

A Fuzzy AHP/DEA Hybrid Model for Allocating Energy R&D Resources Efficiently: In Case of Energy Technologies Against High Oil Prices

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ABSTRACT: To provide Korea's energy security and sustainable development, KIER needs a long term strategic technology roadmap for energy R&D program. In this paper, we establish a strategic technology roadmap against high oil prices considering 5 criteria, which are economic impact, commercial potential, inner capacity, technical spin-off, and development cost. In this research, we suggest two-stage assessment model for measuring the relative efficiency of energy technologies against high oil prices. A fuzzy analytic hierarchy process, reflects the vagueness of human thoughts instead of crisp numbers, allocates the relative weights of criteria and data envelopment analysis measures the relative efficiency of energy technologies against high oil prices. With the scientific decision making approach, we can allocate R&D resources for well focused R&D outputs effectively.

Keywords: Energy technology development, Fuzzy analytic hierarchy process, Data envelopment analysis, Multi-criteria decision making

NOMENCLATURE

AHP: Analytic hierarchy process
CP: Commercial potential
DC: Development cost
DEA: Data envelopment analysis
DMU: Decision making unit
EI: Economic impact

ETRM: Energy technology roadmaps
HVAC: Heating, ventilating and air conditioning
IC: Inner capacity
MCDM: Multi-criteria decision making
TFN: Triangular fuzzy number
TS: Technical spin-off

1. INTRODUCTION

Korea's economy has been easily affected by oil prices change because Korea is poor natural resources and world 10th largest energy consuming nation depending on imports of energy resources. In addition, oil prices has become over \$100 U.S dollars these days. The interests of energy technology development have increased by dint of Korea's poor energy environments.

We establish strategic energy technology roadmaps (ETRM) in the sector of high oil prices coping with next 10 years from 2006 to 2015. Strategic energy technology development is one of the optimal alternatives to solve Korea's energy environment.

We analyzed the world energy outlook to make ETRM against high oil prices and provide energy policy directions in 2005[1]. It focuses on developing energy technology considering Korea's energy circumstance. We make a list of criteria for assessing energy technologies against high oil prices. The 5 criteria include economic impact (EI), and commercial potential (CP), inner capacity (IC), technical spin-off (TS), and development cost (DC). ETRM supplies primary energy technologies to be developed with a long-term view. We suggest Korea's long-term direction and strategy for developing energy technology against high oil prices in the sector of ETRM. The main purpose of this research is to prioritize the weights of energy technology against high oil prices as we allocate the finite R&D budget effectively. We use the two stage-models with the fuzzy AHP and DEA approach. The fuzzy AHP generates the relative weights of low levels of energy technologies against high oil prices. And a DEA approach measures the relative efficiency of them.

The paper is composed as follows: Section 2 presents the concept of fuzzy sets and numbers. Section 3 includes the fuzzy AHP process and DEA approach. Section 4 presents hierarchy of criteria. Section 5

describes the classification of energy technologies against high oil prices. Section 6 shows the numerical examples of energy technologies against high oil prices. Finally, Section 7 presents the conclusion.

2. EXECUTION FLOW CHART

The execution flow chart is composed of 6 phases. Fig. 1 shows the schematic of the execution flow chart. In the first phase, we analyzed the energy policy, energy environment, and a short list of energy technologies against high oil prices. The 2nd phase consists of the formulation of a list of criteria used to weigh the relative importance of criteria and alternatives.

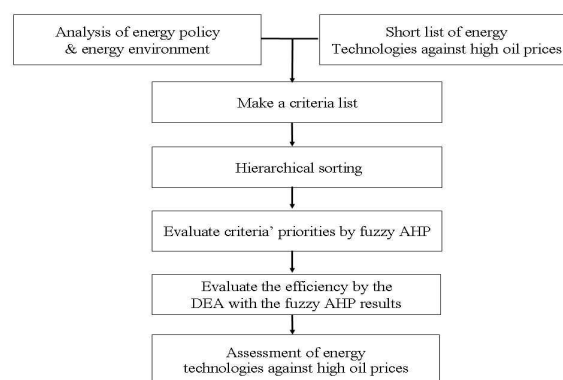


Figure 1: Execution flow chart

In the 3rd phase, the hierarchy structure was built, and the criteria sorted. In the 4th phase, criteria weights of energy technologies against high oil prices were calculated with the use of the fuzzy AHP process. During the 5th phase, the efficiency of energy technologies against high oil prices was measured using the DEA approach. Finally, the efficiency values produced in the 5th phase were evaluated and aggregated in the 6th phase. In this research, the fuzzy AHP/DEA hybrid model is used to measure the relative efficiency of energy technologies against high oil prices with two multi-criteria decision making methods.

3. 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 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 pair-wise comparisons matrix. In this research, we use triangular fuzzy numbers (TFN) to prioritize energy technologies against high oil prices 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:

$$(l_1, m_1, u_1) \oplus (l_2, m_2, u_2) = (l_1 + l_2, m_1 + m_2, u_1 + u_2) \quad (1)$$

$$(l_1, m_1, u_1) \otimes (l_2, m_2, u_2) = (l_1 \times l_2, m_1 \times m_2, u_1 \times u_2) \quad (2)$$

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

4. FUZZY AHP AND DEA APPROACH

4.1 Fuzzy AHP

The analytic hierarchy process (AHP) is a subjective method for analyzing qualitative criteria to weight the alternatives. Saaty suggested AHP as a decision making tool to resolve unstructured problems since 1977[2]. Generally, decision making involves various tasks such as planning[3], selecting a best policy after evaluating a set of alternatives[4], 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 by perception or preference, AHP still cannot reflect the human thoughts totally with crisp numbers. Therefore, fuzzy AHP, which is a fuzzy extension of AHP, is applied to solve the hierarchical fuzzy decision making problems. Fig. 2 shows the hierarchy of criteria.

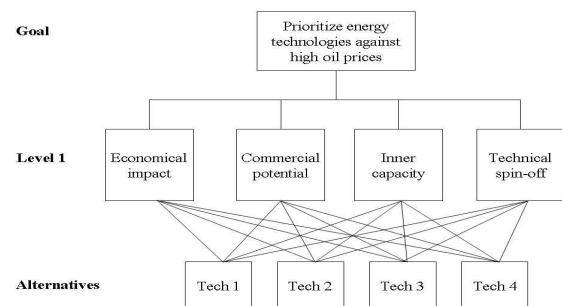


Figure 2: Hierarchy of the fuzzy AHP

To evaluate and prioritize the weights of low level of energy technologies, we compose of 4 criteria in the first stage,

which are economical impact, commercial potential, inner capacity, and technical spin-off. Energy technologies against high oil prices are evaluated by the 1-tier criteria.

Fuzzy scale for pairwise comparisons of one attribute over another is shown in Table I [5]. We use the fuzzy scale when decision makers make pairwise comparisons.

Table I: 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 $M_{ji} = (l_{ij}, m_{ij}, u_{ij})$ be a TFN. The step of fuzzy AHP is as follows:

Step 1: We make pairwise comparisons of attributes by using the fuzzy numbers in the same level of hierarchy structure.

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

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

$$\text{s.t.} \quad \sum_{j=1}^m M_{ij} = \left(\sum_{j=1}^m l_{ij}, \sum_{j=1}^m m_{ij}, \sum_{j=1}^m u_{ij} \right) \quad (5)$$

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

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

We calculate TFN value of $S_i = (l_i, m_i, u_i)$ 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:

$$V(S_j \geq S_i) = \text{height}(S_i \cap S_j) = u_{S_j}(d) = \begin{cases} 1, & \text{if } m_j \geq m_i \\ 0, & \text{if } l_i \geq u_j \\ \frac{l_i - u_j}{(m_j - u_j) - (m_i - l_i)}, & \text{otherwise} \end{cases} \quad (8)$$

where d is the ordinate of the highest intersection point between uS_i and uS_j . 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_j .

Step 4: We calculate the minimum degree possibility $d(i)$ of $V(S_j \geq S_i)$ for $i, j = 1, 2, \dots, k$. $V(S \geq S_1, S_2, S_3, \dots, S_k)$, for $i = 1, 2, 3, \dots, k$ $= V[(S \geq S_1) \text{ and } (S \geq S_2) \text{ and } \dots \text{ and } (S \geq S_k)]$

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

Assume that

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

Then the weight vector is defined as

$$W' = (d'(A_1), d'(A_2), \dots, d'(A_n))^T \quad (10)$$

where $A_i (i = 1, 2, \dots, n)$ are the n elements.

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

$$W = (d(A_1), d(A_2), \dots, d(A_n))^T \quad (11)$$

where W is a non-fuzzy number.

4.2 DEA approach

Data Envelopment Analysis is an evaluation tool used in conjunction with decision making units (DMUs) that effectively solves many decision making problems by simultaneously integrating multiple inputs and outputs. This mathematical method has enjoyed a wide range of applications since 1978. The DEA is generally applied not only to assess the service productivity of banks [6], insurance companies (Mahajan et al, 1991), hospitals [7], universities [8] and restaurants, but also to evaluate the efficiency of R&D programs [9]. Fig. 3 shows the hierarchy structure of the DEA process, which consists of a single input factor and multiple output factors. The

input factor consists of the development cost associated with the development of hydrogen economy technologies. There are four output factors, namely economical impact, commercial potential, inner capacity, and technical spin-off. The relative weights calculated using the fuzzy AHP approach, are applied in conjunction with the output factors employed as part of the DEA approach.

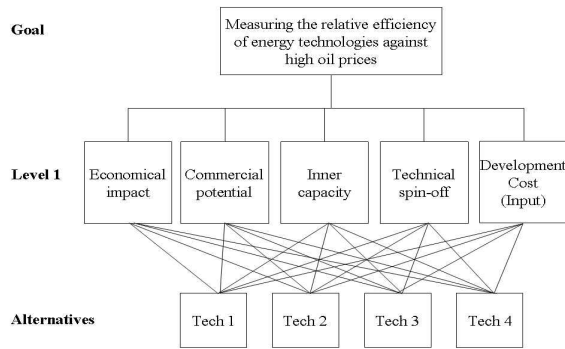


Figure 3: Hierarchy of the DEA approach

The DEA ration form, proposed by Charnes, Cooper and Rhodes (1978) [10], is designed to measure the relative efficiency or productivity of a specific DMU_k. The DEA formulation is given as follows. Suppose that there is a set of n DMUs to be analyzed, each of which uses m common inputs and s common outputs. Let k ($k=1, \dots, n$) denote the DMU whose relative efficiency or productivity is to be maximized.

$$\text{Max } h_k = \frac{\sum_{r=1}^s u_{rk} Y_{rk}}{\sum_{i=1}^m v_{ik} X_{ik}} \quad (12)$$

$$\text{s.t. } \frac{\sum_{r=1}^s u_{rk} Y_{rk}}{\sum_{i=1}^m v_{ik} X_{ik}} \leq 1, \text{ for } j = 1, \dots, n \quad (13)$$

$$u_{rk} > 0, \text{ for } r = 1, \dots, s \quad (14)$$

$$v_{ik} > 0, \text{ for } i = 1, \dots, m \quad (15)$$

where u_{rk} is the variable weight given to the r^{th} output of the k^{th} DMU, v_{ik} is the variable

weight given to the i^{th} input of the k^{th} DMU, u_{rk} and v_{ik} are decision variables determining the relative efficiency of DMU_k, Y_{rj} is the r^{th} output of the j^{th} DMU, and X_{ij} is the i^{th} input of the j^{th} DMU. This also assumes that all Y_{rj} and X_{ij} are positive. h_k is the efficiency score, and is less than and equal to 1. When the efficiency score of h_k is 1, DMU_k is regarded as an efficient frontier.

There are two types of CCR models. One version is the input oriented model, in which inputs are maximized, and the other is the output oriented model in which the outputs are maximized.

As the focus is on maximizing multiple outputs, this paper employs the output-oriented CCR model.

5. CLASSIFICATION OF ENERGY TECHNOLOGIES AGAINST HIGH OIL PRICES

Energy technologies against high oil prices are shown in Table II.

Table II: Classification of Energy Technologies Against High Oil Prices

High-level	Low-level	Shortlisted energy tech
Technologies for high oil prices	Building tech	Lighting tech
		HVAC tech
		Building envelope tech
		Building system tech
	Industry tech	Common tech
		Waste heat tech
		Refinery/Petroleum/Fine chemical tech
Transportation tech	Vehicle tech	
Coal tech		Direct utilization tech
		Conversion utilization tech
Non-conventional fuel tech		Oil shale/Oil sand tech
		Pyrolysis/Gasification tech of waste
Biomass tech		Direct utilization tech
		Conversion tech

6. NUMERICAL EXAMPLES

6.1 Priority of Criteria

We make pairwise comparisons of 4 criteria to assess energy technologies against high oil prices. Table III shows the fuzzy evaluation matrix with response to the goal.

Economical impact, commercial potential, inner capacity, and technical spin-off stand for EI, CP, IC, and TS respectively.

Table III: Fuzzy Evaluation of Goal

	EI	CP	IC	TS
EI	(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) .
CP	(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) .

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

Table IV: Fuzzy Evaluation of Criteria

	EI	CP	IC	TS
EI	(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)

We calculate TFN values of 4 criteria by using the fuzzy evaluation values in Table IV. TFN values of criteria are as follow:

$S_1(EI)$

$$= (3.97, 4.60, 5.40) \otimes (1/20.20, 1/16.60, 1/14.01) \\ = (3.97 \times 1/20.2, 4.60 \times 1/16.60, 5.40 \times 1/14.01) \\ = (0.20, 0.28, 0.39)$$

$S_2(CP)$

$$= (3.97, 4.60, 5.40) \otimes (1/20.20, 1/16.60, 1/14.01) \\ = (0.20, 0.28, 0.39)$$

$S_3(IC)$

$$= (3.23, 3.80, 4.67) \otimes (1/20.20, 1/16.60, 1/14.01) \\ = (0.16, 0.23, 0.33)$$

$S_4(TS)$

$$= (2.85, 3.60, 4.73) \otimes (1/20.20, 1/16.60, 1/14.01) \\ = (0.14, 0.22, 0.34)$$

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 V shows the values of $V(S_j \geq S_i)$.

Table V: Values of $V(S_j \geq S_i)$

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

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

$D'(1)$

$$= \min V(S_i \geq S_2, S_3, S_4) \\ = \min(1.00, 1.00, 1.00) = 1.00$$

$D'(2)$

$$= \min V(S_2 \geq S_1, S_3, S_4) \\ = \min(1.00, 1.00, 1.00) = 1.00$$

$D'(3)$

$$= \min V(S_3 \geq S_1, S_2, S_4) \\ = \min(0.72, 0.74, 1.00) = 0.72$$

$D'(4)$

$$= \min V(S_4 \geq S_1, S_2, S_3) \\ = \min(0.70, 0.70, 0.94) = 0.70$$

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, EI, CP, IC, and TS, are 0.29, 0.29, 0.21, and 0.20 respectively. In 4 criteria, EI and CP are the most preferred criteria comparing with the other criteria.

6.2 Quantitative data of shorted listed energy technologies

Shored listed energy technologies against high oil prices are classified based on a 10-point scale. Table VI shows the 10-point scale for inner capacity and technical spin-off. The numbers 2, 4, 6, 8 and 10, which correspond to the extent of the preference for one element over the others, are used herein as scaling ratios.

Table VI: 10-point Scale for IC and TS

Scale	Definition
2	Inner capacity and technical spin-off are at an extremely low level
4	Inner capacity and technical spin-off are at a low level
6	Inner capacity and technical spin-off are at a medium level
8	Inner capacity and technical spin-off are at a high level
10	Inner capacity and technical spin-off are at an extremely high level
1, 3, 5, 7, 9	Intermediate values are used to compromise between two judgements

Table VII and VIII display, respectively, the 10-point scale for economical impact and commercial potential.

Table VII: 10-point Scale for EI

Scale	Definition
2	Potential energy saving is less than 10,000 TOE/year, CO ₂ emission reduction is less than 10,000 tCO ₂ /year
4	Potential energy saving is between 10,000 and 500,000 TOE/year, CO ₂ emission reduction is between 10,000 and 500,000 tCO ₂ /year
6	Potential energy saving is between 500,000 and 1,000,000 TOE/year, CO ₂ emission reduction is between 500,000 and 1,000,000 tCO ₂ /year
8	Potential energy saving is between 1,000,000 and 2,000,000 TOE/year, CO ₂ emission reduction is between 1,000,000 and 5,000,000 tCO ₂ /year
10	Potential energy savings is greater than 2,000,000 TOE/year, CO ₂ emission reduction is greater than 5,000,000 tCO ₂ /year
1, 3, 5, 7, 9	Intermediate values are used to compromise between two judgements

Table VIII: 10-point Scale for CP

Scale	Definition
2	Phase of quickening technology development, need arises to research new technological concepts
4	Phase of technology development, compent technologies need to be developed
6	Core patent acquirement phase
8	Commercialization phase, core patents can be obtained and technologies commercialized within 3 to 5 years
10	Technological dissemination phase, core patents can be acquired and technologies dissiminated within 3 years
1, 3, 5, 7, 9	Intermediate values are used to compromise between two judgements

Table IX: Single input and multi-outputs against high oil prices

Low-level	Shortlisted energy tech	Inputs DC(mil KRW)	Outputs EI CP IC TS			
Building tech	Lighting tech	550	7.0	7.0	7.0	7.0
	HVAC tech	2,520	7.0	8.0	6.0	7.0
	Building envelope tech	700	8.0	7.0	8.0	8.0
	Building system tech	2,150	8.0	7.0	8.0	8.0
Industry tech	Common tech	4,500	8.0	8.0	8.0	9.0
	Waste heat tech	600	7.0	8.0	5.0	7.0
	Refinery/Petroleum/ Fine chemical tech	805	6.0	7.0	7.0	7.0
Transportation tech	Vehicle tech	1,720	7.0	6.0	6.0	7.0
Coal tech	Direct utilization tech	3,500	7.0	7.0	8.0	8.0
	Conversion utilization tech	700	9.0	8.0	8.0	9.0
Non-Conventional fuel cell tech	Oil shale/Oil sand tech	1,500	8.0	5.0	4.0	7.0
	Pyrolysis/Gasification tech of waste	1,275	9.0	8.0	9.0	9.0
Biomass	Direct utilization tech	400	5.0	7.0	7.0	5.0
	Conversion tech	527	6.0	6.0	7.0	5.0

As shown in Table IX, a single input and multiple outputs data, which is short listed energy technologies against high oil prices, are described. Table IX is multiplied by the

fuzzy AHP results for measuring the relative efficiency of energy technologies against high oil prices using the DEA approach.

Table X shows the preferred data applied to the fuzzy AHP criteria' relative weights, which 4 multiple inputs data were changed.

Table X: Preferred data applied to the fuzzy AHP criteria' relative weights

Low-level	Shortlisted energy tech	Inputs DC(mil KRW)	Outputs EI CP IC TS			
Building tech	Lighting tech	550	2.03	2.03	1.47	1.47
	HVAC tech	2,520	2.03	2.32	1.26	1.47
	Building envelope tech	700	2.32	2.03	1.68	1.68
	Building system tech	2,150	2.32	2.03	1.68	1.68
Industry tech	Common tech	4,500	2.32	2.32	1.68	1.89
	Waste heat tech	600	2.03	2.32	1.05	1.47
	Refinery/Petroleum/ Fine chemical tech	805	1.74	2.03	1.47	1.47
Transportation tech	Vehicle tech	1,720	2.03	1.74	1.26	1.47
Coal tech	Direct utilization tech	3,500	2.03	2.03	1.68	1.68
	Conversion utilization tech	700	2.61	2.32	1.68	1.89
Non-Conventional fuel cell tech	Oil shale/Oil sand tech	1,500	2.32	1.45	0.84	1.47
	Pyrolysis/Gasification tech of waste	1,275	2.61	2.32	1.89	1.89
Biomass	Direct utilization tech	400	1.45	2.03	1.47	1.05
	Conversion tech	527	1.74	1.74	1.47	1.05

6.3 Relative efficiency of energy technologies against high oil prices

We calculate the relative efficiency of energy technologies against high oil prices by using the DEA approach in the second stage.

Table XI: Efficiency Scores and Ranks

Low-level	Shortlisted energy tech	Efficnecy score	Rank
Building tech	Lighting tech	0.996	3
	HVAC tech	0.219	12
	Building envelope tech	0.894	6
	Building system tech	0.291	11
Industry tech	Common tech	0.156	14
	Waste heat tech	0.920	4
	Refinery/Petroleum/Fine chemical tech	0.681	7
Transportation tech	Vehicle tech	0.317	10
Coal tech	Direct utilization tech	0.179	13
	Conversion utilization tech	1.000	1
Non-Conventional fuel cell tech	Oil shale/Oil sand tech	0.415	9
	Pyrolysis/Gasification tech of waste	0.552	8
Biomass	Direct utilization tech	1.000	1
	Conversion tech	0.899	5

Table XI presents the efficiency scores and ranks of energy technologies against high oil prices.

7. CONCLUSIONS

In this research, we expounded up how energy technologies against high oil prices were measured the relative efficiency scores using the Fuzzy AHP/DEA hybrid model approach, which based on the performance and productivity. On the first stage, we allocate the relative weights of low levels of energy technologies against high oil prices using the fuzzy AHP approach. We measured the relative efficiency scores by the DEA approach in the paper. Fuzzy AHP reflects effectively the human thoughts with vagueness of real world decision making problems comparing with AHP, which just evaluates the relative weights with crisp numbers.

The results of this research are calculated by a scientific procedure of multi-criteria decision making. They can also provide the optimal alternatives for resource allocation and well focused R&D outcomes with energy policy makers as they establish and evaluate the priority and efficiency of energy technologies against high oil prices.

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