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

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A B S T R A C T

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.

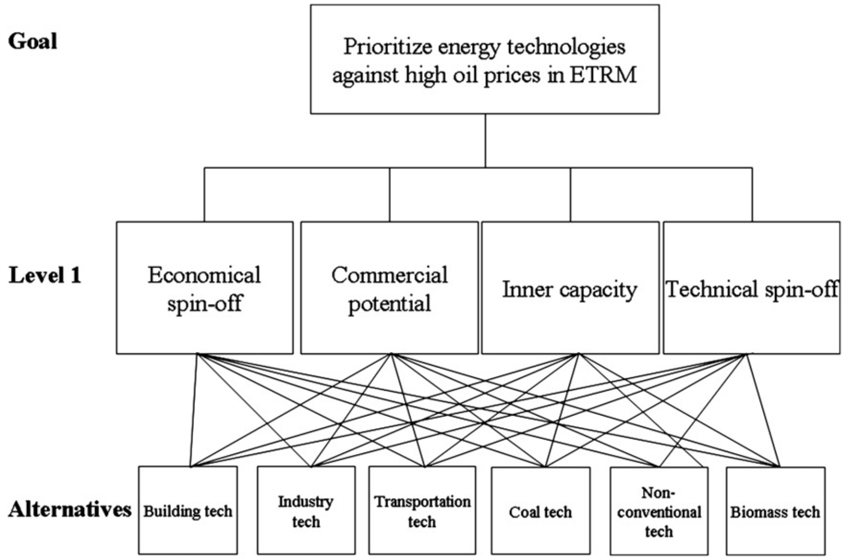

Fig. 1. Hierarchy of criteria.

4. Hierarchy of the criteria and execution flow chart

To evaluate and prioritize the weights of energy technologies of ETRM, we compose of 4 criteria, which are economical spin-off, possibility of commercialization, inner capacity, and technical spin-off. Energy technologies against high oil prices in the ETRM are assessed by the one-tier criteria. When we choose a criterion list of evaluating energy technologies against high oil prices, we consider the 4 aspects of strength, weakness, opportunity, and threat for well focused R&D and production of world class research outcomes. Fig. 1 shows the hierarchy of criteria for the assessment of energy technologies against high oil prices. We executed peer-reviews to collect feedbacks of experts related to energy technology development. As we gather the feedback of the experts, we consider the consistency of the pairwise comparisons with the consistency ratio (Fig. 2).

The execution flow chart for assessing the priority of energy technologies against high oil process is presented in Fig. 2. The first stage sets up the target, which focuses on the assessment of energy technologies against high oil prices. The 2nd stage makes criteria for assessing the alternatives, and the 3rd stage structures the hierarchy. The 4th stage assesses whether the hierarchy is arranged properly or not by considering the target. After assessing the hierarchy, we execute peer-reviews in the 5th stage, which aggregates the weights of experts' feedback. In the 6th stage, we make the pairwise comparisons by the fuzzy numbers composed of the intervals, which are lower, median, and upper value. We then

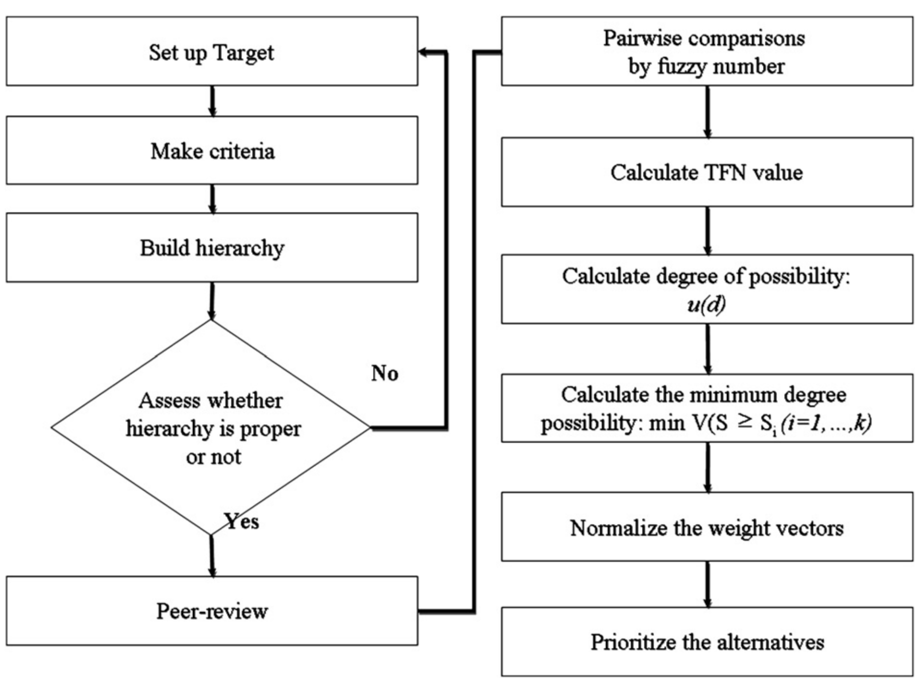

Fig. 2. Execution flow chart.

calculate the triangular fuzzy number value in the 7th stage. Then, in the 8 and 9th stages, we calculate the degree of possibility and the minimum degree of possibility. Finally, we normalize the weight vectors of criteria and prioritize the alternatives related to energy technologies against high oil prices in the 10th and 11th stages.

5. Classification of energy technologies in ETRM

ETRM is classified with 3 major sectors, which are energy technologies against high oil prices, for the UNFCCC, and for the hydrogen economy consider Korea energy environment. In this research, we focus on the energy technologies against high oil prices and weigh the priority of that sector. The classified energy technologies against high oil prices in the ETRM are shown in Table 2.

We gathered the list of energy technlogies against high oil prices and make a short-list of energy technologies against high oil prices with the feedback of experts in the energy efficiency technology. The final short-list of energy technologies against high oil prices accounts for 6 energy technologies, which are building technology, industry technology, transportation technology, coal technology, non-conventional fuel technology, and biomass technology. Building technology develops 4 core technologies composed of the lighting technology, air-conditioning technology, building envelop technology, and building system technology. Industry technology develops 3 core technologies accounted for common technology, waste heat technology, and petroleum refinery and fine chemical technology. Transportation technology only focuses on developing 3 core technologies which are the fuel efficiency improvement technology, hybrid electronic vehicle technology, and biodiesel as a diesel fuel alternative. Coal technology is composed of 2 core technologies, which are direct utilization technology and conversion utilization technology. Non-conventional fuel technology accounts for 2 core technologies, which are oil shale/oil sand technology and pyrolysis/gasification technology of waste. Finally, biomass technology is composed of 2 core technologies, which are direct utilization technology and conversion technology.

In this research, we supply the results of priorities of energy technologies against high oil prices in the ETRM with the fuzzy AHP process approach scientifically and efficiently.

6. Numerical examples: comparison of energy technologies against high oil prices in the ETRM

6.1. Priority of criteria

We make pairwise comparisons of 4 criteria to assess energy technologies against high oil prices in the ETRM. Table 3 shows the fuzzy evaluation matrix with response to the goal. Economic spin-off, Commercial potential, Inner capacity, and Technical spin-off stand for ES, CP, IC, and TS respectively.

As a result of fuzzy evaluation of criteria, which is the mean value, is shown in Table 4.

Table 2
Classification of energy technologies against high oil prices in ETRM.

Major sector	Technologies
Energy technologies against high oil prices	Building technology Industry technology Transportation technology Coal technology Non-conventional fuel technology Biomass technology

Table 3
Fuzzy evaluation of the goal.

	ES	PC	IC	TS
ES	(1, 1, 1)	(1, 1, 1) (2/3, 1, 3/2) (1, 1, 1) ■ ■	(1, 1, 1) (1, 1, 1) (2/3, 1, 3/2) ■ ■	(2/3, 1, 3/2) (2/3, 1, 3/2) (3/2, 2, 5/2) ■ ■
PC	(1, 1, 1) (2/3, 1, 3/2) (1, 1, 1) ■ ■	(1, 1, 1)	(1, 1, 1) (2/3, 1, 3/2) (2/3, 1, 3/2) ■ ■	(2/3, 1, 3/2) (1, 1, 1) (3/2, 2, 5/2) ■ ■
IC	(1, 1, 1) (1, 1, 1) (2/3, 1, 3/2) ■ ■	(1, 1, 1) (2/3, 1, 3/2) (2/3, 1, 3/2) ■ ■	(1, 1, 1)	(2/3, 1, 3/2) (2/3, 1, 3/2) (2/3, 1, 3/2) ■ ■
TS	(2/3, 1, 3/2) (2/3, 1, 3/2) (2/5, 1/2, 2/3) ■ ■	(2/3, 1, 3/2) (1, 1, 1) (2/5, 1/2, 2/3) ■ ■	(2/3, 1, 3/2) (2/3, 1, 3/2) (2/3, 1, 3/2) ■ ■	(1, 1, 1)

We calculate TFN values of 4 criteria by using the fuzzy evaluation values in Table 4.

TFN values of criteria are as follow:

S_1(ES)
$=(3.97,4.60,5.40) \otimes (1/20.20,1/16.60,1/14.01)$
$=(3.97 \times 1/20.2,4.60 \times 1/16.60,5.40 \times 1/14.01)$
$=(0.20,0.28,0.39)$
S_2(CP)
$=(3.97,4.60,5.40) \otimes (1/20.20,1/16.60,1/14.01)$
$=(0.20,0.28,0.39)$
S_3(IC)
$=(3.23,3.80,4.67) \times (1/20.20,1/16.60,1/14.01)$
$=(0.16,0.23,0.33)$
S_4(TS)
$=(2.85,3.60,4.73) \otimes (1/20.20,1/16.60,1/14.01)$
$=(0.14,0.22,0.34)$

We compare the values of S_i respectively and calculate the degree of possibility of $S_j=(l_j, m_j, u_j) \geq S_i = (l_i, m_i, u_i)$ by the formula (8). Table 5 shows the values of $V(S_j \geq S_i)$.

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

$D'(1) = \min V(S_1 \geq S_2, S_3, S_4) = \min(1.00,1.00,1.00) = 1.00$
$D'(2) = \min V(S_2 \geq S_1, S_3, S_4) = \min(1.00,1.00,1.00) = 1.00$
$D'(3) = \min V(S_3 \geq S_1, S_2, S_4) = \min(0.72,0.74,1.00) = 0.72$
$D'(4) = \min V(S_4 \geq S_1, S_2, S_3) = \min(0.70,0.70,0.94) = 0.70$

Then the weight vector is like that.

$W' = (1.00, 1.00, 0.72, 0.70)^T$

We normalize the weight vectors. That is as follows.

$W = (0.29, 0.29, 0.21, 0.20)^T$

The final weights of 4 criteria, ES, CP, IC, and TS, are 0.29, 0.29, 0.21, and 0.20 respectively. In 4 criteria, ES and CP are the most preferred criteria comparing with the other criteria.

Table 4
Fuzzy evaluation of criteria.

	ES	CP	IC	TS
ES	(1.00, 1.00, 1.00)	(0.93, 1.00, 1.10)	(1.03, 1.20, 1.40)	(1.00, 1.40, 1.90)
CP	(0.93, 1.00, 1.10)	(1.00, 1.00, 1.00)	(0.97, 1.20, 1.50)	(1.07, 1.40, 1.80)
IC	(0.81, 0.90, 1.03)	(0.75, 0.90, 1.13)	(1.00, 1.00, 1.00)	(0.67, 1.00, 1.50)
TS	(0.56, 0.80, 1.17)	(0.63, 0.80, 1.07)	(0.67, 1.00, 1.50)	(1.00, 1.00, 1.00)

Table 5
Values of $V(S_j \geq S_i)$.

$V(S_1 \geq S_i)$	Value	$V(S_2 \geq S_i)$	Value
$V(S_1 \geq S_2)$	1.00	$V(S_2 \geq S_1)$	1.00
$V(S_1 \geq S_3)$	1.00	$V(S_2 \geq S_3)$	1.00
$V(S_1 \geq S_4)$	1.00	$V(S_2 \geq S_4)$	1.00
$V(S_3 \geq S_i)$	value	$V(S_4 \geq S_i)$	value
$V(S_3 \geq S_1)$	0.72	$V(S_4 \geq S_1)$	0.70
$V(S_3 \geq S_2)$	0.74	$V(S_4 \geq S_2)$	0.70
$V(S_3 \geq S_4)$	1.00	$V(S_4 \geq S_3)$	0.94

6.2. Priority of energy technologies against high oil prices in the ETRM

We calculate the weights of energy technologies against high oil prices in ETRM.

We calculate TFN values of 6 energy technologies against high oil prices by using the fuzzy evaluation values in Table 6. Building technology, industry technology, transportation technology, coal technology, non-conventional technology, and Biomass technology stand for BuT, InT, TT, CT, NCT, and BioT respectively.

TFN values of energy technologies against high oil prices related to economic spin-off are as follow:

S_1(BuT)
=(8.90,10.40,12.00) ⊗ (1/49.61,1/43.09,1/37.75)
=(8.90 × 1/49.61,10.40 × 1/43.09,12.00 × 1/37.75)
=(0.18,0.24,0.32)
S_2(InT)
=(5.91,6.63,7.73) ⊗ (1/49.61,1/43.09,1/37.75)
=(0.12,0.15,0.20)
S_3(TT)
=(7.31,8.50,9.83) ⊗ (1/49.61,1/43.09,1/37.75)
=(0.15,0.20,0.26)
S_4(CT)
=(8.06,9.20,10.47) ⊗ (1/49.61,1/43.09,1/37.75)
=(0.16,0.21,0.28)
S_5(NCT)
=(4.28,4.75,5.42) ⊗ (1/49.61,1/43.09,1/37.75)
=(0.09,0.11,0.14)
S_6(BioT)
=(3.28,3.62,4.17) ⊗ (1/49.61,1/43.09,1/37.75)
=(0.07,0.08,0.11)

We compare the values of S_i respectively and calculate the degree of possibility of $S_j = (l_j, m_j, u_j) \geq S_i = (l_i, m_i, u_i)$ by the formula (8) related to economic spin-off. Table 7 shows the values of $V(S_j \geq S_i)$ related to economic spin-off.

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

Table 7
Values of $V(S_j \geq S_i)$ related to economic spin-off.

$V(S_1 \geq S_i)$	Value	$V(S_2 \geq S_i)$	Value
$V(S_1 \geq S_2)$	1.00	$V(S_2 \geq S_1)$	0.23
$V(S_1 \geq S_3)$	1.00	$V(S_2 \geq S_3)$	0.57
$V(S_1 \geq S_4)$	1.00	$V(S_2 \geq S_4)$	0.42
$V(S_1 \geq S_5)$	1.00	$V(S_2 \geq S_5)$	1.00
$V(S_1 \geq S_6)$	1.00	$V(S_2 \geq S_6)$	1.00
$V(S_3 \geq S_i)$	value	$V(S_4 \geq S_i)$	value
$V(S_3 \geq S_1)$	0.65	$V(S_4 \geq S_1)$	0.78
$V(S_3 \geq S_2)$	1.00	$V(S_4 \geq S_2)$	1.00
$V(S_3 \geq S_4)$	0.86	$V(S_4 \geq S_3)$	1.00
$V(S_3 \geq S_5)$	1.00	$V(S_4 \geq S_5)$	1.00
$V(S_3 \geq S_6)$	1.00	$V(S_4 \geq S_6)$	1.00
$V(S_5 \geq S_i)$	value	$V(S_6 \geq S_i)$	value
$V(S_5 \geq S_1)$	0.00	$V(S_6 \geq S_1)$	0.00
$V(S_5 \geq S_2)$	0.36	$V(S_6 \geq S_2)$	0.00
$V(S_5 \geq S_3)$	0.00	$V(S_6 \geq S_3)$	0.00
$V(S_5 \geq S_4)$	0.00	$V(S_6 \geq S_4)$	0.00
$V(S_5 \geq S_6)$	1.00	$V(S_6 \geq S_5)$	0.48

$D'(1) = \min V(S_1 \geq S_2, S_3, S_4, S_5, S_6) = \min(1.00,1.00,1.00,1.00,1.00) = 1.00$

$D'(2) = \min V(S_2 \geq S_1, S_3, S_4, S_5, S_6) = \min(0.23,0.57,0.42,1.00,1.00) = 0.23$

$D'(3) = \min V(S_3 \geq S_1, S_2, S_4, S_5, S_6) = \min(0.65,1.00,0.86,1.00,1.00) = 0.65$

$D'(4) = \min V(S_4 \geq S_1, S_2, S_3, S_5, S_6) = \min(0.78,1.00,1.00,1.00,1.00) = 0.78$

$D'(5) = \min V(S_5 \geq S_1, S_2, S_3, S_4, S_6) = \min(0.00,0.36,0.00,0.00,1.00) = 0.00$

$D'(6) = \min V(S_6 \geq S_1, S_2, S_3, S_4, S_5) = \min(0.00,0.00,0.00,0.00,0.48) = 0.00$

Then the weight vector concerning to economic spin-off is like that.

$W' = (1.00, 0.23, 0.65, 0.78, 0.00, 0.00)^T$

We normalize the weight vectors of economic spin-off. That is as follows.

$W = (0.38,0.09, 0.24, 0.29, 0.00, 0.00)^T$

We can calculate the normalized the weight vectors of commercial potential, inner capacity, and technical spin-off by using the formular from 4 through 8 with same approaches.

The normalized weight vectors of commercial spin-off are as follows.

$W = (0.21, 0.16, 0.21, 0.21, 0.09, 0.12)^T$

The normalized weight vectors of inner capacity are described as follows.

$W = (0.20, 0.18, 0.25, 0.22, 0.07, 0.09)^T$

The normalized weight vectors of technical spin-off are presented as follows.

Table 6
Fuzzy evaluation of 6 energy technologies related to economic spin-off.

Tech	But	InT	TT	CT	NFT	BioT
BuT	(1.00,1.00,1.00)	(1.23,1.60,2.00)	(0.87,1.00,1.20)	(1.10,1.20,1.30)	(2.20,2.60,3.00)	(2.50,3.00,3.50)
InT	(0.57,0.70,0.90)	(1.00,1.00,1.00)	(1.11,0.80,0.97)	(0.79,1.00,1.00)	(1.20.1.53,1.60)	(1.23,1.60,2.00)
TT	(0.87,1.00,1.20)	(0.91,1.10,1.33)	(1.00,1.00,1.00)	(1.00,1.00,1.00)	(1.63.2.00,2.40)	(1.90,2.40,2.90)
CT	(0.93,1.00,1.10)	(0.79,1.00,1.27)	(1.00,1.00,1.00)	(1.00,1.00,1.00)	(2.03,2.40,2.80)	(2.03,2.80,3.30)
NFT	(0.45,0.50,0.58)	(0.76,0.80,0.87)	(0.54,0.65,0.82)	(0.50,0.60,0.75)	(1.00,1.00,1.00)	(1.03,1.20,1.40)
BioT	(0.31,0.37,0.46)	(0.52,0.60,0.73)	(0.36,0.45,0.59)	(0.33,0.40,0.51)	(0.76,0.80,0.87)	(1.00,1.00,1.00)

-Building technology(BuT).
-Industry technology(InT).
-Transportation technology(TT).
-Coal technology(CT).
-Non-conventional fuel technology(NFT).
-Biomass technology(BioT).

Table 8
Weights of energy technology against high oil prices related to 4 criteria.

Tech	EP	CP	IC	TC
BuT	0.38	0.21	0.20	0.25
InT	0.09	0.16	0.18	0.07
TT	0.24	0.21	0.25	0.20
CT	0.29	0.21	0.22	0.20
NFT	0.00	0.09	0.07	0.14
BioT	0.00	0.12	0.09	0.14

Table 9
Overall weight and rank of energy technologies against high oil prices.

Tech	EP	CP	IC	TC	Overall weight	Rank
BuT	0.11	0.06	0.04	0.05	0.27	1
InT	0.03	0.05	0.04	0.01	0.12	4
TT	0.07	0.06	0.05	0.04	0.23	3
CT	0.09	0.06	0.05	0.04	0.24	2
NFT	0.00	0.03	0.01	0.03	0.07	6
BioT	0.00	0.03	0.02	0.03	0.08	5

$W = (0.25, 0.07, 0.20, 0.20, 0.14, 0.14)^T$

Table 8 presents the weights of energy technologies against high oil prices related to 4 criteria. Table 9 shows the overall weight and rank of energy technologies against high oil prices in the ETRM by multiplying each column value with the 4 criteria relative weights. In the sector of energy technologies against high oil prices, building technology is the most preferred technology, followed by coal technology and transporation technology.

7. Conclusions

ETRM is a long-term strategic plan coping with 10 years from 2006 to 2015. We focus on the prioritization of the strategic energy technology development as the only government invested research institute related to develop energy technologies with well focused R&D and the production of world class research outcomes, which contribute to the commercialization and transfer for energy technology in domestic or overseas companies, instead of outputs, which are just the quantitative of SCI papers and patents. We need to allocate our finite R&D budgets with strategic approach.

In this research, we prioritize the energy technologies against high oil prices in the ETRM by using the fuzzy AHP approach. It reflects the human thoughts with vagueness of real world decision making problems comparing with AHP, which evaluates the weights with crisp numbers. We use the fuzzy AHP approach to assess and prioritize the strategic energy technology development in the sector of energy policy for the first time.

The results of this research are calculated by a scientific procedure, which is one of MCDM method. This study also provides the optimal alternatives with Korean policy makers as the assessment of energy technology against high oil prices in the ETRM. In addition, this approach, which uses the fuzzy AHP method, can be used in the various sectors including energy policy making, decision making, and technology management in the real world problems usefully.

For further study, we will carry out the integrated fuzzy AHP and DEA approach, which measures the relative efficiency of energy technologies integrating multiple input and output variables simultaneously from an econometric view point (Lee, Mogi, & Kim, 2008c, 2008d; 2009b; Lee, Mogi, Koike, Hui, & Kim, 2009).

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Nomenclature

AHP: Analytic hierarchy process
CP: Commercial potential
ES: Economic spin-off
ETRM: Energy technology roadmap
IC: Inner capacity
MCDM: Multi-criteria decision making
TFN: Triangular fuzzy number
TS: Technical spin-off
UNFCCC: United nations framework convention on climate change