Analysis and evaluation of the applicability of green energy technology

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Abstract. With the seriousness of environmental issues and the shortage of resources, the applicability of green energy technology has been paid more and more attention by scholars in different fields. However, the current researches are often single in perspective and simple in method. According to the Theory of Applicable Technology, this paper analyzes and defines the green energy technology and its applicability from the all-around perspectives of symbiosis of economy, society, environment and science & technology etc., and correspondingly constructs the evaluation index system. The paper further applies the Fuzzy Comprehensive Evaluation to the evaluation of its applicability, discusses in depth the evaluation models and methods, and explains in detail with an example. The author holds that the applicability of green energy technology involves many aspects of economy, society, environment and science & technology and can be evaluated comprehensively by an index system composed of a number of independent indexes. The evaluation is multi-object, multi-factor, multi-level and fuzzy comprehensive, which is undoubtedly correct, effective and feasible by the Fuzzy Comprehensive Evaluation. It is of vital theoretical and practical significance to understand and evaluate comprehensively the applicability of green energy technology for the rational development and utilization of green energy technology and for the better promotion of sustainable development of human and nature.

1. Introduction

With the shortage of resources and the environmental crisis, the development and utilization of green energy technology have become the focus of current society and the analysis and evaluation of its applicability are increasingly highly valued by experts and scholars in different fields and disciplines. Since its applicability involves many aspects of economy, society, environment and science & technology, experts and scholars have conducted some relevant researches, but their perspectives are often single and methods simple [1,2].

In fact, the applicability is the essential requirement of green energy technology. It is very important to analyze and evaluate the applicability of green energy technology correctly and comprehensively. It is of vital theoretical and practical significance to explore the problems for the rational development and utilization of green energy technology, for the better realization of the industrialization, networking and intelligence of green energy technology and for the promotion of sustainable development of human and nature.

For this purpose, this paper analyzes and defines the green energy technology and its applicability guided by the Theory of Applicable Technology [3] from the all-around perspectives of symbiosis of economy, society, environment and science & technology etc. Correspondingly, the evaluation index system is constructed with certain structures by a number of independent indexes which combine the qualitative with quantitative and reflect respectively the requirements of applicability on the basis of the investigation of literature at home & abroad and consulting experts [4-8]. This paper further applies the extensively used and effective Fuzzy Comprehensive Evaluation (FCE) [9,10] to the analysis and evaluation of the applicability of green energy technology, discusses in depth its evaluation models and methods, and explains in detail with an example.

2. Definitions of the green energy technology and its applicability

According to the Theory of Applicable Technology, we hold that the green energy technology is the applicable energy technology and refers to the energy technology without or with very little pollution to the ecological environment. It is essentially a friendly, ecological and symbiotic technology which is compatible and coordinated with the natural environment tolerance and the renewable natural resources [11]. In general, there are two types of the green energy technology. One is a new energy technology to develop clean and pollution-free technology, such as solar energy, wind energy, tidal energy etc.; the other is the energy technology that can fully utilize waste, convert harm into good and improve the environment, such as various biomass energy.

From the all-around perspectives of symbiosis of economy, society, environment and science & technology, the applicability of green energy technology means that it is applicable and symbiotic with economy, society, environment and science & technology etc., it can meet their various requirements and can reap the better, diversified and comprehensive benefits. We hold that the applicability of green energy technology can be specifically analyzed and evaluated from the following aspects, and their requirements of applicability can be described, characterized and evaluated separately by a number of independent indexes [7,8]. Limited to space, the specific meaning of each index is not explained in the following.

2.1. Economic rationality

The green energy technology should be the energy technology of lower capital costs and high economic efficiency, and it should be economical, reasonable and symbiotic with the economic system. The applicability of economic rationality are described and evaluated by 5 indexes such as energy unit price, profit, energy resources quantity, market share rate and industrialized degree.

2.2. Social adaptability

The green energy technology should be the energy technology of lower social costs and better social benefits, and it should be human, social and symbiotic with the human society. The applicability of social adaptability are described and evaluated by 5 indexes such as supply security level, use security level, working conditions improvement level, increased employment rate and life quality improvement level.

2.3. Environmental coordination

The green energy technology should be the energy technology of low ecological costs and good ecological efficiency, and it should be friendly, ecological and symbiotic with the natural environment. Generally speaking, the applicability of ecological coordination are described and evaluated by 4 indexes such as pollutant decrement degree, waste recycling degree, major ecological destruction complaints and energy geography distribution.

2.4. Technical effectiveness

The green energy technology should be the energy technology of more efficient and beneficial, and it should be smart, interconnected and symbiotic with the technological system. The applicability

requirements of technical effectiveness are described and evaluated by 4 indexes such as energy conversion rate, durable years, technical difficulty and technical maturity.

Therefore, we can construct the comprehensive evaluation index system of applicability of green energy technology. It is composed of 4 factors and 18 indexes which are independent, as shown in table 1.

Table 1. Evaluation index system of the applicability of green energy technology.

Applicability of green energy technology			
Economic rationality (C_1)	Social adaptability (C_2)	Environmental coordination (C_3)	Technical effectiveness (C_4)
Energy unit price (c_{11}) Profit (c_{12}) Energy resources quantity (c_{13}) Market share rate (c_{14}) Industrialized degree (c_{15})	Supply security level (c_{21}) Use security level (c_{22}) Working conditions improvement level (c_{23}) Increased employment rate (c_{24}) Life quality improvement level (c_{25})	Pollutant decrement degree (c_{31}) Waste recycling degree (c_{32}) Major ecological destruction complaints (c_{33}) Energy geography distribution (c_{34})	Energy conversion rate (c_{41}) Durable years (c_{42}) Technical difficulty (c_{43}) Technical maturity (c_{44})

3. Comprehensive evaluation models of the applicability of green energy technology

Reasonable selection and determination of the evaluation model is an important prerequisite for scientific analysis and evaluation of the applicability of green energy technology. Due to the diversity and comprehensiveness of applicability of green energy technology, we think it is more effective, feasible and appropriate to analyze and evaluate the applicability of green energy technology by selecting and applying FCE.

The basic principle of FCE is to determine the rating criteria and weights of the evaluation factor and index, to describe the fuzzy boundary of each index by membership degree, to construct the fuzzy evaluation matrix by the transformation principle of fuzzy set, and finally to determine the evaluation level of the object through the multi-layer compound operation.

The evaluation model of the applicability of green energy technology can be obtained by FCE, see equation (1). Generally, it can be referred as the comprehensive evaluation model of generalized fuzzy operation, abbreviated as $M(\overset{\bullet}{*}, \overset{+}{*})$[10]:

$$B = W \circ R = (b_1, b_2, \ldots, b_m) \tag{1}$$

In which,

$$b_j = (w_1 \overset{\bullet}{*} r_{1j}) \overset{+}{*} (w_2 \overset{\bullet}{*} r_{2j}) \overset{+}{*} \ldots \overset{+}{*} (w_n \overset{\bullet}{*} r_{nj}) \quad (j=1,2,\ldots,m)$$

B is the comprehensive evaluation value obtained by the generalized fuzzy operatio$\overset{\bullet}{*}$n "and" and operation $\overset{+}{*}$ "or" with weight W = {w_j} (j=1,2,…,m) and transformation matrix R = {r_{ij}} (i=1,2,…,n, j=1,2,…,m).

W is the weight of index, which refers to the measurement of the role and importance of evaluation index in the evaluation index system. It represents the ability and contribution degree of index and embodies the value orientation of the evaluator. The methods of obtaining weight include expert

consultation method, rating method, experience the look-up table method, statistical test method, grey correlation method, comprehensive evaluation of inverse problem calculation method, Analytic Hierarchy Process(AHP) and other variants [8]. We choose AHP in the following example.

r is the single factor evaluation value, which refers to the rating ratio or membership degree of the index belonging to each evaluation grade. R is the fuzzy evaluation transformation matrix obtained by the single factor evaluation. There are two ways to obtain r: one is Experiential Look-up Tables Method; the other is Statistical Method of Peer Review [8]. We choose the latter in the following example.

In theory, there are infinitely many kinds of fuzzy operators, but only five specific models have been proposed up to now, see table 2.

Table 2. Formula and operator models of fuzzy compound operation.

Type M — Operation b_j — Operator	$M^{(\wedge,\vee)}$	$M^{(\bullet,\vee)}$	$M(^{\bullet,\oplus})$	$M(^{\wedge,\oplus})$	$M^{(\bullet^k,\wedge)}$
	$b_j = \max[\min(a_1, r_{1j}), \min(a_2, r_{2j}), \cdots \min(a_n, r_{nj})]$	$b_j = \max[a_1 r_{1j}, a_2 r_{2j}, \cdots a_n r_{nj}]$	$b_j = [1, \sum_{i=1}^{n} a_i r_{ij}]$	$b_j = \min[1, \sum_{i=1}^{n} \min(a_i r_{ij})]$	$b_j = \min[r_{1j}^1, r_{2j}^2, \cdots r_{nj}^n]$
$\overset{\bullet}{*}$	$\overset{\bullet}{*} \to \wedge$ $\alpha \wedge \beta = \min(\alpha, \beta)$	$\overset{\bullet}{*} \to \bullet$ $\alpha \bullet \beta = \alpha \times \beta$	$\overset{\bullet}{*} \to \bullet$ $\alpha \bullet \beta = \alpha \times \beta$	$\overset{\bullet}{*} \to \wedge$ $\alpha \wedge \beta = \min(\alpha, \beta)$	$\overset{\bullet}{*} \to \bullet^k$ $\alpha \bullet^k \beta = \beta^\alpha$
$\overset{+}{*}$	$\overset{+}{*} \to \vee$ $\alpha \vee \beta = \max(\alpha, \beta)$	$\overset{+}{*} \to \vee$ $\alpha \vee \beta = \max(\alpha, \beta)$	$\overset{+}{*} \to \oplus$ $\alpha \oplus \beta = \min(1, \alpha + \beta)$	$\overset{+}{*} \to \oplus$ $\alpha \oplus \beta = \min(1, \alpha + \beta)$	$\overset{+}{*} \to \wedge$ $\alpha \wedge \beta = \min(\alpha, \beta)$

The different operators of fuzzy compound operation in table 2 have different characteristics, which play different roles and reflect different value orientation of evaluators, see table 3.

Table 3. Characteristics of operators in fuzzy compound operation.

Operators — Characteristics	$M^{(\wedge,\vee)}$	$M^{(\bullet,\vee)}$	$M(^{\bullet,\oplus})$	$M(^{\wedge,\oplus})$	$M^{(\bullet^k,\wedge)}$
Types	Main factor determinant	Main factor prominent	Weighted average	Main factor prominent	Weighted average
Weight role	Non prominent	Prominent	Prominent	Non prominent	Prominent
R information	Incomplete	Incomplete	Complete	More complete	Complete
Comprehensive degree	Low	Low	High	High	Low

It is of great significance for fuzzy comprehensive evaluation to select the operators of fuzzy compound operation. The choice of compound operator depends on the scope of the analysis. We consider five specific operators are used respectively in the following different situations [8]: a. $M^{(\wedge,\vee)}$ is the operator of main factor determinant type, which is suitable for evaluating only the key factors, that is to say, the optimum of the key factors is considered as the best case for the comprehensive evaluation; b. $M(^{\bullet,\oplus})$ is the operator of weighted average type, which is suitable for evaluating things according to the comprehensive requirements of each factor; c. $M^{(\bullet,\vee)}$ and $M(^{\wedge,\oplus})$ are the operators of main factor prominent type, which are suitable for both to consider the

overall but also focus on the evaluation of the situation; d. $M^{(\bullet^k, \wedge)}$ is the operator of weighted average type, which is suitable for the weight of all the factors based on the weight of the index, with the smallest weight even as the best requirements to evaluate the situation of things. We choose $M^{(\wedge, \vee)}$, $M^{(\bullet, \vee)}$ and $M(^{\wedge, \oplus})$ in the following example.

4. Comprehensive evaluation methods of the applicability of green energy technology

In the following, we illustrate the basic process and method of analyzing and evaluating the applicability of green energy technology by FCE with an example [12].

4.1. Determine the tender object set $E= \{E_k\}$ $(k=1,2,…,q)$

A green industrial region in a city conducts a public tender for the 3 tender companies of the green energy technology E_1, E_2, E_3 (q=3) and evaluates respectively their applicability of green energy technology.

4.2. Obtain the index set $C= \{c_i\}$ $(i=1,2,…,n)$

Through the research of related literature at home and abroad and consulting experts, we construct the evaluation index system of the applicability of green energy technology, see table 1.

4.3. Obtain the comment set $G= \{g_l\}$ $(l=1,2,…,s)$

According to the identified evaluation criteria, we determine the rating criteria of applicability of green energy technology, and obtain the corresponding comment set $G= \{g_l\}$ = {very good, good, pass, poor, very poor} (s=5).

4.4. Determine the weight set $W= \{w_j\}$ $(j=1,2,…,m)$

The distribution of weight is the key to the whole comprehensive evaluation. Here we choose AHP and invite 7 experts of energy technology to determine the weight of the various indexes at all levels, see table 4.

Table 4. Summarization of the evaluation data of applicability of green energy technology.

Evaluation indexes and weight				Tender company's applicability, evaluation grades and rating ratio															
Factor level(C_i)	Weight（W）	Index level(c_{ii})	Weight（W_i）	Company applicability				E_1's	Company applicability				E_2's	Company applicability				E_3's
				G_1	G_2	G_3	G_4	G_5	G_1	G_2	G_3	G_4	G_5	G_1	G_2	G_3	G_4	G_5
C_1	0.3	c_{11}	0.20	1/7	4/7	2/7	0	0	1/7	3/7	2/7	1/7	0	1/7	2/7	2/7	1/7	1/7
		c_{12}	0.25	2/7	3/7	1/7	1/7	0	0	2/7	3/7	1/7	1/7	1/7	4/7	1/7	1/7	0
		c_{13}	0.25	2/7	3/7	2/7	0	0	1/7	2/7	3/7	1/7	0	2/7	4/7	1/7	0	0
		c_{14}	0.15	2/7	4/7	1/7	0	0	0	3/7	3/7	1/7	0	2/7	3/7	2/7	0	0
		c_{15}	0.15	1/7	3/7	2/7	1/7	0	1/7	2/7	2/7	1/7	1/7	1/7	4/7	2/7	0	0
C_2	0.25	c_{21}	0.25	2/7	4/7	1/7	0	0	1/7	3/7	2/7	1/7	0	1/7	3/7	2/7	1/7	0
		c_{22}	0.25	1/7	4/7	2/7	0	0	1/7	2/7	2/7	1/7	1/7	2/7	3/7	1/7	1/7	0
		c_{23}	0.20	2/7	3/7	1/7	1/7	0	1/7	3/7	2/7	1/7	0	2/7	4/7	1/7	0	0
		c_{24}	0.15	1/7	3/7	3/7	0	0	0	1/7	3/7	2/7	1/7	2/7	3/7	2/7	0	0
		c_{25}	0.15	2/7	2/7	3/7	0	0	0	1/7	3/7	3/7	0	1/7	3/7	1/7	1/7	1/7
C_3	0.25	c_{31}	0.30	2/7	3/7	2/7	0	0	1/7	2/7	2/7	1/7	1/7	2/7	4/7	1/7	0	0
		c_{32}	0.25	1/7	4/7	2/7	0	0	1/7	1/7	2/7	2/7	1/7	1/7	3/7	2/7	1/7	0

		c_{33}	0.25	3/7	3/7	1/7	0	0	1/7	3/7	2/7	1/7	0	2/7	3/7	2/7	0	0
		c_{34}	0.20	2/7	3/7	1/7	1/7	0	0	2/7	3/7	1/7	1/7	1/7	4/7	1/7	1/7	0
C_4	0.2	c_{41}	0.30	4/7	2/7	1/7	0	0	1/7	3/7	1/7	1/7	0	1/7	3/7	2/7	1/7	0
		c_{42}	0.25	3/7	3/7	1/7	0	0	0	3/7	2/7	1/7	1/7	1/7	2/7	2/7	1/7	1/7
		c_{43}	0.20	2/7	3/7	1/7	1/7	0	1/7	2/7	3/7	1/7	0	2/7	4/7	1/7	0	0
		c_{44}	0.25	2/7	3/7	2/7	0	0	1/7	2/7	2/7	1/7	1/7	1/7	3/7	2/7	1/7	0

4.5. Obtain the evaluation matrix R= {r_{ij}} (i=1,2,…,n, j=1,2,…,m)

We can obtain the evaluation transformation matrix R = {r_{ij}} through the single factor evaluation. Single factor evaluation value r_{ij} is the rating ratio or membership degree of index c_i belonging to the evaluation grade g_j.

The data for the weight, the evaluation grade and the rating ratio are summarized in table 4.

4.6. Obtain the final comprehensive evaluation results

By evaluating comprehensively on each level, we can obtain the final comprehensive evaluation results. We first choose the operation $M^{(\wedge,\vee)}$ (take $\wedge$(min) and $\vee$(max) instead of $\overset{\bullet}{*}$ and $\overset{+}{*}$ in equation (1) to calculate. For the sake of space saving, the calculation process is omitted, and only the results are given here.

Evaluation matrix R_{1E1} of Company E_1's applicability of green energy technology in single factor C_{1E1} is:

$$R_{1E1} = \begin{bmatrix} 1/7 & 4/7 & 2/7 & 0 & 0 \\ 2/7 & 3/7 & 1/7 & 1/7 & 0 \\ 2/7 & 3/7 & 2/7 & 0 & 0 \\ 2/7 & 4/7 & 1/7 & 0 & 0 \\ 1/7 & 3/7 & 2/7 & 1/7 & 0 \end{bmatrix} = \begin{bmatrix} 0.14 & 0.57 & 0.29 & 0 & 0 \\ 0.29 & 0.43 & 0.14 & 0.14 & 0 \\ 0.29 & 0.43 & 0.29 & 0 & 0 \\ 0.29 & 0.57 & 0.14 & 0 & 0 \\ 0.14 & 0.43 & 0.29 & 0.14 & 0 \end{bmatrix}$$

Comprehensive evaluation value B_{1E1} of Company E_1's applicability of green energy technology in single factor C_{1E1} is:

$$B_{1E1} = {}_1 o R_{1E1} = [0.2\ 0.25\ 0.25\ 0.15\ 0.15] o \begin{bmatrix} 0.14 & 0.57 & 0.29 & 0 & 0 \\ 0.29 & 0.43 & 0.14 & 0.14 & 0 \\ 0.29 & 0.43 & 0.29 & 0 & 0 \\ 0.29 & 0.57 & 0.14 & 0 & 0 \\ 0.14 & 0.43 & 0.29 & 0.14 & 0 \end{bmatrix} = [0.25\ 0.25\ 0.25\ 0.14\ 0]$$

Similarly, comprehensive evaluation values B_{2E1}, B_{3E1}, B_{4E1} of Company E_1's applicability of green energy technology in single factor C_{2E1}, C_{3E1}, C_{4E1} are:

$B_{2E1} = W_2 o R_{2E1} = [0.25\ 0.25\ 0.25\ 0.14\ 0.14]$

$B_{3E1} = W_3 o R_{3E1} = [0.29\ 0.30\ 0.29\ 0.14\ 0]$

$B_{4E1} = W_4 o R_{4E1} = [0.3\ 0.29\ 0.25\ 0.14\ 0]$

Thus we obtain the evaluation matrix R_{E1} of Company E_1's applicability of green energy technology in all the single factors:

NEFES 2017
IOP Conf. Series: Earth and Environmental Science **93** (2017) 012076

IOP Publishing
doi:10.1088/1755-1315/93/1/012076

$$R_{E1} = \begin{bmatrix} B_{1E1} \\ B_{2E1} \\ B_{3E1} \\ B_{4E1} \end{bmatrix} = \begin{bmatrix} 0.25 & 0.25 & 0.25 & 0.14 & 0 \\ 0.25 & 0.25 & 0.25 & 0.14 & 0.14 \\ 0.29 & 0.30 & 0.29 & 0.14 & 0 \\ 0.3 & 0.29 & 0.25 & 0.14 & 0 \end{bmatrix}$$

Finally, we reach the comprehensive evaluation result B_{E1} of Company E_1's applicability of green energy technology in all the single factors, which is in the overall evaluation system:

$$B_{E1}=WoR_{E1}=[0.3\ 0.25\ 0.25\ 0.2]o\begin{bmatrix} 0.25 & 0.25 & 0.25 & 0.14 & 0 \\ 0.25 & 0.25 & 0.25 & 0.14 & 0.14 \\ 0.29 & 0.30 & 0.29 & 0.14 & 0 \\ 0.3 & 0.29 & 0.25 & 0.14 & 0 \end{bmatrix}=[0.25\ 0.25\ 0.25\ 0.14\ 0.14].$$

Similarly, we reach the comprehensive evaluation results B_{E2} and B_{E3} of Company E_2 and E_3's applicability of green energy technology in all the single factors, which is in the overall evaluation system.

$B_{E2} = W\ o\ R_{E2} = [0.20\ \ 0.20\ \ 0.25\ \ 0.15\ \ 0.14]$

$B_{E3} = W\ o\ R_{E3} = [0.20\ \ 0.25\ \ 0.25\ \ 0.14\ \ 0.14]$

For the sake of clarity, the above final comprehensive evaluation results B_{E1}, B_{E2} and B_{E3} can be converted into comprehensive evaluation values Z_{E1}, Z_{E2} and Z_{E3} by the evaluation level $G = \{G_1, G_2, G_3, G_4, G_5\} = [2, 1, 0, -1, -2]$.

$$\begin{bmatrix} 2 \\ 1 \\ 0 \\ -1 \\ -2 \end{bmatrix}$$

$Z_{E1}=B_{E1}\cdot G=[0.25\ 0.25\ 0.25\ 0.14\ \ 0.14]\cdot \qquad = 0.33$

$Z_{E2} = B_{E2}\cdot G = 0.22$

$Z_{E3} = B_{E3}\cdot G = 0.27$

If the operations $M^{(\bullet,\vee)}$ and $M^{(\wedge,\oplus)}$ are chosen, the corresponding comprehensive evaluation values of the 3 companies' applicability of green energy technology are shown in table 5.

Table 5. Multi-operator values of comprehensive evaluation.

Operators Values of comprehensive evaluation Z Tender companies E	$M^{(\wedge,\vee)}$	$M^{(\bullet,\oplus)}$	$M^{(\wedge,\oplus)}$
E_1's applicability of green energy technology	0.33	0.42	0.78
E_2's applicability of green energy technology	0.22	0.29	0.43
E_3's applicability of green energy technology	0.27	0.36	0.67

4.7. Reach the conclusion of evaluation by sorting and selecting
According to the final evaluation results, we can sort, select and reach the conclusion of evaluation of the 3 tender companies' applicability of green energy technology.

From the final comprehensive evaluation value, we can clearly see that in the applicability of green energy technology, Company E_1's technology is better than Company E_3's technology, Company E_3's

technology is better than Company E_2's technology. Therefore, Company E_1's applicability of green energy technology is the best and will be the winner.

5. Conclusion

The applicability of green energy technology is complex, systematic and dynamic. It needs to be analyzed and evaluated from various aspects of economy, society, environment and science & technology, which is a problem of multi-object, multi-factor, multi-level and fuzzy comprehensive evaluation. Thus it is feasible and effective to analyze and evaluate the applicability of green energy technology by FCE which plays an irreplaceable important role. Compared with the traditional evaluation method, the advantage of FCE is that it can quantify some indexes with unclear and difficult quantitative, combine qualitative analysis with quantitative analysis, subjective value judgment and objective data, and then it is more suitable for solving the problems of comprehensive evaluation. Of course, the defect of FCE is mainly that the amount of calculation of FCE is relatively large and complex in the case of a large number of indexes. In short, we believe that with the scientific methods such as FCE, the problems of the applicability of green energy technology will be increasingly explored in depth to provide the important theoretical guidance for the rational development and utilization of green energy technology and the better promotion of its industrialization, networking and intelligence.

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