistency index of the process, respectively. Therefore, A is consistent if and only if the equation (1) is satisfied:

$$A * w = \lambda * w, \quad (1)$$

Where A represents the reciprocal matrix of paired comparisons (importance assessment of one criterion over another); λ, maximum eigenvalue of A; w, eigenvector of λ.

As a result, AHP calculates the consistency reason (CR), which is given by the equation 2.

$$CR = CI/RI, \qquad (2)$$

Where CI is the consistency index of A; RI is the random consistency index (this value is taken from the table 2).

The consistency index is determined by the equation 3.

$$CI = (\lambda_{max} - n) / (n-1), \qquad (3)$$

Where n corresponds to the number of items that are compared (criteria)

Table 2. Random consistency index

(n)	1	2	3	4	5	6	7	8	9	10	11	12	13	14
(RI)	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.54	1.56	1.57

A value less than 0.10 RC is considered to be acceptable; otherwise, it must ask the decision-maker to make their ratings again.

With regard to the applications of AHP, Herrar [17] presented a list of references which highlights the following areas: process of manufacturing, machinery selection, selection of technology parks, supply chain, selection and evaluation of suppliers, university management, assessment of companies, assessment of projects, food, etc. Other applications of AHP: management of water resources [18], allocation of resources [19], technologies selection for energy generation [13], energy planning from the transport sector [20], multicriteria renewable energy planning using an integrated fuzzy VIKOR and AHP methodology [21], etc.

The purpose of AHP in this research is related with the preference estimation of the different variables considered in the hierarchical structure levels of the decision tree, with the aim of obtaining absolute preferences of the criteria. Therefore, an expert group, with conflicting interests, have been consulted to facilitate the selection of the system power supply from a small town (village) located in a rural-remote area of the Venezuelan Andes. The expert groups have been subdivided in four categories: Academics (university professors, researchers, etc.); Companies and consulting agencies; Regulators or operators and Non-governmental organizations (integrated by environmental organizations and community organizations belonging to the village such as irrigation committee and the health-environment committee).

Once forming expert groups, individual preferences in a single collective valuation estimate is required. Therefore, in this work, the collective preference aggregation has been using the arithmetic mean weighted taking into account the interactive participation of all stakeholders.

3.2 Multicriteria optimization and compromise solution (VIKOR)

Opricovic [22] and Tzeng Opricovic [23] developed the VIKOR method for multicriteria optimization of complex systems, by determining a ranking of compromise solutions, the compromise solution and the weighting of stability interval [23]. VIKOR was proposed as a MCDM method to solve problems of discrete type [24] with conflicting and non-quantifiable criteria [23]. The multicriteria ranking index achieved is based on the particular measure of proximity to ideal solution [22]. Assuming that each alternative is evaluated according to each criterion function, the compromise ranking can be then performed by comparison of proximity measure to the ideal solution [23]. The multicriteria measure for compromise ranking is developed from the Lp-metric used as an aggregation function in compromise programming method (Yu [25] and Zeleny [26]):

$$Lp, j = \left\{ \sum_{i=1}^{n} [wi.(fi* - fij)/(fi* - fi^{-})]^{p} \right\}^{1/p}, \qquad (4)$$

$$1 \leq p \leq \infty; \; j = 1, 2, \ldots, J$$

Where $fi*$ = max fij y fi^{-} = min fij if the ith function represents a benefit criterion.

The compromise solution would be accepted by decision makers since it provides the maximum group utility (represented by the minimum value of S) and a minimum individual regret of the opponents (represented by the minimum value of R).

VIKOR has been widely applied in the treatment of MCDM problems from various fields such as sustainable reconstruction after the earthquake [27], environmental policy associated with the quality of the air [28] and in comparison with other methods as Data Envelopment Analysis (DEA) [24]. More recently, VIKOR has been applied to design of experiments [29], water resources planning [30], selection of a web service [31], selection of raw materials distributor under a fuzzy environment [32] and in the selection of renewable energy project from Spanish energy system [33]. In this last application, VIKOR has been combined with AHP method, as in reference [21].

One of the limitations of VIKOR in its classical version is associated with numerical difficulties that have been detected in the final ranking of compromise solution. In this regard, Chang [34] has development the modified VIKOR for avoiding or rectifying these numerical difficulties. More recently, Jahan et al. [35] adapted the modified method using a new technique of standardization and it is also known as *comprehensive VIKOR. The main advantage of the comprehensive proposal over traditional VIKOR is that it covers all objectives in MCDM.* In addition, *the proposed model exceeds the critical problem of classical VIKOR* that was demonstrated by Huang et al. [36].

The steps required to implement the comprehensive VIKOR method is presented in figure 1.

3.2.1 Normalization of the input data

The standards proposed by Jahan et al. [35] must be made through the equation 5 and 6.

$$Aij = |(rij - Tj)| \text{ x } (- Aj)^{-1}, \qquad (5)$$

$$Aj = rj\max - rj\min, \qquad (6)$$

Where Aij represents the normalized value of the alternative i on criterion j; rij (i = 0 1, 2, 3,..., m and j = 1, 2, 3,..., n) correspond to the elements of the decision matrix (alternative i respect the criterion j); Tj represents the ideal value or target value of rij for all criterion j (T1, T2, T3, …., Tj, …., Tn); Aj is the difference between the minimum and maximum value of the criterion j; $rj\max$ is the maximum value on the criterion j; and $rj\min$, the minimum element in the criterion j.

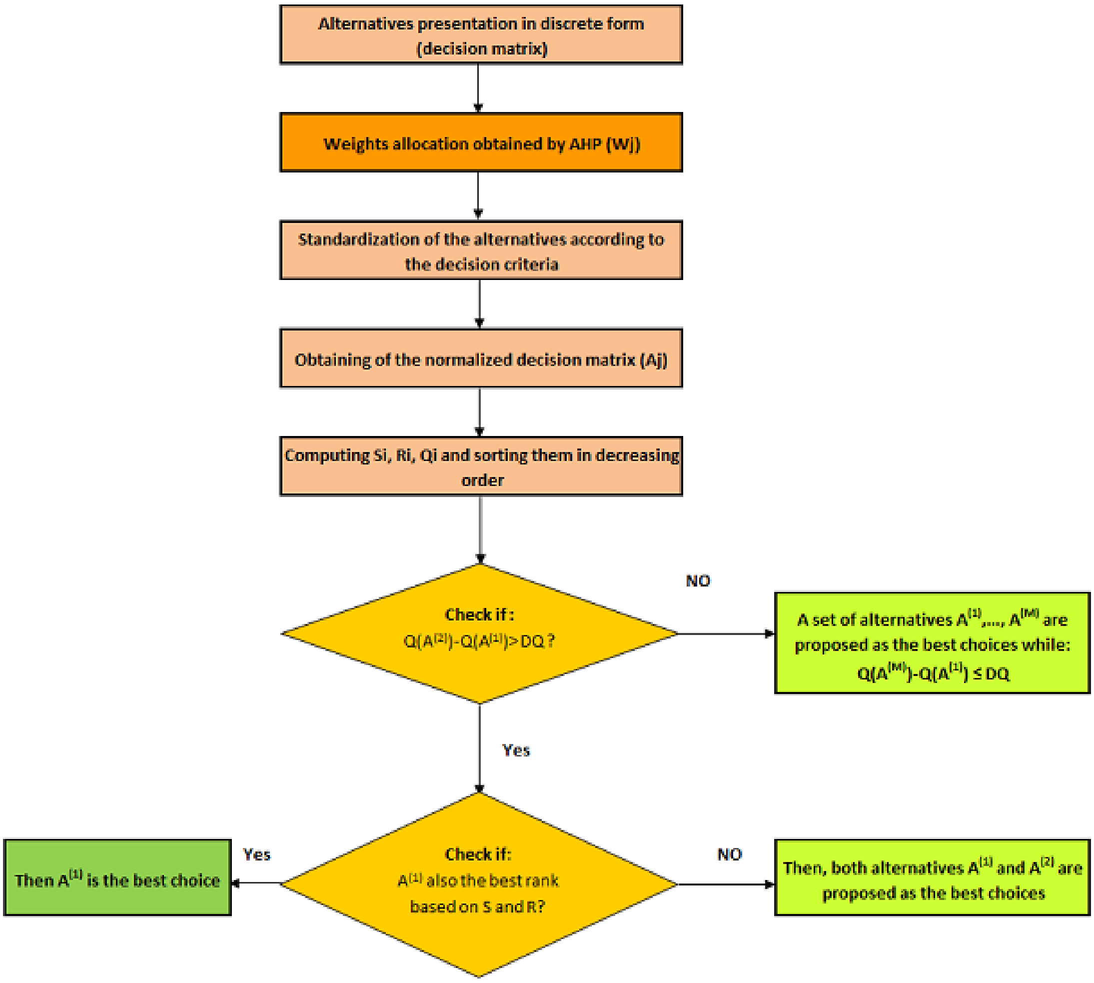

Figure 1. Flowchart of VIKOR comprehensive; adapted of Jahan et al. [35]

3.2.2 Calculation of Si, Ri and Qi

Jahan et al. [35] the values of Si, Ri can be calculated using equations 7 and 8; Qi, depending on the condition, can be calculated using the equation 9, 10 and 11:

$$Si = \sum_{i=1}^{n} wj \text{ x } (1\text{-}e^{-Aij}), \tag{7}$$

$$Ri = \underset{j}{Max} \, [wj \text{ x } (1\text{-}e^{-Aij})], \tag{8}$$

If $S^{+} = S^{-}$ then:

$$Qi = (Ri - R^{-})/(R^{+} - R^{-}), \tag{9}$$

If $R^{+} = R^{-}$ then:

$$Qi = (Si - S^{-})/(S^{+} - S^{-}), \tag{10}$$

Otherwise:

$$Qi = [(Si - S^{-})/(S^{+} - S^{-})]v + [(Ri - R^{-})/(R^{+} - R^{-})](1 + v), \tag{11}$$

Where Si represents the utility measure; Ri is the regret measure; Qi is the VIKOR value; S^{-} = Min Si; S^{-} = Max Si; R^{-} = Min Ri; R^{+} = Max Ri; and υ represents the weight of the strategy associated with the maximum group utility, 1 - υ is the weight of the individual regret. The value of υ lies in the range between 0 and 1. A value of υ = 0.5 implies a consensus between both strategies. The results of Si, Ri and Qi are three ranking lists sorted in a decreasing way.

3.2.3 Verification of compromise ranking stability

The verification establishes a compromise solution for the alternative $A^{(1)}$ which is the best ranked by the measure Qi (minimum) if the following two conditions are satisfied:

C1. Acceptable advantage:

$$Q(A^{(2)}) - Q(A^{(1)}) \geq DQ, \tag{12}$$

$$DQ = 1 / (M\text{-}1), \tag{13}$$

Where $A^{(2)}$ is the alternative with second place in the ranking list given by Q; M is the alternatives number.

C2. Acceptable stability in the decision making:

The alternative $A^{(1)}$ should be the best ranked by S and/or R. Otherwise, a set of compromise solutions should be proposed if one of the conditions is not satisfied.

- Alternative $A^{(1)}$ and $A^{(2)}$ if only the C2 is not satisfied, or

- Alternatives $A^{(1)}$, $A^{(2)}$,…, $A^{(M)}$ if the C1 is not satisfied; where $A^{(M)}$ is determined by the following relation.

$$Q(A^{(M)}) - Q(A^{(1)}) \leq DQ, \quad (15)$$

3.3 Criteria for alternatives assessment

This assessment is developed on a decision tree scheme. As it is shown in figure 2, different criteria such as technical, economic, environmental and social features are proposed in order to the global goal associated with the selection of the best energy supply system to the study case in a Venezuelan rural-remote village. In the third level of hierarchy thirteen sub-criteria have been proposed. From a technical point of view, it contains sub-criteria as efficiency, non-served energy, long term supply security and reliability. Economic criteria also consist on net present cost and variable cost of operation and maintenance. Environmental criteria include the evaluation of CO_2 emissions, SO_2 emissions, NO_x emissions and the land use. Social criteria are associated to job creation, energy social acceptation and human development index (HDI). As is shown in figure 2 the fourth level of the hierarchy is organized as follows: dispersed decentralized generation (DDG), compact decentralized generation (CDG) and the extension of the public network or centralized generation (CG). In the last level of the hierarchy, specifically for the decentralized generation, five types of technologies such as solar photovoltaic (SPV), small wind (SWT), small hydro (SHP), internal combustion engines (ICE) and fuel cells (FC) have been considered; and for the alternative of network extension, the national energy production mix.

The dispersed decentralized generation shown in figure 3a implies the on-site generation of electric resource using one or several technologies (hybrid system) and a reserve subsystem (batteries), which must satisfy the energy requirements of housing and public institutions (school, medical module, etc.). For this modality, a street lighting system through solar street lamps has been proposed.

The CDG shown in figure 3b involves the integration of a set of generation and storage (batteries) technologies to supply electricity to the entire village. In turn, CDG consists on micro-grid deployment (on low voltage) to distribute electricity from the generation system to the different loading points of the village.

Finally, the CG involves the extension of a medium voltage network from national or regional interconnected system closer to the village. Then, the final distribution to the different loading points is achieved thanks to a low voltage network (see figure 3c).

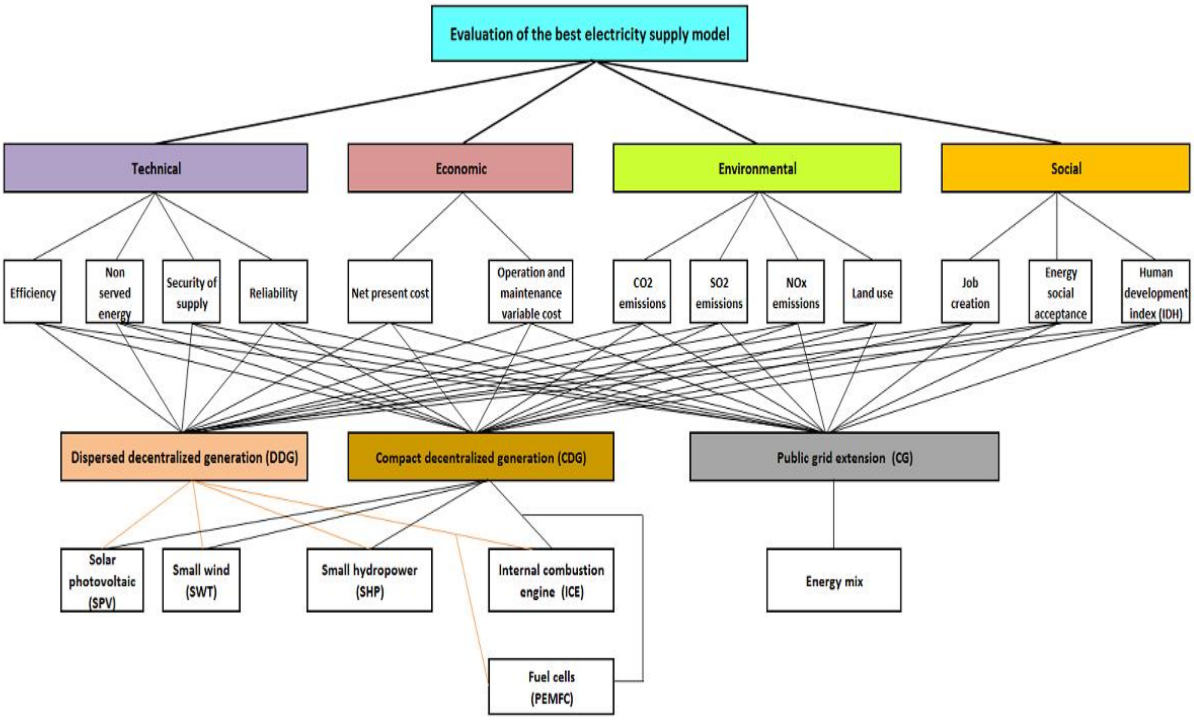

Figure 2. The hierarchical structure for the selection of the electricity supply model

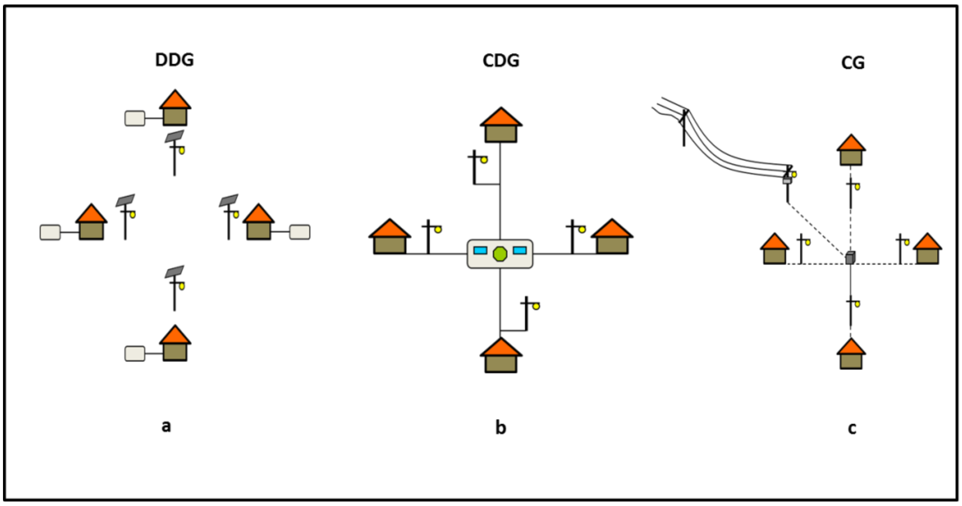

Figure 3. Power supply models

4. APPLICATION TO A VENEZUELAN RURAL-REMOTA VILLAGE

The methodology has been applied to a rural-remote people settled in a mountainous region of the Venezuelan Andes, at an altitude of 3400 meters above the sea level. The town was composed of a group of 35 household (216 people) distributed in a protected natural area (National Park) of 3.2 km^2. In addition to the houses, there is a health care centre and a primary school. Currently, the availability of energy of the population is very limited.

In this regard, a large part of the village uses candles, flashlight and kerosene for home lighting; another very small part uses the gasoline engine for lighting and other household appliances. The medical center and the school have no electrical supply and lighting system. The distance from the village to national electric networks is 25 km. The parameters used for the construction of the decision matrix are shown in table 3.

Table 3. Parameters used in the applied example

Parameters used in the applied example	Value	Parameters used in the applied example	Value
Population growth rate	0.5 % per year	River flow (average)	68 liter per second
Rate of growth in energy consumption	1.6 % per year	Cost reduction rate of solar modules	1.30% per year
Initial power consumption (includes housing and public services)	242 kWh per person	Cost reduction rate of fuel cells	1.27% per year
Fuel price (Gasoline; includes the distribution)	0.25 € per liter	Cost reduction rate of the batteries	1.73% per year
Hydrogen cost (H2-gas; includes the distribution)	5 € per kg	Cost reduction rate of wind turbines	0.10% per year
Discount rate	8 % per year	Cost reduction rate of ICE	0.12% per year
Inflation rate	3.5 % per year	CO2 emissions of solar energy (SPV)	2472.07 kg per kWp
Network investment cost (medium voltage)	10500 € per km	CO2 emissions of batteries	56.45 kg per kWh
Consideration of field factor	2.44	CO2 emissions of ICE (generator)	192.17 kg per kW
Technical losses (medium and low tension)	12%	CO2 emissions of fuel-ICE (gasoline)	3.15 kg per liter
Generation technical losses (DDG and CDG)	17%	CO2 emissions of fuel cells	50 kg per kW
Microgrid technical losses	10.14%	CO2 emissions of hydrogen energy (natural gas steam reforming with capture and	3.23 kg per kg-H2g
Average daily solar radiation per year	4.93 kWh per m²	useful life of the project (two periods of 20 year)	40 years

Alternatives considered for the village's electricity supply are shown in table 4. On these alternatives, HRES-ICE represents a hybrid system integrated by renewable energy technologies (SPV, SWT and SHP) supported by a gasoline generator (ICE); HRES-FC are alternative similar to the previous case but running with a fuel cells (support); HRES implies a power supply system working exclusively with renewable energy technologies; MCI, FC and SPV are associated with the exclusive use of every one of these technologies, respectively.

Table 4. Alternatives for power supply

Code	Alternatives	Code	Alternatives
DDG1	HRES -ICE	CDG11	HRES -ICE
DDG2	HRES -ICE	CDG12	HRES - FC
DDG3	HRES - FC	CDG13	HRES - FC
DDG4	HRES - FC	CDG14	HRES
DDG5	HRES	CDG15	HRES
DDG6	HRES	CDG16	ICE
DDG7	ICE	CDG17	FC
DDG8	FC	CDG18	SPV
DDG9	SPV	CG19	Grid extension
CDG10	HRES - ICE		

The sub-criteria proposed for decision making are shown in table 5.

Table 5. Sub-criteria used to evaluate the alternatives

Sub-criteria	Name	Unit
f1	Net present cost (NPC)	€
f2	Operation and maintenance variable cost (OMVC)	€ per year
f3	Emissions of CO2 (ECO2)	Tons per year
f4	Emissions of SO2 (ESO2)	kg per year
f5	Emissions of NOx (ENOx)	kg per year
f6	Land use (LU)	hectares
f7	Job creation (JC)	Jobs per year
f8	Human development index (HDI)	
f9	Energy social acceptance (ESA)	%
f10	Efficiency coefficient (EC)	%
f11	Energy not supplied (ENS)	kWh per year
f12	Security of supply in the long term (SSLT)	%
f13	Reliability of the technologies (RT)	%

Table 6 summarizes the results of the performance of each of the alternatives evaluated on the basis of decision sub-criteria. As you can be seen from this table, the multicriteria evaluation allows visualizing the alternatives performance under different points of view. As noted, when an alternative achieves better performance in one dimension (criterion) usually affect the next. For example, when an alternative is better from an environmental point of view (less impact), is more expensive economically.

Table 6. Decision matrix for the selection of the power supply system

	Economic criterion		Environmental criterion				Social criterion			Technical criterion			
Proposal	NPC	OMVC	ECO2	ESO2	ENOx	LU	JC	HDI	ESA	EC	ENS	SSLT	RT
SDG1	1337. 50	11.72	22.42	46.34	29.31	0.69	0.17	0.69	81.21	36.6	484.8	100.00	28.21
SDG2	1408.29	10.12	20.46	40.78	26.96	0.65	0.16	0.69	83.28	41.77	281.1	99.99	28.21
SDG3	1311.8	11.42	21.76	45.31	28.7	0.67	0.17	0.69	81.36	37.05	169.6	99.94	28.21
SDG4	1456.12	7.11	20.08	30.95	20.89	0.51	0.12	0.69	85.4	48.69	3.10	98.7	28.21
SDG5	1327.51	11.69	22.83	46.24	29.25	0.69	0.17	0.69	81.22	36.64	15.7	100.00	28.21
SDG6	1405.86	10.13	20.39	40.79	26.76	0.65	0.16	0.69	83.32	41.84	361.3	100.00	28.21
SDG7	2996.65	11.16	319.31	322.77	2307.52	1.23	0.11	0.69	33.91	30.26	3.30	39.25	30.09
SDG8	1921.96	11.63	45.74	110.52	46.47	0.32	0.10	0.69	56,00	40.08	10.00	48.18	51.97
SDG9	1679.18	17.61	31.01	66.03	36.98	0.79	0.23	0.69	71.43	12.28	356.4	100.00	28.06
CDG10	909.35	5.65	43.75	71.52	411.99	0.48	0.08	0.67	69.74	42.95	422.7	80.96	28.10
CDG11	1029.32	8.77	16.71	34.37	21.34	0.49	0.13	0.67	80.05	33.71	0.00	100.00	28.10
CDG12	1057.90	8.19	16.55	34.15	20.78	0.46	0.12	0.67	79.83	35.65	3.30	98.05	28.10
CDG13	1082.62	7.71	15.41	31.95	19.53	0.47	0.11	0.67	80.59	37.21	0.00	98.06	28.10
CDG14	1191.66	6.98	22.84	27.68	17.6	0.42	0.10	0.67	81.54	37.41	14.70	100.00	28.10
CDG15	1153.51	6.98	12.98	27.68	17.6	0.42	0.10	0.67	81.54	37.41	46.20	100.00	28.10
CDG16	1230.45	3.62	211.75	231.7	1781.22	0.72	0.02	0.67	14.29	39.67	340.00	7.48	31.85
CDG17	1649.58	5.39	35.26	90.68	34.55	0.03	0.02	0.67	45,00	59.90	0.10	11.22	75.25
CDG18	1358.56	13.22	23.99	49.56	27.75	0.59	0.17	0.67	71.43	12.28	0.00	100.00	27.82
CG19	1710.53	1.39	42.02	116.55	195.9	37.21	0.03	0.66	57.14	56.21	97.78	70.46	97.79

The weighting factors obtained by AHP taking into account the opinions of the expert panel (twelve experts) are shown in table 7.

Table 7. Summary of sub-criteria overall weight (resulting of AHP)

	Economic criterion		Environmental criterion				Social criterion			Technical criterion			
Sub-criteria	NPC	OMVC	ECO2	ESO2	ENOx	LU	JC	HDI	ESA	EC	ENS	SSLT	RT
Weight (Wi)	0.135	0.024	0.056	0.052	0.107	0.089	0.049	0.098	0.100	0.065	0.058	0.095	0.072

The implementation of the comprehensive VIKOR method to the set of power supply alternatives (table 6), and given the expert's preference weights (table 7), the ranking of compromise solutions is shown in table 8.

Ranking the alternatives by the comprehensive VIKOR method, an ordered list is obtained (for all values of υ equal to 0.5; consensus solution), where the alternative DDG4 (HRES-FC) is shown as the best solution (ranked by minimum Q). However, the C1 condition is not satisfied (unacceptable advantage) but C2 is true (stability in the decision-making process). Therefore, DDG4 is the best solution obtained by Q (VIKOR value), but not by S (utility measure) and R (regret measure). The compliance of C1 condition (acceptable advantage) requires the grouping of more alternatives as final solution, i.e., DDG4, DDG5, DDG3 and DDG2 are good solutions by R and S.

Table 8. Values of Si, Ri, Qi and Ranking compromise for the applied example

Alternatives	Si	Ri	Qi (υ=0.5)	Ranking
DDG4	0,1209	0,0454	0,0000	1
DDG5	0,1315	0,0454	0,0171	2
DDG3	0,1449	0,0454	0,0387	3
DDG2	0,1510	0,0454	0,0487	4
DDG6	0,1557	0,0454	0,0563	5
DDG1	0,1669	0,0454	0,0743	6
CDG11	0,1647	0,0477	0,0999	7
CDG13	0,1673	0,0477	0,1041	8
CDG12	0,1683	0,0477	0,1057	9
CDG15	0,1726	0,0477	0,1126	10
CDG14	0,1730	0,0477	0,1133	11
DDG9	0,2018	0,0454	0,1315	12
CDG18	0,2090	0,0477	0,1715	13
CDG10	0,2438	0,0477	0,2277	14
DDG8	0,2380	0,0519	0,2710	15
CDG17	0,2607	0,0586	0,3918	16
CG19	0,2359	0,0619	0,3933	17
CDG16	0,4301	0,0632	0,7233	18
DDG7	0,4258	0,0853	0,9931	19

5. CONCLUSIONS

The selection of the best proposal of power supply under multiple criteria requires that different groups of experts are involved in the decision-making process. The inclusion of aspects of technical, economic, environmental and social makes the decision-making process more complex, but more consistent and appropriate to development local needs. The combination of two multicriteria techniques (as AHP for criteria's preference estimation and VIKOR for the proposal selection) makes that decision process is carried out in a coherent manner, transparent, participatory and understandable. This may allow designers, planners or decision-makers get better decisions, especially in case of multiple influence factor as rural and remote electricity supply from developing countries. The results of the applied example also demonstrate that dispersed decentralized generation is the best form of electrification for small rural and remote locations. Therefore, hybrid systems composed of renewable technologies, supported by a fuel cell (fed with sustainable hydrogen), are the most convenient solution. This work shows that the extension of the network is not always the most suitable solution for rural electrification.

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