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Decision support for prioritizing energy technologies against high oil prices: A fuzzy analytic hierarchy process approach

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ABSTRACT

To provide national energy security in the 21st century, establishing a long-term strategic energy technology development is essential through selection and specialization. We established a strategic energy technology roadmap (ETRM) taking economic spin-offs, commercial potential, inner capacity, and technical spin-off into account. In this research, we suggest an integrated multi-criteria decision making (MCDM) approach, which is composed of more than two criteria as the assessment of the optimal alternatives and solutions in the real world with the fuzzy theory and analytic hierarchy process (AHP), to prioritize the weights of energy technologies of ETRM as we allocate R&D budget using a fuzzy analytic hierarchy process. Building technology is the most preferred technology in the sector of energy technologies against high oil prices. And the coal technology and transportation technology follows and take the 2nd and 3rd place with the fuzzy AHP approach.

1. Introduction

Korea has been easily affected by oil prices change as Korea is the 10th largest energy consuming nation in the world. Moreover, Korea depends over 98% of consumed energy resources on import. The interests of energy technology development have been increasing by dint of her poor natural resources. In addition, a strategic energy technology development is the ultimate alternative to breakthrough Korea's energy status from a view point of her national energy security.

We establish the strategic energy technology roadmap for coping with upcoming 10 years from 2006 to 2015 as an aspect of energy technology development (Lee, Mogi, & Kim, 2009a). A strategic energy technology development can be one of the best alternatives to solve and cope with Korean energy environments, ETRM is meaningful guidelines to drive well focused energy technology development.

We analyzed the world energy outlook to make ETRM and provide energy policy directions in 2005(Lee & Kim, 2005). ETRM focused on the strategic energy technology development considering Korean energy status including economic spin-offs, commercial potential, inner capacity, and technical spin-off. ETRM supplies primary energy technologies to be developed with a long-term view point. We suggest Korean long-term directions and the strategy of energy technology development through ETRM.

Technology roadmap has been gaining in popularity as supporting the strategy of developing technology. TRM has been developed with applying to various levels from academics to industry.

The main purpose of this research is to prioritize the weights of energy technology against high oil prices in the ETRM as we allocate R&D budget strategically. We use the fuzzy analytic hierarchy process, which integrates the fuzzy theory into the AHP approach, to generate the weights of energy technology against high oil prices of the ETRM.

This paper is composed as follows: Section 2 presents the concept of fuzzy sets and numbers. Section 3 includes fuzzy AHP process. Section 4 presents hierarchy of criteria and execution flow chart. Section 5 describes the classification of energy technologies against high oil prices in ETRM. Section 6 shows the numerical examples of energy technologies against high oil prices in ETRM. Finally, Section 7 presents the conclusion.

2. Fuzzy sets and numbers

In the real world, precise data concerning measurement indicators are very hard to be extracted. And decision makers also prefer natural language expression rather than crisp numbers in assessing. Fuzzy set theory deals with ambiguous or not well defined situations. It looks like human thoughts and perceptions of

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using approximate information and uncertainty to generate the reasonable alternative of decision making problem.

For the first time, the concept of fuzzy theory is introduced by Zadeh in 1965. Fuzzy theory includes fuzzy set, membership function, and fuzzy number to change vague data into useful data efficiently.

Fuzzy set theory implements groups of data with boundaries that are not sharply defined. The merit of using fuzzy approach is to express the relative importance of the alternatives and the criteria with fuzzy numbers instead of using crisp numbers because most of the decision making in the real world takes place in a situation where the pertinent data and the sequences of possible actions are not precisely known.

Triangular and trapezoidal fuzzy numbers are usually used to capture the vagueness of the parameters related to select the alternatives. TFN is expressed with boundaries instead of crisp numbers for reflecting the fuzziness as decision makers select the alternatives or pairwise comparisons matrix. In this research, we use triangular fuzzy numbers (TFN) to prioritize energy technology in ETRM with fuzziness. TFN is designated as $M_{ij} = (l_{ij}, m_{ij}, u_{ij})$. m_{ij} is the median value of fuzzy number M_{ij}. l_{ij} and u_{ij} is the left and right side of fuzzy number M_{ij} respectively.

Consider two TFN M_1 and M_2, $M_1 = (l_1, m_1, u_1)$ and $M_2 = (l_2, m_2, u_2)$. Their operations laws are as follows:

$$(l_1, m_1, u_1) \oplus (l_2, m_2, u_2) = (l_1 + l_2, m_1 + m_2, u_1 + u_2) \tag{1}$$

$$(l_1, m_1, u_1) \oplus (l_2, m_2, u_2) = (l_1 \times l_2, m_1 \times m_2, u_1 \times u_2) \tag{2}$$

$$(l_1, m_1, u_1)^{-1} = (1/u_1, 1/m_1, 1/l_1) \tag{3}$$

3. Fuzzy AHP

The analytic hierarchy process (AHP) is a common method and is applied for various sectors for analyzing qualitative criteria to weight the alternatives. Saaty suggested AHP as a decision making tool to resolve unstructured problems since 1977 (Saaty, 1980). In general, decision making approach involves lots of tasks such as planning (Lee, Yoon, & Kim, 2007), selecting a best policy after the assessment of alternatives (Lee, Mogi, & Kim, 2008a), allocating resources efficiently, determining requirements, measuring performance, optimizing and resolving conflict. Decision making process is modeled as a hierarchical structure in the AHP method.

In this research, though the AHP is to capture the expert's knowledge and experiences by perception or preference, AHP still cannot reflect the human thoughts totally with crisp numbers such as one, two, three, and so on. In hence, fuzzy AHP, which integrates the fuzzy theory into the AHP technique, is applied to solve the hierarchical fuzzy decision making problems in the real world (Lee, Mogi, & Kim, 2008b).

Fuzzy scale for pairwise comparisons of one attribute over another is shown in Table 1 (Chang, 1996). We use the fuzzy scale when decision makers make pairwise comparisons.

Table 1
Fuzzy scale.

Preference of pairwise comparisons	Fuzzy numbers
Equal	(1, 1, 1)
Moderate	(2/3, 1, 3/2)
Fairly strong	(3/2, 2, 5/2)
Very strong	(5/2, 3, 7/2)
Absolute	(7/2, 4, 9/2)

Let $A = (a_{ij})_{n \times m}$ be a fuzzy pairwise comparison judgements matrix. Let $M_{ij} = (l_{ij}, m_{ij}, u_{ij})$ be a TFN. The step of fuzzy AHP is as follows:

Step 1: We make pairwise comparisons of attributes by using the fuzzy numbers, which is composed of low, median and upper value, in the same level of hierarchy structure.

Step 2: The value of fuzzy synthetic extent with respect to the ith object is defined as

$$S_i = \sum_{j=1}^{m} M_{ij} \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{ij} \right]^{-1} \tag{4}$$

$$\sum_{j=1}^{m} M_{ij} = \left(\sum_{j=1}^{m} l_{ij}, \sum_{j=1}^{m} m_{ij}, \sum_{j=1}^{m} u_{ij} \right) \tag{5}$$

s.t

$$\sum_{i=1}^{n} \sum_{j=1}^{m} M_{ij} = \left(\sum_{i=1}^{n} l_{ij}, \sum_{i=1}^{n} m_{ij}, \sum_{i=1}^{n} u_{ij} \right) \tag{6}$$

$$\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{ij} \right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} u_{ij}}, \frac{1}{\sum_{i=1}^{n} m_{ij}}, \frac{1}{\sum_{i=1}^{n} l_{ij}} \right) \tag{7}$$

we calculate TFN value of S_i, which is composed of the each row value divided by the sum of column value in the matrix M_{ij} by the formula (4), (5), (6), and (7).

Step 3: We compare the values of S_i respectively and calculate the degree of possibility of $S_j = (l_j, m_j, u_j) \geq S_i = (l_i, m_i, u_i)$. That can be equivalently expressed as follows:

$$V(S_j \geq S_i) = \text{height} \quad (S_i \cap S_j) = uS_j(d)$$

$$= \begin{cases} 1, & \text{if} \quad m_j \geq m_i \\ 0, & \text{if} \quad l_i \geq u_j \\ \dfrac{l_i - u_j}{(m_j - u_j) - (m_i - l_i)}, & \text{otherwise} \end{cases} \tag{8}$$

where d is the ordinate of the highest intersection point between u_{Si} and u_{Sj}. We need to both the values of $V(S_j \geq S_i)$ and $V(S_i \geq S_j)$ to compare S_i and S_i.

Step 4: We calculate the minimum degree possibility $d(i)$ of $V(S_j \geq S_i)$ for i,j=1,2,….,k.

$$V(S \geq S_1, S_2, S_3 \cdots\cdots, S_k), \quad \text{for} \quad i = 1, 2, 3, \cdots\cdots, k$$

$$= V[(S \geq S_1) \text{ and } (S \geq S_2) \text{ and} \cdots\cdots (S \geq S_k)]$$

$$= \min V(S \geq S_i) \text{ for } i = 1, 2, 3, \cdots\cdots, k \tag{9}$$

Assume that

$$d'(A_i) = \min V(S \geq S_i), \text{ for } i = 1, 2, 3, \cdots\cdots, k$$

Then the weight vector is defined as

$$W' = (d'(A_1), d'(A_2), \cdots\cdots, d'(A_n))^T \tag{10}$$

where A_i (i=1,2,….,n) are the n elements.

Step 5: We normalize the weight vectors. That is as follows.

$$W = (d(A_1), d(A_2), \ldots\ldots\ldots, d(A_n))^T \tag{11}$$

where W is a non-fuzzy number.