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The competitiveness of Korea as a developer of hydrogen energy technology: The AHP approach

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Abstract

Korea's need for energy conservation and alternative energy is greater than for any other nation. Korea imports more than 97% of its total energy consumption and ranks 10th in the world in terms of energy consumption. Developing hydrogen energy technology has great potential to cope with Korea's energy security and to establish Korea's hydrogen economy. In this study, we analysed the potential of Korea to be competitive in development of hydrogen energy technology using the analytic hierarchy process (AHP) approach. In this paper, two scenario analyses are presented: in the first, the R&D budget is a criterion and in the second it is not. The results show that Korea is the sixth most competitive nation because of the low score for infrastructure required for hydrogen technology. In addition, compared with US results for both scenarios, patents, papers and proceedings, R&D budgets, and infrastructure for hydrogen technology are inferior to the US, which is ranked in first place for this sector. Korean policymakers have to concentrate on those sectors to strengthen Korea's competitiveness in the development of hydrogen energy technology.

Keywords: Hydrogen energy competitiveness; Technology assessment; AHP

1. Introduction

The US, Japan, and the EU have been strategically investing their R&D budgets developing hydrogen energy technology to establish the hydrogen economy and reduce the dependence on fossil fuel. Developing hydrogen technology has aroused considerable interest since 1973 in Korea because of its great potential as an energy carrier. Korea consumes a large amount of energy, importing more than 97% of the total energy consumed. Korea was ranked 10th in the world for energy consumption. The Korean government has selected hydrogen technology development as one of the next-generation growth drivers. The Ministry of Science and Technology (MOST) launched the Hydrogen Energy R&D Centre in 2003. The Ministry of Commerce, Industry and Energy (MOCIE) established a national R&D organization for hydrogen and fuel cell development in 2004. In this paper, we analyse Korea's competitiveness for hydrogen energy technology using the analytic hierarchy process (AHP) approach. The result will provide Korean energy policymakers with policy advice on strengthening the competitiveness of Korea's hydrogen energy technology.

AHP is a useful method for evaluating multi-criteria decision-making problems. AHP, which was developed by T.L. Saaty in the early 1970s, is a subjective tool for analysing qualitative criteria to generate priorities and preference between alternatives (Saaty, 1980). AHP is used in various decision-making areas such as planning R&D, choosing the best policy alternative, predicting outcomes, measuring performance, and optimizing and resolving decision conflicts (Saaty, 1986). Specifically, Seongkon Lee applied AHP to making long-term improvements in national energy efficiency and greenhouse gas control plans

Abbreviations: AHP, analytic hierarchy process; CI, consistency index; CR, consistency ratio; MOCIE, Ministry of Commerce, Industry and Energy; MOST, Ministry of Science and Technology; RI, random index; SCI, science citation index.

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for the first time in Korean national energy policy (Lee et al., 2007). In AHP, a decision-making process is modelled as a hierarchical structure. At each level of hierarchy, AHP uses pairwise comparison and matrix algebra to identify and prioritize the criteria and alternatives for decision-making. AHP then uses these criteria to determine the relative preference for the alternatives (Saaty, 1992).

We consider six factors to assess Korea's competitiveness in developing hydrogen energy technology. We use four criteria: technological status, R&D human resources, R&D budget, and infrastructure required for hydrogen technology. We create two scenarios, the first using all four criteria and the second excluding the R&D budget.

We apply AHP to weigh the relative importance of criteria under these two scenarios. We chose 33 experts in the hydrogen energy technology sector to peer-review relative weights of pairwise criteria comparisons as a consistency check. The results of this research provide

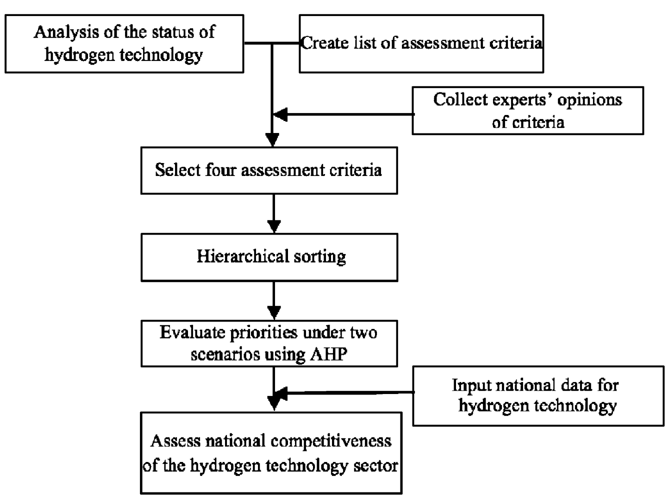

Fig. 1. Execution flow chart.

policymakers and decision-makers with a strategic approach to making up for weak points in developing Korea's hydrogen technology.

This paper comprises the following: Section 2 presents the flow chart describing the execution of AHP. Section 3 describes the AHP concept. Section 4 presents the data related to hydrogen energy technology for each nation. Section 5 presents the numerical examples of scenarios 1 and 2. Finally, Section 6 concludes.

2. Execution flow chart

The execution flow chart for assessing Korea's competitiveness in developing hydrogen technology has five stages. Fig. 1 presents the execution flow chart schematically. In the first stage, we analyse the status of hydrogen technology and list criteria for assessment of national competitiveness. We then reflect on the experts' opinions of these criteria. The second stage selects four criteria: technological status, R&D human resources, R&D budget, and hydrogen technology infrastructure. The third stage sorts the criteria into a hierarchy. The fourth stage uses the AHP approach to evaluate the priorities under the scenarios. Finally, the fifth stage weighs the criteria and determines Korea's competitiveness in developing hydrogen energy technology.

3. Analytic hierarchy process

AHP enables decision-makers to structure a complex problem in the form of a simple hierarchy and to evaluate a large number of quantitative and qualitative factors in a systematic manner under multiple conflicting criteria. AHP is a powerful decision analysis technique in the area of multi-criteria decision-making. AHP makes use of pairwise comparisons, hierarchical structures, and 9-point ratio scaling to apply weights to attributes.

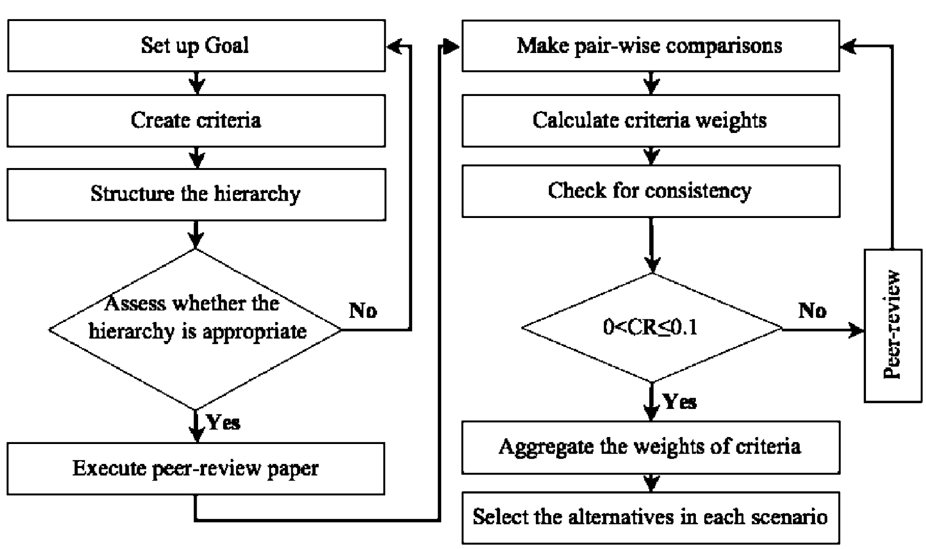

Fig. 2. The AHP process.

AHP decomposes problems into a hierarchy of a goal, attributes, and alternatives. Fig. 2 shows this process. The first stage sets up the goal, the assessment of national competitiveness in the hydrogen technology sector. The second stage creates criteria for assessing the alternatives, and the third stage structures the hierarchy, which breaks down the complex problem into a number of small constituent elements and structures the elements into a hierarchical form. The fourth stage assesses the hierarchical arrangement in terms of the goal. After assessing the hierarchy, we aggregate the weights of our experts into a peer-review paper in the fifth stage. In the sixth stage, we devise our pairwise comparisons, and then calculate criteria weights and check for consistency in the seventh and eighth stages. In the ninth stage, we review the consistency ratio (CR), which should be between 0 and 0.1. If the CR is greater than 0 and less than 0.1, we move to the 10th stage, which aggregates the weights. Finally, we select the alternatives and analyse national competitiveness in the hydrogen technology sector.

The pairwise comparison is conducted using the scale in Table 1. AHP uses an ordinal scaling ratio, in our case, 1, 3, 5, 7, and 9. Each number corresponds to the strength of preference for one element over another. For example, 9 signifies that one element is of extreme importance relative to another element. Generally, the 9-point scale is used because the qualitative distinctions are meaningful in practice and have an element of precision when the items are compared with one another (Saaty, 1980). The ability to make qualitative distinctions is well represented by the five possible points: equal, moderate, strong, very strong, and extreme (Saaty, 1980).

In applying AHP, the decision-maker should be consistent in the preference ratings given in the pairwise comparison matrix. Formulation 1 presents the calculation of the overall weights of the alternatives:

$$\begin{pmatrix} \frac{w_1}{w_1} & \frac{w_1}{w_2} & \cdots & \frac{w_1}{w_n} \\ \frac{w_2}{w_1} & \frac{w_2}{w_2} & \cdots & \frac{w_2}{w_n} \\ \vdots & \vdots & \cdots & \vdots \\ \frac{w_n}{w_1} & \frac{w_n}{w_2} & \cdots & \frac{w_n}{w_n} \end{pmatrix} \begin{pmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{pmatrix} = \begin{pmatrix} nw_1 \\ nw_2 \\ \vdots \\ nw_n \end{pmatrix} \Rightarrow AX = nX. \tag{1}$$

Table 1
Pairwise comparison scale

Scale of importance	Definition	Explanation
1	Equal importance	Two elements contribute equally
3	Moderate importance	One element is slightly favoured over another
5	Strong importance	One element is strongly favoured over another
7	Very strong importance	An element is very strongly favoured over another
9	Extreme importance	One element is most favoured over another
2,4,6,8	The intermediate values	Adjacent to the two scales

Table 2
Random index

Matrix															
Size (n)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.54	1.56	1.57	1.58

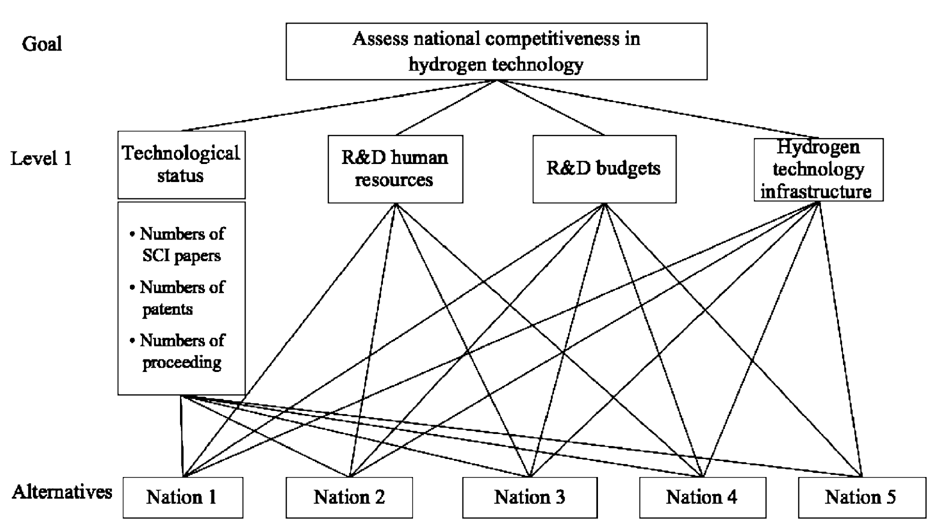

Fig. 3. Hierarchical model to assess criteria and alternatives.

If a_{ij} represents the importance of alternative i over alternative j and a_{ik} represents the importance of alternative i over alternative k, $a_{ik} \cdot a_{jk}$ must be equal to a_{ik}, which is an estimate of the relative weight of alternatives i to k, W_i/W_k. If matrix A is not a non-zero vector, there is a $\lambda_{\max}$ of $Ax = \lambda_{\max}$, which is the largest eigenvector of matrix A. If the pairwise comparison matrix is perfectly consistent, then $\lambda = n$ and CR is 0.

For each alternative, the CR is measured by the ratio of the consistency index (CI) to the random index (RI). Eq. (2) calculates the CI values. The values of RI are also described in Table 2.

$$\mathrm{CI} = \frac{\lambda_{\max} - n}{n-1}, \tag{2}$$

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}}. \tag{3}$$

$\mathrm{CR} \leqslant 0.10$ implies a satisfactory degree of consistency in the pairwise comparison matrix, but if $\mathrm{CR} > 0.10$, serious inconsistencies might exist and AHP might not yield meaningful results (Saaty, 1980).

Assessment of Korea's competitiveness uses one-tier criteria. The hierarchy of criteria is shown in Fig. 3. Our goal is at the top of the control hierarchy. This goal is to assess Korea's competitiveness in developing hydrogen energy technology. At Level 1 are the four criteria: technological status, R&D human resources, R&D budgets, and hydrogen technology infrastructure. Technological status has three sub-criteria: number of science citation index (SCI) papers, patents, and conference proceedings.

4. Quantitative data related to hydrogen energy technology

We collected quantitative data on hydrogen energy on our four criteria. We measured technological status using an index of SCI papers, patents, and conference proceedings. Table 3 shows these data.

The number of SCI papers includes the top 30 journals listed in *Chemical Abstracts* since 2000. For example, representative journals include *International Journal of Hydrogen Energy*, *Journal of Alloys and Compounds*,

Table 3
Quantitative data related to hydrogen technology

Nation	Technological status			R&D human resources	R&D budgets (million dollar)	Hydrogen technology infrastructure
	SCI paper	Patents	Conference proceedings			
Korea	199	69	23	590	22	1
Japan	577	645	92	2663	191	18
China	378	10	13	934	NA	2
Taiwan	51	28	5	167	NA	0
India	73	6	6	161	NA	0
Israel	19	9	2	67	NA	0
Singapore	23	3	3	54	NA	2
Turkey	35	0	0	67	4.6	0
Australia	17	8	2	62	NA	2
USA	571	1023	578	3813	340	43
Canada	127	94	19	429	26	9
Mexico	22	1	0	75	NA	0
Brazil	42	0	1	100	NA	0
Germany	161	201	26	885	76	19
England	77	31	44	405	32	1
France	84	47	2	361	48	1
Italy	95	11	4	327	52	2
Holland	45	15	1	168	36	1
Norway	40	6	1	102	11	0
Switzerland	47	7	3	134	16	1
Sweden	41	3	3	97	NA	1
Russia	37	5	4	157	NA	0
Denmark	28	10	5	94	22	1
Spain	48	1	3	182	12	2
Austria	5	3	3	37	9.1	0
Poland	33	0	0	78	NA	0
Belgium	0	1	0	3	9.2	2
Portugal	12	0	0	36	NA	2
Greece	28	2	0	81	6.1	1
Iceland	0	0	2	4	NA	1
Total	2915	2239	845	12,333	913	114

NA: not available.

Journal of Power Sources, *Applied Catalysis*, *Journal of the American Chemical Society*, and *Fuel Cells*.

The number of patents is calculated by patents registered and opened in the US and Europe since 2000, which includes Korean and Japanese patents that are registered and opened in the US and Europe. We used keyword filtering, international patent code filtering, patentee, and inventor filtering to create our hydrogen production, storage, and utilization patent database.

The number of conference proceedings papers is selected from the top eight listed proceedings in hydrogen production, storage, and utilization from *Chemical Abstracts* since 2000. These eight are *Material Research Society Symposium Proceedings*, *AIP Conference Proceedings*, *American Chemical Society National Meeting*, *Proceedings of SPIE*, *AIChE Annual Meeting*, *International conference of fuel cell science*, *Proceedings—Electrochemical Society*, and *Proceedings of the power sources conference*.

R&D human resources are collected from the number of researchers listed as authors of SCI papers and conference proceedings and researchers nominated in patent applications. Our database includes 31 nations.

Data for R&D budgets for development of hydrogen technology come from IEA/OECD (2004). Korean R&D budgets, which come from the total budgets of MOST and MOCIE in 2004, are \$21.74m (US) at an exchange rate of \$1/1150 KRW. Hydrogen technology infrastructure is measured by the number of hydrogen fuelling stations in each nation (Fuelcells, 2006).

5. Numerical examples

5.1. Scenario 1

In this section, we describe two scenarios. Scenario 1 includes R&D budgets as a criterion shown in Fig. 3. Scenario 2 excludes R&D budgets as a criterion because some nations do not have R&D budgets.

Fifty-one experts affiliated to university, government, industry, and research institutes were solicited as

Table 4
Normalized quantitative data related to hydrogen technology

Nation	Technological status			R&D human resources	R&D budgets (million dollar)	Hydrogen technology infrastructure
	SCI paper	Patents	Conference proceedings			
Korea	0.0683	0.0308	0.0272	0.0478	0.0241	0.0088
Japan	0.1979	0.2881	0.1089	0.2159	0.2092	0.1579
China	0.1297	0.0045	0.0154	0.0757	NA	0.0175
Taiwan	0.0175	0.0125	0.0059	0.0135	NA	0.0000
India	0.0250	0.0027	0.0071	0.0131	NA	0.0088
Israel	0.0065	0.0040	0.0024	0.0054	NA	0.0000
Singapore	0.0079	0.0013	0.0036	0.0044	NA	0.0175
Turkey	0.0120	0.0000	0.0000	0.0054	0.0050	0.0000
Australia	0.0058	0.0036	0.0024	0.0050	NA	0.0000
USA	0.1959	0.4569	0.6840	0.3092	0.3724	0.3772
Canada	0.0436	0.0420	0.0225	0.0348	0.0285	0.0789
Mexico	0.0075	0.0004	0.0000	0.0061	NA	0.0000
Brazil	0.0144	0.0000	0.0012	0.0081	NA	0.0000
Germany	0.0552	0.0898	0.0308	0.0718	0.0832	0.1667
England	0.0264	0.0138	0.0521	0.0328	0.0350	0.0088
France	0.0288	0.0210	0.0024	0.0293	0.0526	0.0088
Italy	0.0326	0.0049	0.0047	0.0265	0.0570	0.0175
Holland	0.0154	0.0067	0.0012	0.0136	0.0394	0.0088
Norway	0.0137	0.0027	0.0012	0.0083	0.0120	0.0000
Switzerland	0.0161	0.0031	0.0036	0.0109	0.0175	0.0088
Sweden	0.0141	0.0013	0.0036	0.0079	NA	0.0088
Russia	0.0127	0.0022	0.0047	0.0127	NA	0.0000
Denmark	0.0096	0.0045	0.0059	0.0076	0.0241	0.0088
Spain	0.0165	0.0004	0.0036	0.0148	0.0131	0.0175
Austria	0.0017	0.0013	0.0036	0.0030	0.0100	0.0000
Poland	0.0113	0.0000	0.0000	0.0063	NA	0.0000
Belgium	0.0000	0.0004	0.0000	0.0002	0.0101	0.0175
Portugal	0.0041	0.0000	0.0000	0.0029	NA	0.0175
Greece	0.0096	0.0009	0.0000	0.0066	0.0067	0.0088
Iceland	0.0000	0.0000	0.0024	0.0003	NA	0.0088
Total	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

NA: not available.

peer-reviewers. We had responses from 33. Nine experts' responses did not satisfy the CR condition of the AHP approach and were excluded from consideration. The remaining 24 experts' responses were used to calculate the weights of the four criteria. These weights are 0.2743, 0.2745, 0.2775, and 0.1737. The technological status criterion comprises three sub-criteria: number of SCI papers, patents, and conference proceedings. The weights of the three sub-criteria are 0.367, 0.542, and 0.091. The final weights of these sub-criteria are multiplied by the weight of technological status. The final relative weights of the number of SCI papers, patents, and conference proceedings are 0.1007, 0.1487, and 0.0249. R&D budgets are the most heavily weighted of the criteria. Number of patents is most heavily weighted of the technological status sub-criteria.

We normalized each column's quantitative hydrogen energy technology data shown in Table 3 by dividing the total values of each column to obtain the relative weights of the four criteria. The normalized data are shown in Table 4. We then multiplied the normalized data by the relative weights of the four criteria to calculate overall weights and ranks for each nation. Table 5 shows the overall weights and ranks of the competitiveness of hydrogen energy technology.

The US (0.3584) is the most competitive nation for hydrogen energy technology, followed by Japan (0.2102), Germany (0.0914), Canada (0.0424), China (0.0379), and Korea (0.0335). The US takes first places in the number of patents and conference proceedings, R&D human resources, R&D budget, and hydrogen technology infrastructure, apart from the number of SCI papers (second place). Japan takes second place in the number of patents and conference proceedings, R&D human resources, and R&D budget, apart from the number of SCI papers (first place). Japanese hydrogen technology infrastructure is placed in third place. Korea takes sixth place given overall weights and normalized data. Specifically, Korea is fifth in the number of patents and conference proceedings, including R&D human resources. The number of SCI papers and R&D budget rank Korea in fourth and ninth places, respectively. Hydrogen technology infrastructure, in 12th place, is the lowest factor for Korea.

5.2. Scenario 2

Scenario 2 shows how excluding R&D budgets affects rankings compared with those of scenario 1. The analysis of scenario 2 did not change the results for the top three nations.

Table 5
Overall weights and ranks in scenario 1

Nation	Technological status			R&D human resources	R&D budgets (million dollar)	Hydrogen technology infrastructure	Weight	Rank
	SCI paper	Patents	Conference proceedings					
Korea	0.0069	0.0046	0.0007	0.0131	0.0067	0.0015	0.0335	6
Japan	0.0199	0.0428	0.0027	0.0593	0.0580	0.0274	0.2102	2
China	0.0131	0.0007	0.0004	0.0208	0.0000	0.0030	0.0375	5
Taiwan	0.0018	0.0019	0.0001	0.0037	0.0000	0.0000	0.0075	15
India	0.0025	0.0004	0.0002	0.0037	0.0000	0.0015	0.0082	14
Israel	0.0007	0.0006	0.0001	0.0015	0.0000	0.0000	0.0028	28
Singapore	0.0008	0.0002	0.0001	0.0012	0.0000	0.0030	0.0053	21
Turkey	0.0012	0.0000	0.0000	0.0015	0.0014	0.0000	0.0041	24
Australia	0.0006	0.0005	0.0001	0.0014	0.0000	0.0030	0.0056	19
USA	0.0197	0.0679	0.0170	0.0849	0.1033	0.0655	0.3584	1
Canada	0.0044	0.0062	0.0006	0.0095	0.0079	0.0137	0.0424	4
Mexico	0.0008	0.0001	0.0000	0.0017	0.0000	0.0000	0.0025	29
Brazil	0.0015	0.0000	0.0000	0.0022	0.0000	0.0000	0.0037	26
Germany	0.0056	0.0133	0.0008	0.0197	0.0231	0.0290	0.0914	3
England	0.0027	0.0021	0.0013	0.0090	0.0097	0.0015	0.0263	9
France	0.0029	0.0031	0.0001	0.0080	0.0146	0.0015	0.0302	8
Italy	0.0033	0.0007	0.0001	0.0073	0.0158	0.0030	0.0303	7
Holland	0.0016	0.0010	0.0000	0.0037	0.0109	0.0015	0.0188	10
Norway	0.0014	0.0004	0.0000	0.0023	0.0033	0.0000	0.0074	16
Switzerland	0.0016	0.0005	0.0001	0.0030	0.0049	0.0015	0.0115	13
Sweden	0.0014	0.0002	0.0001	0.0020	0.0000	0.0015	0.0054	20
Russia	0.0013	0.0003	0.0001	0.0035	0.0000	0.0000	0.0052	22
Denmark	0.0010	0.0007	0.0001	0.0021	0.0067	0.0015	0.0121	12
Spain	0.0017	0.0001	0.0001	0.0041	0.0036	0.0030	0.0126	11
Austria	0.0002	0.0002	0.0001	0.0008	0.0028	0.0000	0.0040	25
Poland	0.0011	0.0000	0.0000	0.0017	0.0000	0.0000	0.0029	27
Belgium	0.0000	0.0001	0.0000	0.0001	0.0028	0.0030	0.0060	18
Portugal	0.0004	0.0000	0.0000	0.0008	0.0000	0.0030	0.0043	23
Greece	0.0010	0.0001	0.0000	0.0018	0.0019	0.0015	0.0063	17
Iceland	0.0000	0.0000	0.0001	0.0001	0.0000	0.0015	0.0017	30

Table 6 shows the overall weights and ranks of scenario 2. The US remains the most competitive nation for hydrogen technology in scenario 2, followed by Japan (0.1522), Germany (0.0683), China (0.0379), Canada (0.0345), and Korea (0.0268). For the top six rankings of Table 6, the Chinese and Canadian ranks are reversed by scenario 2. The US still takes first places in the number of patents and conference proceedings, R&D human resources, and hydrogen technology infrastructure, but not for the number of SCI papers, for which it took second place. Japan also takes second place in the number of patents and conference proceedings and for R&D human resources, but is first for the number of SCI papers. Japanese hydrogen technology infrastructure is in third place. Korea remains in sixth place overall. However, it is in fifth place in the number of patents and conference proceedings, including R&D human resources. The number of Korean SCI papers and hydrogen technology infrastructure are ranked in fourth and 12th place, respectively. The change of criteria between scenarios 1 and 2 did not change Korea's ranking on national competitiveness in hydrogen energy technology.

6. Conclusions

We assessed Korea's competitiveness in developing hydrogen energy technology. We applied the AHP approach to prioritize the relative weights of criteria to assess Korea's competitiveness. We devised a single-tier hierarchy structure, including three sub-criteria, and evaluated competitiveness using four criteria. We evaluated 30 nations' hydrogen energy technology ranking using the AHP approach, which allocates the relative weights of criteria and normalizes quantitative data.

The results indicate that the national competitiveness of the US is the highest, followed by Japan, Germany, Canada, China, and Korea in scenario 1. In scenario 2, we excluded R&D budgets as a criterion of the AHP approach because some nations have no R&D budget. There were slight changes of rank. Chinese and Canadian rankings were reversed between fourth and fifth place, respectively. The US, Germany, Japan, and Korea remained in first, second, third, and sixth places, respectively. Korea's sixth place is due to its lower score for hydrogen technology infrastructure.

Table 6
Overall weights and ranks in scenario 2

Nation	Technological status			R&D human resources	Hydrogen technology infrastructure	Weight	Rank
	SCI paper	Patents	Conference proceedings				
Korea	0.0069	0.0046	0.0007	0.0131	0.0015	0.0268	6
Japan	0.0199	0.0428	0.0027	0.0593	0.0274	0.1522	2
China	0.0131	0.0007	0.0004	0.0208	0.0030	0.0379	4
Taiwan	0.0018	0.0019	0.0001	0.0037	0.0000	0.0075	13
India	0.0025	0.0004	0.0002	0.0037	0.0015	0.0082	11
Israel	0.0007	0.0006	0.0001	0.0015	0.0000	0.0028	26
Singapore	0.0008	0.0002	0.0001	0.0012	0.0030	0.0053	18
Turkey	0.0012	0.0000	0.0000	0.0015	0.0000	0.0027	27
Australia	0.0006	0.0005	0.0001	0.0014	0.0030	0.0056	15
USA	0.0197	0.0679	0.0170	0.0849	0.0655	0.2551	1
Canada	0.0044	0.0062	0.0006	0.0095	0.0137	0.0345	5
Mexico	0.0008	0.0001	0.0000	0.0017	0.0000	0.0025	28
Brazil	0.0015	0.0000	0.0000	0.0022	0.0000	0.0037	23
Germany	0.0056	0.0133	0.0008	0.0197	0.0290	0.0683	3
England	0.0027	0.0021	0.0013	0.0090	0.0015	0.0166	7
France	0.0029	0.0031	0.0001	0.0080	0.0015	0.0156	8
Italy	0.0033	0.0007	0.0001	0.0073	0.0030	0.0145	9
Holland	0.0016	0.0010	0.0000	0.0037	0.0015	0.0078	12
Norway	0.0014	0.0004	0.0000	0.0023	0.0000	0.0041	22
Switzerland	0.0016	0.0005	0.0001	0.0030	0.0015	0.0067	14
Sweden	0.0014	0.0002	0.0001	0.0020	0.0015	0.0054	17
Russia	0.0013	0.0003	0.0001	0.0035	0.0000	0.0052	19
Denmark	0.0010	0.0007	0.0001	0.0021	0.0015	0.0054	16
Spain	0.0017	0.0001	0.0001	0.0041	0.0030	0.0089	10
Austria	0.0002	0.0002	0.0001	0.0008	0.0000	0.0013	30
Poland	0.0011	0.0000	0.0000	0.0017	0.0000	0.0029	25
Belgium	0.0000	0.0001	0.0000	0.0001	0.0030	0.0032	24
Portugal	0.0004	0.0000	0.0000	0.0008	0.0030	0.0043	21
Greece	0.0010	0.0001	0.0000	0.0018	0.0015	0.0044	20
Iceland	0.0000	0.0000	0.0001	0.0001	0.0015	0.0017	29

Although the quantitative data presented in this paper are limited, we have demonstrated Korea's competitiveness in this sector by the AHP process. According to the AHP results, Korea needs to focus on enhancing its hydrogen technology infrastructure. In addition, compared with the US data in both scenarios, patents, conference proceedings, R&D budgets, and hydrogen technology infrastructure are inferior specifically to the US. Korea's hydrogen energy R&D centre and Korean policymakers involved in the development of hydrogen energy technology have to concentrate on technological status, R&D budgets, and hydrogen technology infrastructure to enhance Korea's competitiveness.

Finally, we have provided the decision-makers and policymakers of MOST and MOCIE, Korea, with fundamental data to direct policy to improve Korea's competitiveness in this important sector.

We are now planning to analyse Korea's competitiveness in this sector using the fuzzy AHP approach, which defines the values of pairwise comparisons as range values instead of the crisp numbers used in this paper.

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References

Fuelcells 2006, 2006 ⟨http://www.fuelcells.org/info/charts/h2fuelingstations.pdf⟩.

IEA/OECD, 2004. Hydrogen & fuelcells—reviews of national R&D programs.

Lee, S.K., Yoon, Y.J., Kim, J.W., 2007. A study on making a long-term improvement in the national energy efficiency and GHG control plans by the AHP approach. Energy Policy 35, 2862–2868.

Saaty, T.L., 1980. The Analytic Hierarchy Process, first ed. McGraw-Hill, New York.

Saaty, T.L., 1986. Exploring optimization through hierarchies and ratio scales. Socio-Economic Planning Sciences 20 (6), 355–363.

Saaty, T.L., 1992. How to make a decision: the analytic hierarchy process. European Journal of Operations research 48, 9–26.