INTERNATIONAL JOURNAL OF HYDROGEN ENERGY 35 (2010) 2236–2246

Available at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/he

Econometric analysis of the R&D performance in the national hydrogen energy technology development for measuring relative efficiency: The fuzzy AHP/DEA integrated model approach

Seong Kon Lee [a,*], *Gento Mogi* [b], *Sang Kon Lee* [c], *K.S. Hui* [d], *Jong Wook Kim* [a]

[a] *Energy Policy Research Center, Korea Institute of Energy Research, 71-2, Jang-dong, Yuseong-gu, Daejeon 305-343, Republic of Korea*
[b] *Department of Technology management for innovation, Graduate School of Engineering, The University of Tokyo, 7-3-1, Hongo, Bunkyo-ku, Tokyo 113-8656, Japan*
[c] *PNU-IFAM Joint Research Center, Pusan National University, 30 Jangjeon-Dong, Kumjeong-Gu, Busan 609-735, Republic of Korea*
[d] *Department of Manufacturing Engineering and Engineering Management, City University of Hong Kong, 83 Tat Chee Avenue, Kowloon Tong, Hong Kong*

ARTICLE INFO

Article history:
Received 10 November 2009
Received in revised form
4 January 2010
Accepted 4 January 2010
Available online 1 February 2010

Keywords:
Hydrogen energy competitiveness
Fuzzy AHP
DEA
MCDM

ABSTRACT

Hydrogen energy technology can be one of the best key players related to the sector of the United Nations Framework Convention on Climate Change (UNFCCC) and the hydrogen economy. Comparing to other technologies, hydrogen energy technology is more environmentally sound and friendly energy technology and has great potential as a future dominant energy carrier. Advanced nations including Korea have been focusing on the development of hydrogen energy technology R&D for the sustainable development and low carbon green society. In this paper, we applied the integrated fuzzy analytic hierarchy process (Fuzzy AHP) and the data envelopment analysis (DEA) for measuring the relative efficiency of the R&D performance in the national hydrogen energy technology development. On the first stage, the fuzzy AHP effectively reflects the vagueness of human thought. On the second stage, the DEA approach measures the relative efficiency of the national R&D performance in the sector of hydrogen energy technology development with economic viewpoints. The efficiency score can be the fundamental data for policymakers for the well focused R&D planning.

1. Introduction

U.S., Japan, and the EU have invested significant funds and R&D resources into the development of hydrogen energy technologies which include the production and storage of fuel cell vehicles, the use of fuel cells for power generation and residential purposes, and the development of hydrogen infrastructure. Hydrogen energy technology is one of the most important alternatives preparing for the United Nations Framework Convention on Climate Change (UNFCCC). Hydrogen will be used in portable power generation systems, micro-power systems, transportation applications, residential applications, and industrial and distributed generation systems after 2020 timeframe. Hydrogen would be produced and delivered using the existing infrastructure and would eventually change to renewable sources of energy after 2020. The

* *Corresponding author*. Tel.: +82 42 860 3036; fax: +82 42 860 3097.
E-mail address: sklee@kier.re.kr (S.K. Lee).
0360-3199/$ – see front matter
doi:10.1016/j.ijhydene.2010.01.009

global economy will depend on hydrogen in the future for environmentally sustainable development and the low carbon green growth. As part of its efforts to develop future energy technologies, the Korean government has identified hydrogen energy technologies such as hydrogen and fuel cells as one of the green energy industrializations and sustainable developments for implementing the low carbon green growth of Korea. To this end, Korean government established the Hydrogen Energy R&D Center (HERC) and the National R&D Organization for Hydrogen & Fuel Cells (H2FC) in 2003 and 2004. Korea has focused on strategic investment in the sector of hydrogen and fuel cells development.

In reality, inputs and outputs of real world problems are often imprecise, and it is hard to tackle them with crisp numbers as reflecting human's appraisals related to pairwise comparisons. The AHP, which was developed by Saaty in the early 1970s, is a subjective tool with which to analyze the qualitative criteria needed to generate alternative priorities with 9-point scales [1]. The AHP enables decision makers to structure complex problems in a simple hierarchical form, and to assess a large number of quantitative and qualitative factors in a systematic manner. However, the AHP method is unable to provide the crisp values needed to properly reflect the fuzziness associated with decision-making problems in the real world. Nevertheless, the AHP method has proven to be a powerful decision analysis technique in the area of multi-criteria decision making (MCDM), and has been successfully applied to the tackling of MCDM problems generally. It's utilization area is as follows: R&D planning, the best policy selection, the assessment of alternatives, the allocation of resources, the determination of requirements, the prediction of outcomes, design systems, performance measurement, and the optimization and resolution of decision conflicts. Lee et al. applied the AHP approach to assess national competitiveness in the hydrogen energy technology sector [2,3] and establish national long-term improvements in energy efficiency and GHG control plans related to the Korea's energy policy [4].

To successfully produce well focused R&D outcomes in the hydrogen energy technology R&D sector, it is very meaningful to economically measure national hydrogen energy technology competitiveness. This study is the extension of our previous works [2,3], which aims to analyze Korea's national competitiveness in the hydrogen energy technology R&D sector based on the quantitative data accrued using the integrated fuzzy analytic hierarchy process (fuzzy AHP) and data envelopment analysis (DEA) approaches from an economic viewpoint. On the first stage, we applied the Fuzzy AHP approach to effectively reflect the fuzziness of human thoughts and alternatives. On the second stage, we applied the DEA approach to economically evaluate the relative efficiency and ranking of national R&D performance related to the hydrogen energy technology development sector.

In this study, we employed 4 criteria, namely technological status, R&D human resources, R&D budget, and the hydrogen technology infrastructure, to assess national competitiveness in the hydrogen technology sector. In addition, a peer-review, consisting of 33 experts in the area of hydrogen economy, was conducted, and the weights of pairwise comparisons of the criteria were synthesized. We compared the results of national competitiveness in the hydrogen energy technology sector. The results of this study will provide policy and decision makers with the strategic approach needed to effectuate well focused R&D and to produce an econometrical efficiency outcomes in the hydrogen energy technology R&D sector, as well as the fundamental data required to forge energy policy.

This paper is organized as follows: Section 2 introduces the general knowledge of the fuzzy set and fuzzy numbers. Section 3 describes the fuzzy AHP and the DEA approach. Section 4 deals with the hierarchy of the criteria used to evaluate national competitiveness in the hydrogen energy technology R&D performance sector. Section 5 displays the quantitative data obtained in relation to hydrogen energy technology R&D. Section 6 gives an illustrative example of the integrated fuzzy AHP and DEA approaches. Finally, Section 7 concludes this study.

2. Fuzzy set and fuzzy numbers

In the real world, it is very hard to extract precise data, pertaining to measurement indicators, from human judgments. It is because human preferences encompass a degree of uncertainty, and decision makers may very well be reluctant or unable to assign crisp numerical values to pairwise comparison. Decision makers prefer natural language expressions comparing with the crisp numbers when evaluating criteria and alternatives.

The concept of fuzzy theory was first introduced by Zadeh in 1965 [5]. Fuzzy theory includes elements such as fuzzy set, membership function, and the fuzzy numbers used to efficiently change vague information into useful data. Fuzzy set theory deals with the ambiguous situations well. By approximating information and uncertainty where the generation of reasonable alternatives to problems needing decisions is concerned, it effectively resembles human's fuzziness and perceptions. Fuzzy set theory uses groups of data with boundaries that feature lower, median, and upper values that are not sharply defined. Because most of the decision-making problems in the real world take place amidst situations where pertinent data and the sequences of possible actions are not precisely known, the merit of using the fuzzy approach is that it expresses the relative importance of the alternatives and the criteria with fuzzy numbers rather than crisp ones. A fuzzy set is characterized by a membership function, which assigns a membership range value between 0 and 1 to each criterion and alternative.

Triangular fuzzy numbers (TFN) and trapezoidal fuzzy numbers are usually employed to capture the vagueness of the parameters related to the selection of the alternatives. In order to reflect the fuzziness which surrounds the decision makers when they select alternatives or conduct a pairwise comparison judgment matrix, TFN is expressed with boundaries instead of crisp numbers. In this study, we use TFN to prioritize national competitiveness in the fuzzy hydrogen energy sector. 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: