Integrated Fuzzy VIKOR and AHP Methodology for Selection of Distributed Electricity Generation through Renewable Energy in India

Asif Jamil Ansari*, Imtiaz Ashraf**, Bal Gopal***

*(Department of Electrical & Electronics Engineering, Integral University, Lucknow, India)
** (Department of Electrical Engineering, College of Engineering, Taibah University, Madina, KSA)
*** (Department of Electronics & Communication Engineering, Integral University, Lucknow, India)

ABSTRACT

This study presents application of Multi-criteria methodologies for selection of Distributed Electricity Generation through Renewable Energy in India. The first example is a review of an attempt towards identifying potential areas in India where electricity can be generated and supplied through renewable energy-based decentralized generation options by undertaking a comparison of the indicators of financial performance. The second example is aimed at determining the best renewable energy alternative for India by using an Integrated fuzzy VIKOR-AHP methodology. Attempt has been made to arrive at a conclusion as to what is the best method of analysis and the appropriate scheme for India.

Keywords - **AHP, Fuzzy, Multi-criteria, Renewable energy, VIKOR**

I. INTRODUCTION

One way of providing access to electricity in remote areas is through the extension of the grid [1]. Wherever providing grid connectivity is not cost-effective, decentralized electricity generation is an option for which both renewable energy as well as conventional technologies, whichever is suitable and economical, is considered.

This paper first makes a review of study in India, where electricity can be generated and supplied through renewable energy-based decentralized generation options or by extending the grid, by undertaking a comparison of unit capital cost and the levelised unit cost of electricity (LUCE). Next the paper uses an integrated fuzzy VIKOR-AHP methodology to make multi-criteria selection among energy options. Finally an attempt is made to compare the two methods.

II. THE LEVELISED UNIT COST OF ELECTRICITY (LUCE) METHOD

In terms of the unit capital cost, diesel generating set-based systems is the most attractive followed by coal thermal (CTPP), nuclear and large hydro (HPP) [1]. Among renewable energy-based options, biomass gasifier-based systems (BGPP) option is the most attractive option in terms of unit capital cost. In terms of the LUCE, CTPP is the most attractive among the conventional electricity-generating options. In the hilly terrain the cost of delivered electricity is estimated to vary in the range of 0.074–5.123 $/kWh. When compared with the values of LUCE (0.101–1.045 $/kWh) of decentralized generation options, it is observed that the latter may emerge financially attractive in comparison to former in some potential areas [2-5].

The Small hydro (SHP) is the preferred option in hilly areas for a grid extension of 2 km if the village is small. For larger villages, the SHP option becomes viable for grid extension of 15km. The dual-fuel biomass gasifier-based system (DF BGPP) for larger villages is the preferred option if the grid extension is about 14–22km in plain areas. For smaller villages in hilly areas, DF BGPP option is the preferred option, if grid extension is of 5–15km and SHP is not feasible. Small wind electric generators and Photo-voltaic options are preferable in hilly areas for smaller villages if grid extension is of 3–16km and SHP and DF BGPP options are not feasible [1].

III. THE INTEGRATED FUZZY VIKOR AND AHP METHOD

VIKOR is a multi-attribute decision making technique having simple computation procedure that allows simultaneous consideration of the closeness to ideal and anti-ideal alternatives [6]. In this study, a modified fuzzy VIKOR methodology is used to make a multi-criteria selection among energy options for India. The decision makers' opinions on the relative importance of the selection criteria are determined by a fuzzy AHP procedure. Table I lists the criteria utilized in evaluating renewable energy alternatives. The energy alternatives considered are: Thermal (E_1), Large hydro (E_2), Nuclear (E_3), Biomass (E_4), Diesel engine (E_5), Small hydro (E_6), Solar (E_7) and Wind (E_8). The structure of the renewable energy planning decision making problem formulated in this study is presented in Fig. 1.

Next, the steps of the integrated fuzzy VIKOR-AHP algorithm are implemented. In order to determine the importance of each criterion, the experts employed a nine point scale given in Table II. Table III gives the results of the pair wise comparisons of the evaluation criteria made by three experts. In the next step, using Table II and Table III, the fuzzy evaluation matrix for the criteria weights is obtained as in Table IV. Finally, the normalized weight vector is obtained as in Table V [7].

Next step is the determination of the best energy source with the modified fuzzy VIKOR procedure. To do this, three experts evaluated the eight energy alternatives with respect to each criterion using Table VI. Evaluation results are given in Table VII. After calculating the arithmetic means of the associated fuzzy evaluation scores, fuzzy evaluation matrix is obtained as in Table VIII. Then, separation measures are computed as in Table IX. In the next step, S^*, S^-, R^* and R^- fuzzy values are calculated (Table X). Table XI gives the results of the integrated fuzzy VIKOR-AHP analysis results. Based on the crisp Q_i index values, the ranking of the alternatives in descending order is determined as E_6, E_3, E_4, E_7, E_8, E_2, E_5 and E_1. The best alternative is found to be E_6 (Small hydro).

TABLE I. LIST OF EVALUATION CRITERIA IN MULTI-CRITERIA DECISION MAKING

Aspects	Criteria	Notation
Technical	Efficiency	C_1
	Exergy (rational) efficiency	C_2
Economic	Investment cost	C_3
	Operation & maintenance cost	C_4
Environmental	NO_x emission	C_5
	CO_2 emission	C_6
	Land use	C_7
Social	Social acceptability	C_8
	Job creation	C_9

TABLE II. FUZZY EVALUATION SCORES FOR THE WEIGHTS

Linguistic terms	Notation	Fuzzy score
Absolutely Strong	AS	(2, 5/2, 3)
Very strong	VS	(3/2, 2, 5/2)
Fairly strong	FS	(1, 3/2, 2)
Slightly strong	SS	(1, 1, 3/2)
Equal	E	(1, 1, 1)
Slightly weak	SW	(2/3, 1, 1)
Fairly weak	FS	(1/2, 2/3, 1)
Very weak	VS	(2/5, ½, 2/3)
Absolutely weak	AW	(1/3, 2/5, ½)

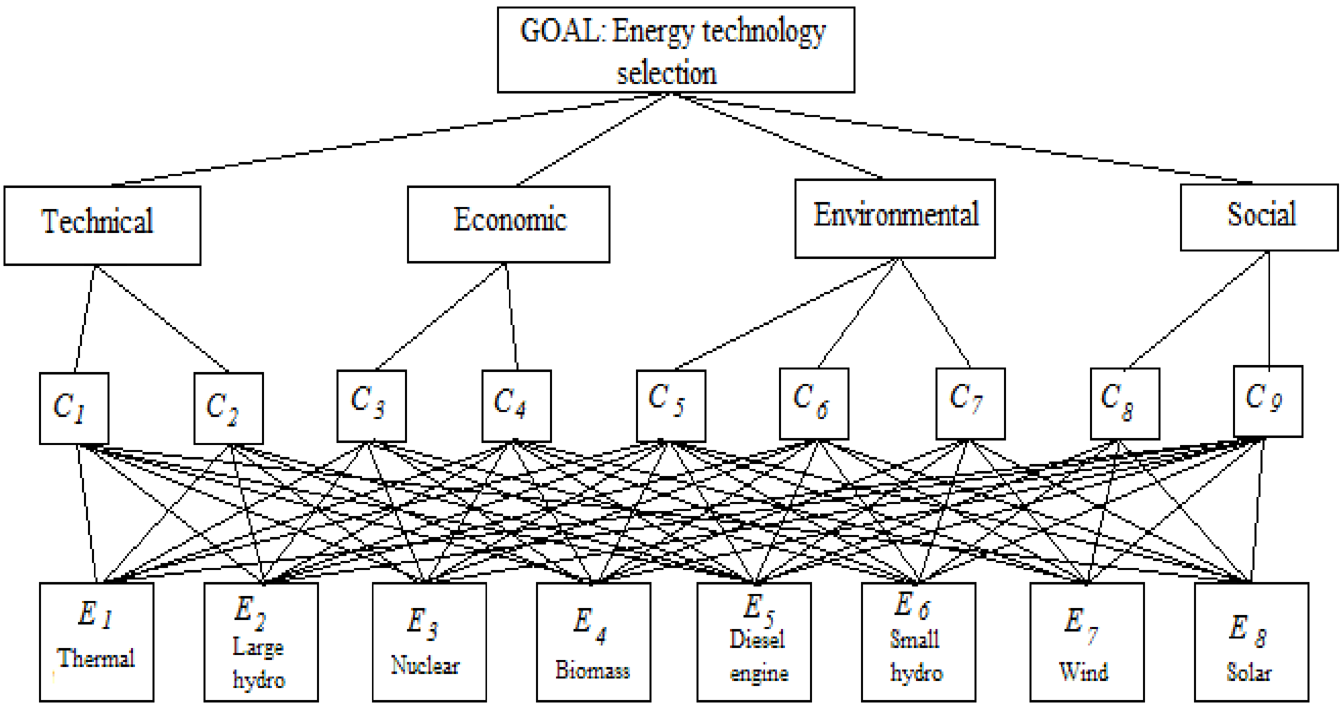

Figure 1. The hierarchical structure for the selection of energy technology.

TABLE III. PAIRWISE COMPARISON OF ENERGY SOURCE EVALUATION CRITERIA

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
C_1	1	E_1:SS E_2:SW E_3:SS	E_1:VS E_2:FS E_3:FS	E_1:FS E_2:SW E_3:E	E_1:SW E_2:VW E_3:SW	E_1:SW E_2:VW E_3:VW	E_1:SW E_2:SS E_3:E	E_1:SS E_2:SS E_3:SS	E_1:FS E_2:SS E_3:FS
C_2	E_1:SW E_2:SS E_3:SW	1	E_1:SS E_2:SS E_3:E	E_1:E E_2:FW E_3:SW	E_1:SW E_2:E E_3:E	E_1:SW E_2:VW E_3:SW	E_1:FW E_2:VS E_3:E	E_1:SS E_2:VS E_3:VS	E_1:SW E_2:SS E_3:SW
C_3	E_1:VW E_2:FW E_3:FW	E_1:SW E_2:SW E_3:E	1	E_1:FS E_2:E E_3:E	E_1:FW E_2:SS E_3:FW	E_1:SW E_2:FW E_3:SW	E_1:FW E_2:SS E_3:E	E_1:E E_2:VS E_3:SS	E_1:E E_2:SS E_3:SS
C_4	E_1:FW E_2:SS E_3:E	E_1:E E_2:FS E_3:FS	E_1:FW E_2:E E_3:E	1	E_1:FW E_2:AW E_3:FW	E_1:FW E_2:FS E_3:FW	E_1:SW E_2:FS E_3:E	E_1:SW E_2:FW E_3:SW	E_1:E E_2:FW E_3:SW
C_5	E_1:SS E_2:VS E_3:SS	E_1:SS E_2:E E_3:E	E_1:FS E_2:SW E_3:FS	E_1:FS E_2:AS E_3:FS	1	E_1:FW E_2:AW E_3:FW	E_1:SW E_2:FW E_3:SW	E_1:E E_2:AS E_3:FS	E_1:SW E_2:FS E_3:E
C_6	E_1:SS E_2:VS E_3:VS	E_1:SS E_2:VS E_3:SS	E_1:SS E_2:FS E_3:SS	E_1:FS E_2:FW E_3:FS	E_1:FS E_2:AS E_3:FS	1	E_1:SS E_2:AW E_3:SS	E_1:SS E_2:SW E_3:E	E_1:FS E_2:VW E_3:E
C_7	E_1:SS E_2:SW E_3:E	E_1:FS E_2:VW E_3:E	E_1:FS E_2:SW E_3:E	E_1:SS E_2:FW E_3:E	E_1:SS E_2:FS E_3:SS	E_1:SW E_2:AS E_3:SW	1	E_1:FS E_2:FS E_3:E	E_1:VS E_2:AS E_3:AS
C_8	E_1:SW E_2:SW E_3:SW	E_1:SW E_2:VW E_3:VW	E_1:E E_2:VW E_3:SW	E_1:SS E_2:FS E_3:SS	E_1:E E_2:AW E_3:FW	E_1:SW E_2:SS E_3:E	E_1:FW E_2:FW E_3:E	1	E_1:VS E_2:E E_3:SS
C_9	E_1:FW E_2:SW E_3:FW	E_1:SS E_2:SW E_3:SS	E_1:E E_2:SW E_3:SW	E_1:E E_2:FS E_3:SS	E_1:SS E_2:FW E_3:E	E_1:FW E_2:VS E_3:E	E_1:VW E_2:AW E_3:AW	E_1:VW E_2:E E_3:SW	1

TABLE IV. FUZZY EVALUATION MATRIX FOR THE WEIGHTS

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
C_1	1.0, 1.0, 1.0	0.9, 1.0, 1.3	1.2, 1.7, 2.2	0.9, 1.2, 1.3	0.6, 0.8, 0.9	0.5, 0.7, 0.8	0.9, 1.0, 1.2	1.0, 1.0, 1.5	1.0, 1.3, 1.8
C_2	0.8, 1.0, 1.2	1.0, 1.0, 1.0	1.0, 1.0, 1.3	0.7, 0.9, 1.0	0.9, 1.0, 1.0	0.6, 0.8, 0.9	1.0, 1.2, 1.5	1.3, 1.7, 2.2	0.8, 1.0, 1.2
C_3	0.5, 0.6, 0.9	0.8, 1.0, 1.0	1.0, 1.0, 1.0	1.0, 1.2, 1.3	0.6, 0.8, 1.0	0.6, 0.9, 1.0	0.8, 0.9, 1.2	1.2, 1.3, 1.7	1.0, 1.0, 1.3
C_4	0.8, 0.9, 1.2	1.0, 1.3, 1.7	0.8, 0.9, 1.0	1.0, 1.0, 1.0	0.4, 0.6, 0.8	0.7, 1.0, 1.3	0.9, 1.2, 1.3	0.6, 0.9, 1.0	0.7, 0.9, 1.0
C_5	1.2, 1.3, 1.8	1.0, 1.0, 1.2	0.9, 1.3, 1.7	1.3, 1.8, 2.3	1.0, 1.0, 1.0	0.4, 0.6, 0.8	0.6, 0.9, 1.0	1.3, 1.7, 2.0	0.9, 1.2, 1.3
C_6	1.3, 1.7, 2.2	1.2, 1.3, 1.8	1.0, 1.2, 1.7	0.9, 1.3, 1.7	1.3, 1.8, 2.3	1.0, 1.0, 1.0	0.8, 0.8, 1.2	0.9, 1.0, 1.2	0.8, 1.0, 1.2
C_7	0.9, 1.0, 1.2	0.8, 1.0, 1.2	0.9, 1.2, 1.3	0.8, 0.9, 1.2	1.0, 1.2, 1.7	1.1, 1.5, 1.7	1.0, 1.0, 1.0	1.0, 1.3, 1.7	1.8, 2.3, 2.8
C_8	0.7, 1.0, 1.0	0.5, 0.7, 0.8	0.7, 0.8, 0.9	1.0, 1.2, 1.7	0.6, 0.7, 0.8	0.9, 1.0, 1.2	0.7, 0.8, 1.0	1.0, 1.0, 1.0	1.2, 1.3, 1.7
C_9	0.6, 0.8, 1.0	0.9, 1.0, 1.3	0.8, 1.0, 1.0	1.0, 1.2, 1.5	0.8, 0.9, 1.2	1.0, 1.2, 1.5	0.4, 0.4, 0.6	0.7, 0.8, 0.9	1.0, 1.0, 1.0

TABLE V. RESULTS OF FUZZY AHP EXTENT ANALYSIS PROCEDURE

	$S_i = M_i = (l_i, m_i, u_i)$	$W'_i=d'(C_i)^T$	$W_i=d(C_i)^T$
C_1	0.076, 0.112, 0.167	0.806	0.116
C_2	0.077, 0.111, 0.157	0.775	0.111
C_3	0.071, 0.100, 0.144	0.644	0.092
C_4	0.066, 0.100, 0.143	0.640	0.092
C_5	0.082, 0.124, 0.182	0.931	0.134
C_6	0.087, 0.128, 0.198	0.973	0.140
C_7	0.088, 0.131, 0.191	1.000	0.143
C_8	0.069, 0.098, 0.140	0.611	0.088
C_9	0.068, 0.096, 0.139	0.593	0.085

TABLE VI. FUZZY EVALUATION SCORES FOR THE ALTERNATIVES

Linguistic terms	Notation	Fuzzy score
Very poor	VP	(0, 0, 1)
Poor	P	(0, 1, 3)
Medium poor	MP	(1, 3, 5)
Fair	F	(3, 5, 7)
Medium good	MG	(5, 7, 9)
Good	G	(7, 9, 10)
Very good	VG	(9, 10, 10)

IV. CONCLUSION

The LUCE method, based on site specific data, concludes that in terms of the unit capital cost, diesel generating set-based systems appear to be the most attractive followed by coal thermal, nuclear and large HPP for India. Among renewable energy-based options, Biomass gasifier-based system is the most attractive option in terms of unit capital cost. In terms of the LUCE, coal thermal option is the most attractive options among the conventional electricity-generating options. The 'Small hydro (SHP)' is the preferred option in hilly areas for grid extension.

The integrated Fuzzy VIKOR and AHP method also determines 'Small hydro' as the best energy alternative for India followed by Nuclear and Biomass.

Overall these methods agree but the LUCE method (being site specific) gives the best assessment.

TABLE VII. EVALUATION SCORES OF THE ENERGY ALTERNATIVES

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
E_1	E_1:P	E_1:P	E_1:P	E_1:F	E_1:MP	E_1:MP	E_1:P	E_1:MP	E_1:F
	E_2:F	E_2:F	E_2:F	E_2:F	E_2:VP	E_2:P	E_2:F	E_2:F	E_2:F
	E_3:P	E_3:MP	E_3:MP	E_3:F	E_3:MP	E_3:P	E_3:MP	E_3:MP	E_3:F
E_2	E_1:F	E_1:F	E_1:MG	E_1:F	E_1:G	E_1:G	E_1:MP	E_1:MP	E_1:G
	E_2:P	E_2:P	E_2:P	E_2:G	E_2:VG	E_2:VG	E_2:P	E_2:P	E_2:F
	E_3:F	E_3:P	E_3:P	E_3:MG	E_3:G	E_3:G	E_3:P	E_3:P	E_3:MG
E_3	E_1:VG	E_1:G	E_1:MP	E_1:MP	E_1:MG	E_1:MG	E_1:MG	E_1:G	E_1:G
	E_2:G	E_2:G	E_2:P	E_2:F	E_2:VG	E_2:VG	E_2:F	E_2:P	E_2:P
	E_3:MG	E_3:MG	E_3:MP	E_3:F	E_3:G	E_3:G	E_3:MG	E_3:P	E_3:G
E_4	E_1:VP	E_1:P	E_1:G	E_1:G	E_1:G	E_1:G	E_1:G	E_1:G	E_1:VP
	E_2:F	E_2:F	E_2:G	E_2:F	E_2:F	E_2:F	E_2:VG	E_2:VG	E_2:P
	E_3:P	E_3:MP	E_3:VG	E_3:G	E_3:G	E_3:MG	E_3:MG	E_3:MG	E_3:MP
E_5	E_1:MP	E_1:MP	E_1:F	E_1:F	E_1:MP	E_1:MP	E_1:MG	E_1:MG	E_1:F
	E_2:VP	E_2:VP	E_2:F	E_2:F	E_2:P	E_2:P	E_2:F	E_2:F	E_2:P
	E_3:VP	E_3:MP	E_3:F	E_3:F	E_3:MP	E_3:MP	E_3:F	E_3:MG	E_3:MP
E_6	E_1:G	E_1:G	E_1:MG	E_1:MG	E_1:VG	E_1:VG	E_1:MG	E_1:MG	E_1:MG
	E_2:P	E_2:P	E_2:G	E_2:G	E_2:G	E_2:G	E_2:G	E_2:G	E_2:P
	E_3:MG	E_3:MG	E_3:G	E_3:G	E_3:VG	E_3:MG	E_3:G	E_3:MG	E_3:F
E_7	E_1:MP	E_1:MP	E_1:MP	E_1:VG	E_1:VG	E_1:VG	E_1:MG	E_1:MG	E_1:VP
	E_2:P	E_2:P	E_2:P	E_2:VG	E_2:VG	E_2:VG	E_2:G	E_2:G	E_2:F
	E_3:MP	E_3:P	E_3:P	E_3:VG	E_3:VG	E_3:VG	E_3:G	E_3:MG	E_3:MP
E_8	E_1:MP	E_1:MP	E_1:F	E_1:F	E_1:VG	E_1:VG	E_1:MP	E_1:F	E_1:VP
	E_2:G	E_2:G	E_2:P	E_2:F	E_2:VG	E_2:VG	E_2:P	E_2:G	E_2:G
	E_3:F	E_3:F	E_3:F	E_3:F	E_3:VG	E_3:VG	E_3:MP	E_3:G	E_3:G

TABLE VIII. FUZZY EVALUATION MATRIX FOR THE ALTERNATIVES

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
E_1	1.0, 2.3, 4.3	1.7, 3.7, 5.7	1.7, 3.7, 5.7	3.0, 5.0, 7.0	0.7, 2.0, 3.7	0.3, 1.7, 3.7	1.3, 3.0, 5.0	1.7, 3.7, 5.7	3.0, 5.0, 7.0
E_2	2.0, 3.7, 5.7	1.0, 2.3, 4.3	1.7, 3.0, 5.0	5.0, 7.0, 8.7	7.7, 9.3, 10.0	7.7, 9.3, 10.0	0.3, 1.7, 3.7	0.3, 1.7, 3.7	5.0, 7.0, 8.7
E_3	7.0, 8.7, 9.7	6.3, 8.3, 9.7	0.7, 2.3, 4.3	2.3, 4.3, 6.3	7.0, 8.7, 9.7	7.0, 8.7, 9.7	4.3, 6.3, 8.3	2.3, 3.7, 5.3	4.7, 6.3, 7.7
E_4	1.0, 2.0, 3.7	1.3, 3.0, 5.0	7.7, 9.3, 10.0	5.7, 7.7, 9.0	5.7, 7.7, 9.0	5.0, 7.0, 8.7	7.0, 8.7, 9.7	7.0, 8.7, 9.7	0.3, 1.3, 3.0
E_5	0.3, 1.0, 2.3	0.7, 2.0, 3.7	3.0, 5.0, 7.0	3.0, 5.0, 7.0	0.7, 2.3, 4.3	0.7, 2.3, 4.3	3.7, 5.7, 7.7	4.3, 6.3, 8.3	1.3, 3.0, 5.0
E_6	4.0, 5.7, 7.3	4.0, 5.7, 7.3	6.3, 8.3, 9.7	6.3, 8.3, 9.7	8.3, 9.7, 10.0	7.0, 8.7, 9.7	6.3, 8.3, 9.7	5.7, 7.7, 9.3	2.7, 4.3, 6.3
E_7	0.7, 2.3, 4.3	0.3, 1.7, 3.7	0.3, 1.7, 3.7	9.0, 10, 10	9.0, 10, 10	9.0, 10, 10	6.3, 8.3, 9.7	5.7, 7.7, 9.3	1.3, 2.7, 4.3
E_8	3.7, 5.7, 7.3	3.7, 5.7, 7.3	3.0, 5.0, 7.0	3.0, 5.0, 7.0	9.0, 10, 10	9.0, 10, 10	0.7, 2.3, 4.3	5.7, 7.7, 9.0	4.7, 6.0, 7.0

TABLE IX. SEPARATION MEASURES OF ALTERNATIVES

	S_i	R_i
E_1	0.572, 0.795, 1.106	0.087, 0.128, 0.198
E_2	0.405, 0.561, 0.726	0.088, 0.131, 0.191
E_3	0.261, 0.359, 0.463	0.067, 0.100, 0.143
E_4	0.305, 0.405, 0.506	0.068, 0.098, 0.139
E_5	0.459, 0.758, 1.040	0.083, 0.119, 0.179
E_6	0.186, 0.224, 0.212	0.034, 0.046, 0.063
E_7	0.296, 0.398, 0.539	0.077, 0.111, 0.157
E_8	0.274, 0.384, 0.532	0.083, 0.120, 0.172

TABLE X. S^*, S^-, R^* AND R^- VALUES

S^*	0.186, 0.224, 0.212
S^-	0.572, 0.795, 1.106
R^*	0.034, 0.046, 0.063
R^-	0.088, 0.131, 0.198

TABLE XI. INTEGRATED FUZZY VIKOR-AHP ANALYSIS RESULTS

	$\tilde{Q}_i$	Q_i	Rank order
E_1	0.991, 0.982, 1.000	0.986	8
E_2	0.784, 0.795, 0.762	0.788	6
E_3	0.402, 0.436, 0.437	0.430	2
E_4	0.469, 0.464, 0.446	0.462	3
E_5	0.807, 0.897, 0.893	0.881	7
E_6	0.000, 0.000, 0.000	0.000	1
E_7	0.541, 0.535, 0.531	0.535	4
E_8	0.568, 0.575, 0.583	0.575	5

REFERENCES

[1] M.R. Nouni, S.C. Mullick, T.C. Kandpal, Providing Electricity Access to Remote Areas in India: An Approach towards identifying Potential Areas for Decentralized Electricity Supply, *Renewable and Sustainable Energy Reviews*, 12 (2008), 1187-1220.

[2] M.R. Nouni, S.C. Mullick, T.C. Kandpal, Techno-economics of Small Wind Electric Generator Projects for Decentralized Power Supply in India, *Energy Policy* 35 (2007), 2491–2506.

[3] M.R. Nouni, S.C. Mullick, T.C. Kandpal, Biomass gasifier projects for decentralized power supply in India: A financial evaluation, *Energy Policy* 35 (2007), 1373–1385.

[4] M.R. Nouni, S.C. Mullick, T.C. Kandpal, Photovoltaic projects for decentralized power supply in India: A financial evaluation, *Energy Policy* 34 (2006), 3727–3738.

[5] M.R. Nouni, S.C. Mullick, T.C. Kandpal, Techno-economics of micro-hydro projects for decentralized power supply in India, *Energy Policy* 34 (2006), 1161–1174.

[6] Tolga Kaya, Cengiz Kahraman, Multicriteria renewable energy planning using an integrated fuzzy VIKOR & AHP methodology: The case of Istanbul, *Energy* 35 (2010), 2517-2527.

[7] Ji-Feng Ding, Partner selection of strategic alliance for a liner shipping company using extent analysis method of fuzzyAHP, *Journal of Marine Science and Technology*, Vol. 17, No. 2, pp. 97-105 (200