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Hydrogen is not an utopia for Turkey

Melih Soner Celiktas [a,*], *Gunnur Kocar* [b]

[a] EBILTEM, Ege University Science & Technology Research Center, 35100 Izmir, Turkey
[b] Solar Energy Institute of Ege University, Izmir Turkey

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ABSTRACT

The aim of this study was to explore how the future of technological developments in hydrogen will be shaped in Turkey by using a two-round Delphi method undertaken to determine and measure the expectations of the sector representatives through online surveys where a total of 60 experts responded from 18 different locations. The article discusses not only the expert sights on hydrogen technologies but also all bibliometrical approaches. The results showed that the hydrogen economy *will enhance* innovations as well as economic prosperities with the support of appropriate policies. Formulating such policies requires a timely and detailed understanding of the latest R&D trends and developments in science and technology policy in all developed countries, and the comprehensive analysis of these developments to enable accurate predictions of future science and technology trends. Therefore, we hope that this study can shed a light on the future use of hydrogen technologies, especially for policy makers.

1. Introduction

Looking at the development of the hydrogen technologies road map from Cavendish to the present day, many research studies [2,12,15,20,24,27,28] have been conducted and reported in the literature. Although many researchers [4,9,10,13,22,25,30] have made significant contributions to improving hydrogen technologies and awareness, the present global energy system is dominated by fossil fuels, and this pattern is expected to continue till 2030. An important question is for how long these business-as-usual projections can continue without running into constraints in the form of limited reserves of fossil fuels, or severe environmental problems from their combustion, including not only global climate change from CO_2 and methane emissions, but also air pollution problems [23].

Holland and Provenzano [19] stated as the age of hydrogen is close at hand. According to Holland and Provenzano, a few decades from now, perhaps by the middle of the twenty first century, hydrogen likely will have replaced oil as the world's primary on-demand energy currency. Or is hydrogen really a utopia [7]?

The aim of this study was to identify the most important hydrogen technologies and research priorities likely to be demanded by the Turkish energy industry and contribute to the achievement of strategic goals in the hydrogen energy sub sectors vital for the national wealth creation, environmental effect and improvement of the quality & security of life. On the other hand, the study was to describe trends in the development of hydrogen energy technologies and to bring out research and development needs in order to reach the priorities identified in the hydrogen energy technologies.

2. Methodology

The Delphi method was developed at the RAND Corporation in the late 1950s and 1960s as an effective means for collecting

* *Corresponding author*. Tel.: +90 (232) 343 44 00; fax: +90 (232) 374 42 89.
E-mail addresses: soner.celiktas@ege.edu.tr (M.S. Celiktas), gunnur.kocar@ege.edu.tr (G. Kocar).
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and synthesizing expert judgments. Since the first RAND study was published 1964. Since the first RAND study was published 1964, the technique has been used very often across a broad spectrum of topics. It is a principal method of futures research and has found application in planning, decision making, and policy research. Participants are carefully chosen for their expertise in some aspect of the problem under study and are promised anonymity with respect to their answers. In general, Delphi studies involve feedback of information from one round to the next, including (for numerically answered questions) the average or median of responses, and typically, reasons furnished by participants for holding extreme positions. The method is certainly not limited to numerical applications, however [17].

The Delphi method is perhaps the best known prospective research method in use today [31]. In a broad sense, the method is a specialized methodology for technology assessment [21]. On the other hand, the method has both characteristics and can be used to define and structure issue exploration as well as to forecast and assess technology trends [11].

In this study, three different methods are used for a multitude of purposes, including: Bibliometric analysis, SWOT analysis and two-round Delphi survey. Bibliometric analysis study [6] was conducted to find out the development trends of the scientific studies in the field of renewable energies in Turkey. In the SWOT analysis [5], different information gathering strategies have been applied for the analysis of Turkish hydrogen energy technologies, market and policies. Delphi statements were developed by using the results obtained from the bibliometric and SWOT analysis. The Survey was thus able to give a comprehensive view of the future of hydrogen energy technologies from basic research to social impact and from subjective and normative points of view to objective and extrapolative perspectives.

The Delphi survey was comprised of two sections, where the first section was designed to cover participants' demographic properties and the second section was dedicated to questioning of nineteen Delphi statements. The foresight period was ascertained as 40 years from today to 2050.

The web-based questionnaire was developed and designed using PHP and MySQL databases. The survey was structured and functionally designed as a web-based, flexible, scalable, analogical and analyzable format which had a user-friendly interface. It was pre-tested with some expert participants from Ege University. Subsequent to considerable refinements made to the survey tool, particularly to the navigational structures, the survey was validated.

Some definitions used in structuring the Delphi questionnaire are given in Table 1. Respondents were asked to assess the time occurrence of Delphi statements for seven time intervals from today to 2050 and never. Regarding times of technological realization, the earliest and latest quarters of the answers were discarded and the half in between was used to obtain a value. The quartile including the top statistically ranked members is called the first quartile and denoted Q1. The centre half (Q1–Q3) is used as the range of answers and the median (Q2) is used as the representative value for achievement. An average time of occurrence of the statements was evaluated after the second round of Delphi. First and third quartiles were used respectively for the evaluation of the time of occurrence.

Table 1 – Some definitions about the Delphi questionnaires.

The terms	Indicate
1	The first round of the questionnaire,
2	The second round of the questionnaire
E	High degree of expertise in the second round of the questionnaire.
Expert	If participant consider yourself to belong to that community of people who currently dedicate themselves to this topic
Knowledgeable	If participants once engaged in research or work related to the topic;
Familiar	If participant know most of the arguments used in discussions on the topic, participants have read about it, and have formed an opinion about it. Or has read technical books or literature about the topic or has listened to experts connected with the topic;
Unfamiliar	Has no expertise
Wealth creation	Is defined as the economic growth of the European economy measured in GNP/capita.
Environment	Is defined as the natural environment, biological diversity, air and water.
Quality of life	Is defined as major advancement in health and safety, education, employment, affordable housing, and cultural and recreational opportunities for most people.
Security of supply	Is defined as robustness of security of energy supply to ensure that European citizens are not exposed to shortages of energy supply and that Europe is not affected by international policy and conflicts in this area.
Standard deviation	Is a measure of the variability or dispersion of a time occurrence between 1st and 2nd round of delphi participants expectations. A low standard deviation indicates that the data points tend to be very close to the same value (the mean), while high standard deviation indicates that the data are spread out over a large range of values.
Time of occurrence	The mean, median, and quartiles are single numbers that help describe how the individual scores in a data set are distributed in value. A data set consists of the observations for some variable is referred to as raw data or ungrouped data.
High importance degree	Extremely important
Medium importance degree	Important
Low importance degree	Somewhat important
Unnecessary importance degree	Not important

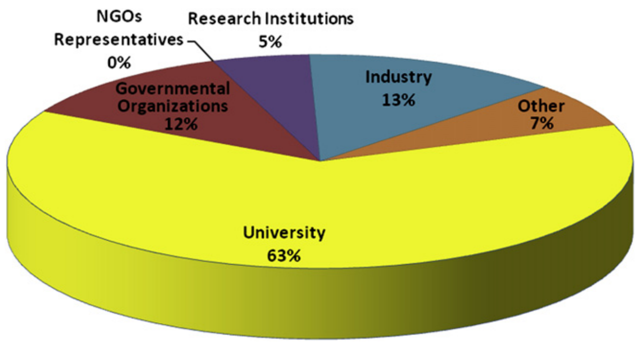

Fig. 1 – Distribution of the Delphi survey participants according to foundations.

Furthermore, the Delphi survey participants were asked to qualify their expertise level for each Delphi statement based on four categories; expert, knowledgeable, familiar and unfamiliar. The respondents were also invited to assess each statement in terms of its impact on the four following elements: Wealth creation, Environment, Life quality and Energy supply safety. The results of the impacts were subsequently weighted using the weights attributed to a particular level. The particular expertise categories and corresponding weight are calculated as (High (expert) responses $\times$ (2) + Knowledgeable responses $\times$ (1) + Familiar responses $\times$ (0) + Unfamiliar responses $\times$ (−1)) $\div$ total responses on impacts (non-responses not included). Finally, overall impact was calculated as overall impact index = [(index of wealth creation impacts)^2 + (index of environmental impacts)^2 + (index of life quality impacts)^2 + (index of Energy supply safety impacts)^2]^{0,5}.

The respondents were asked to assess which of the following actions could promote an early occurrence of the statement:

- Increase in basic R&D,
- Increase in applied R&D,
- A well qualified teaching workforce,
- Fiscal measures (supports, incentives),
- Increase in R&D supports and R&D infrastructure,
- Internationalization of R&D studies,
- Increase in University-Industry-Government grid cooperation,
- Encourage of multidisciplinary studies,

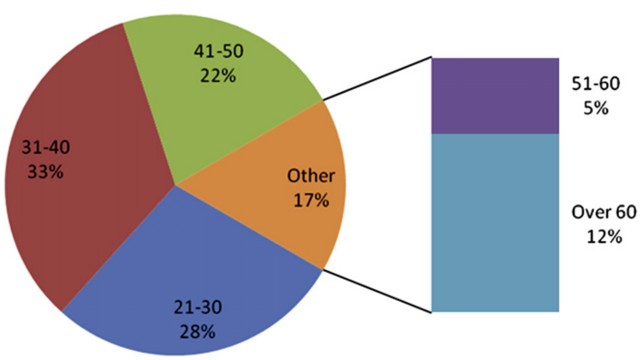

Fig. 2 – Age classification of the Delphi survey participants.

- Legal arrangements (Adjust relevant regulations, standards etc.),
- Increase social awareness (Public acceptance),
- Other

The degree of importance of the statements to Turkey was reflected as a percentage breakdown of respondents who indicated ‘‘high,’’ ‘‘medium,’’ ‘‘low’’ or ‘‘unnecessary’’. The index was worked out from the following equation; the index was accepted as 100 when all respondents indicated ‘‘high’’ and 0 when all indicated ‘‘unnecessary’’. Degree of importance index was calculated as;

Degree of importance index = (number of ‘‘high’’ responses*100 + number of ‘‘medium’’ responses*50 + number of ‘‘low’’ responses*25 + number of ‘‘unnecessary’’ responses*0) $\div$ total number of degree of importance responses.

Finally, all the outcomes of the Delphi survey were evaluated using Access, Microsoft Excel and macros software tools.

3. Results and discussion

A two-round Delphi research study was undertaken to determine and measure the expectations of the technology representatives regarding foresight of hydrogen energies. First and second round of Delphi study was carried out by using online survey, among experts representing different entities of the energy sector. Totally 60 experts from 18 different locations participated in the whole Delphi questionnaire process which shaped out the future of hydrogen energies in Turkey. The list of experts was composed of representatives from industry, science and technology institutes, academia and governmental authorities as well as non-governmental organizations corresponding to all Turkish renewable Energy actors.

The majority of the Delphi survey respondents were from 26 different universities (63%), automotive, textile, consultant, gas distributor, electricity generation industries (13%), six different governmental organizations (12%) research institutions (5%) and other institutions (7%) (Fig. 1). The respondents were classified into 5 different age groups (Fig. 2) and the gender distribution was 76.7% male and 23.3% female.

The time of occurrence was evaluated on the data from the first and second round of the Delphi results which is presented in Fig. 3. The Delphi statements and their time of occurrence were assessed by all participants. The number of the respondents and the distribution (%) were displayed on the left side of the figure. A slight shift towards a later time of occurrence between the first and second round was observed for the majority of the statements which is a typical outcome of the Delphi technique and can be interpreted as a greater degree of consensus among the respondents.

The answers obtained in the second round and experts for all those participants claiming to be either experts, knowledgeable or at least familiar with the topic were displayed on the right hand side of the figure. The bars indicate the statistical distribution of the responses. The distribution gets narrower from the first to the second round, as intended with the Delphi method, thus signifying a higher reliability of the results. The shares of respondents evaluating the corresponding statement

Time of Occurence	No	Statements	Round	Respondent(s)	Expert	Knowledgeable	Familiar	Unfamiliar	Never	Standart Deviation (S)
2020 -2025	15	Boron-based hydrogen storage mechanism has become feasible.	1	52	48	29	17	6	3,8	9,4
			2	46	52	26	17	4	4,3	8,0
			E	24	100				8,3	0,0
	7	Hydrogen production from natural gas using reformer method has been utilised in industrial scale.	1	56	34	32	30	4	7,1	13,1
			2	51	43	25	31	0	5,9	13,4
			E	22	100				0,0	0,0
	14	First hydrogen-fueled internal combustion vehicle is produced by Turkish Automotive industry.	1	52	40	37	17	6	0,0	13,5
			2	46	48	33	17	2	0,0	13,0
			E	22	100				0,0	0,0
	17	H2 Fuel Cell manufacturing technology know-how is available in Turkey.	1	52	38	35	23	4	0,0	12,4
			2	46	46	30	22	2	0,0	12,8
			E	21	100				0,0	0,0
	12	Methane–hydrogen hybrid fuel mixtures have been provided for catalytic combustion process.	1	53	30	32	28	9	1,9	11,0
			2	47	40	26	28	6	2,1	11,2
			E	19	100				0,0	0,0
	2	About 3% of hydrogen is produced from renewables in Turkey.	1	59	39	39	19	3	3,4	11,8
			2	53	43	38	17	2	3,8	11,5
			E	23	100				4,3	0,0
	5	High efficiency hydrogen production has been realised by hydrogen based membrane biofilm reactors.	1	56	25	32	27	16	3,6	12,1
			2	51	35	27	24	14	3,9	12,4
			E	18	100				0,0	0,0
	19	Hydrogen (gained by electrolysis in solar or wind parks) is stored for electricity generation.	1	52	40	33	25	2	7,7	13,7
			2	46	46	26	28	0	8,7	13,9
			E	21	100				9,5	0,0
	13	Nanocomposite catalysts developed for hydrogen generation by methane reforming processes are manufacture in industrial scale.	1	53	34	17	30	19	3,8	11,5
			2	47	38	17	28	17	4,3	11,5
			E	18	100				0,0	0,0
	18	H2 is used in residential buildings for cogeneration of heat and electricity	1	52	35	29	33	4	5,8	13,0
			2	46	43	22	35	0	6,5	13,4
			E	20	100				5,0	0,0
2025 - 2030	3	Industrial scale hydrogen production has started in Turkey.	1	57	44	39	16	2	1,8	13,3
			2	51	53	33	14	0	2,0	14,3
			E	27	100				0,0	0,0
	16	Nanotechnology-based hydrogen sensors have been developed & manufactured.	1	52	27	25	29	19	3,8	12,3
			2	46	39	15	26	20	4,3	12,3
			E	18	100				0,0	0,0
	10	Hydrogen production from biomass has been realised in industrial scale.	1	54	28	33	31	7	5,6	13,0
			2	49	35	31	31	4	6,1	13,1
			E	17	100				0,0	0,0
	4	Hydrogen is used in gas turbines manufactured by the know-how created through national technologies	1	56	29	25	34	13	1,8	13,7
			2	51	41	16	31	12	2,0	13,6
			E	21	100				0,0	0,0
	8	The biological production of hydrogen has become economical and performed in industrial scale.	1	55	27	38	25	9	9,1	14,2
			2	50	34	34	26	6	10,0	14,6
			E	17	100				5,9	0,0
	1	National Industry has been operating in the field of hydrogen distribution, transmission and storage technologies.	1	60	47	33	17	3	0,0	13,0
			2	54	50	33	13	4	0,0	12,6
			E	27	100				0,0	0,0
2030 - 2035	9	Continous bioprocesses have been developed for hydrogen production via microorganisms and solar energy.	1	54	26	30	35	9	5,6	14,2
			2	49	31	27	37	6	6,1	14,3
			E	15	100				0,0	0,0
	11	Nanostructures for hydrogen storage has been developed for industrial usage.	1	53	36	30	25	9	0,0	14,4
			2	48	46	21	25	8	0,0	15,2
			E	22	100				0,0	0,0
	6	Hydrogen is used in energy systems as a common practice	1	56	43	39	14	4	7,1	13,5
			2	51	51	33	14	2	5,9	13,5
			E	26	100				3,8	0,0

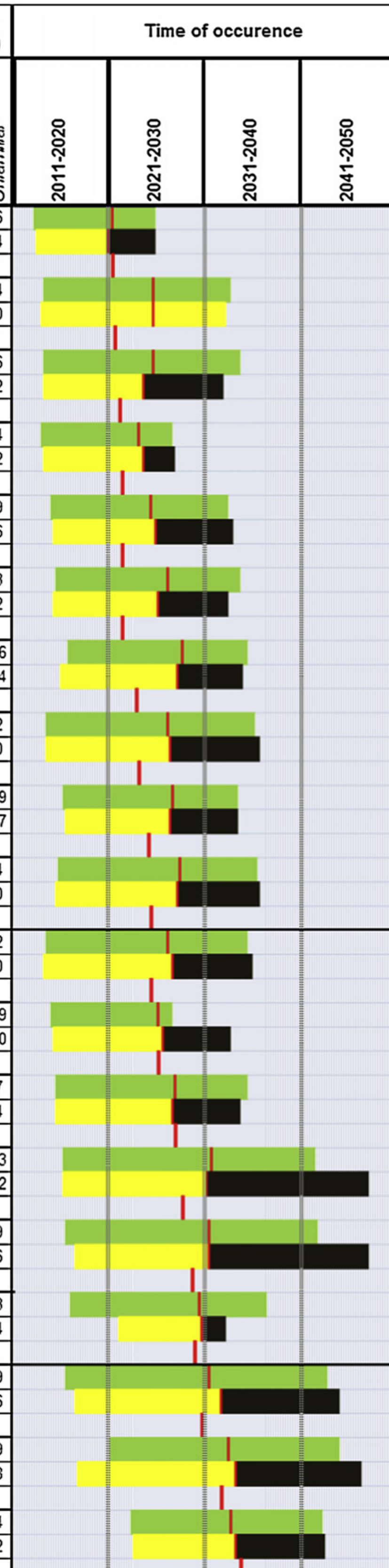

Fig. 3 – The Delphi statements and their time of occurrence. (P.S: Mean value of time of occurrence of Delphi statements for first and second round answers, including answers of "experts only" for the second round. Left hand side of the bar indicates 25% quartile and right hand side 75% quartile.)

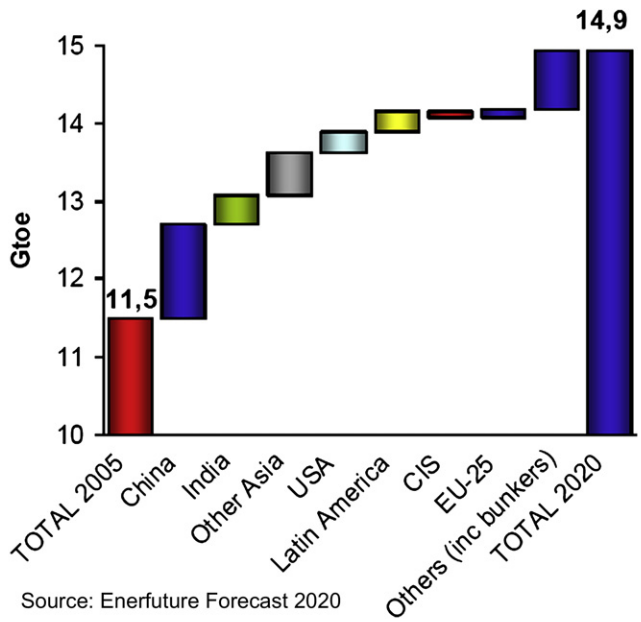

Fig. 4 – Total world energy consumption growth.

to be totally unlikely and classified it to happen never were displayed on the far right hand side of Fig. 3. The experts always expected the occurrence for the stated technologies to be earlier than or at the same period with the overall group of respondents as can be seen in Fig. 3. This phenomenon is described as ''professional optimism'' and can be found in literature [18]. On the other hand, the expected times of the experts were in a fairly narrow range of 2021–2033 indicating that the shift to the hydrogen economy will be realised within these periods.

According to respondents, hydrogen will play a major role in the Turkish energy system by around 2030. Although, no industrial scale facilities currently exist in Turkey, the participants believe that a national industry which will be operated in the field of hydrogen distribution, transmission and storage technologies will be established. However, it is also worth to mention the category of 'time of occurrence: never' which is interesting as it breaks with the linear times scale. In particular, statements 15 and 19 related to the storage of hydrogen have received relatively higher ''never'' responses from the experts reflecting the storage bottleneck in hydrogen technology which can be interpreted as an ambitious research goal.

The geopolitical implications of hydrogen are enormous as well. Coal fueled the 18th- and 19th-century rise of Great Britain and modern Germany; in the 20th century, oil laid the foundation for the United States' unprecedented economic and military power. Today's US superpower status, in turn, may eventually be eclipsed by countries that harness hydrogen as aggressively as the United States tapped oil a century ago. Countries that focus their efforts on producing oil until the resource is gone will be left behind in the rush for tomorrow's prize [13]. According to Delphi survey results, Turkey is willing for transition of the hydrogen economy. The transition to a hydrogen economy will require a huge investment in new areas which Turkey has already initiated. In 1992, the Government of Turkey took up the issue of international cooperation in the area of hydrogen energy technologies and supported a feasibility project for the establishment of the centre in Turkey. By the Cabinet Meeting on 26 May 1996, the Government of Turkey accepted to propose the establishment of the centre in Turkey and agreed to support the centre financially. The establishment of the International Centre of Hydrogen Energy Technologies (ICHET) is located in Istanbul, at the crossroads of two continents and many civilizations,

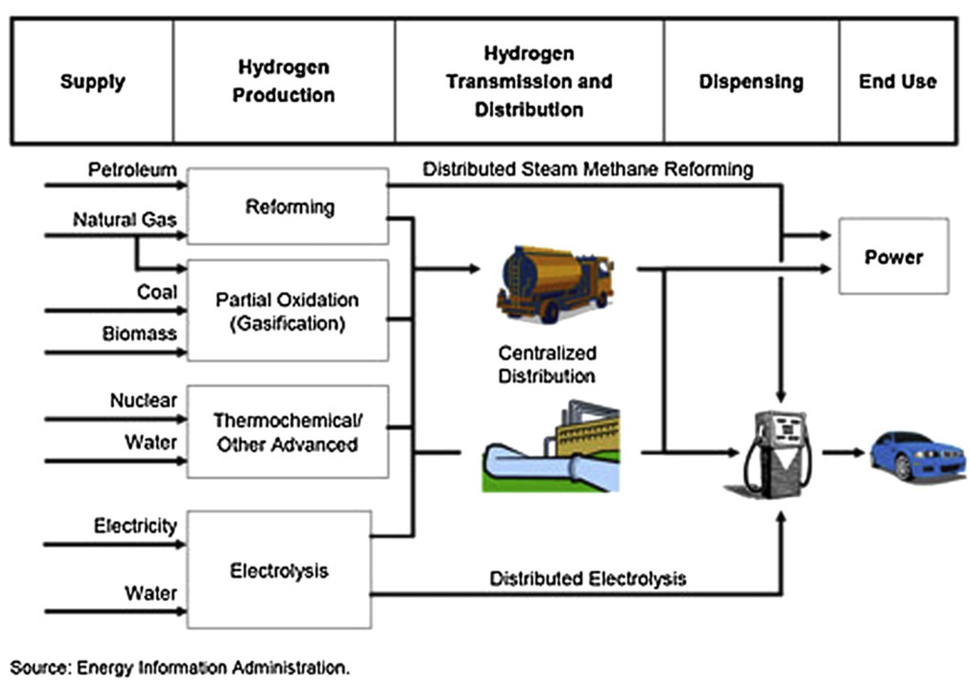

Fig. 5 – Overview of the H_2 economy.

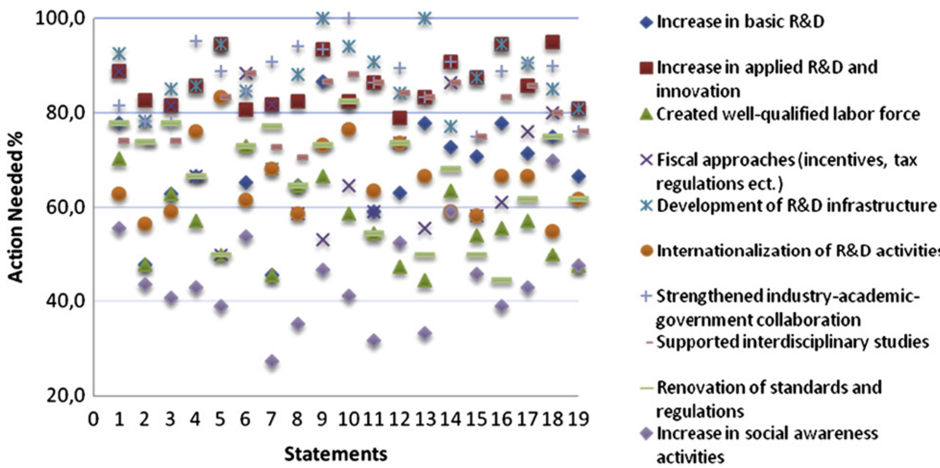

Fig. 6 – Comparison of actions needed to enhance the Delphi statements.

the International Centre for Hydrogen Energy Technologies (UNIDO-ICHET) is a United Nations Industrial Development Organization project whose statuary mission is to demonstrate viable technologies for the implementation of a hydrogen inclusive economy as well as to facilitate their widespread use, more particularly in developing countries (http://www.iea.org/textbase/work/2003/hydrogen-coIEA/AG4-5TUR.PDF; http://www.unido-ichet.org/ichet.org/index.html).

The other institution is the National Boron Research Institute. This institute has investigated new application areas of the boron and its compounds and carries out studies regarding new products and improvement of product quality. Especially boron is the most important research material for the hydrogen storage [1,14,16,26,29].

Other opportunity for Turkey on the hydrogen issue is Black Sea which contains hydrogen sulphur after 60 m depth. The amount of hydrogen sulphur is about 2.5–3.0 million tonnes. This huge hydrogen sulphur potential can be evaluated as hydrogen fuel sources Fakioglu et al. [16]. Presently no commercial technology is available for both hydrogen and sulphur production from H_2S. Any new technology will have as reference the established steam methane reforming (SMR) process regarding hydrogen production, and the established Claus process for sulphur recovery. The supply costs of hydrogen produced by SMR at a capacity of 220–1000 kmol H_2/day can be as low as approximately 6–4.7 $/GJ (Cox et al. [8]; Baykara et al. [3]).

Economic growth is among the most important factors to be considered in projecting changes in the world energy consumption. In the IEO2009 projections (http://www.eia.doe.gov/oiaf/ieo/world.html), assumptions about regional economic growth ''measured in terms of real GDP in 2005 U.S. dollars at purchasing power parity rates'' underlie the projections of regional energy demand. According to the latest estimates by Enerdata (http://www.enerdata.fr/enerdatauk/publications/pages/forecasts_2007.php), China and India will account for 45% of the world energy growth in 2020, while global energy consumption will increase by 30%. Growth is slow in Europe and the Commonwealth of Independent States (CIS). European energy consumption should increase by 12% between 2005 and 2020. On the other hand, the continent of America (8% for both the USA and Latin America) account for about 15% of this growth (Fig. 4). On the other hand looking at the situation in Turkey, annual increase in energy consumption is 8–10% since 1985 parallel to economic growth, industrialization and urbanization except for the recession years.

The Delphi second round results showed that hydrogen will be used in energy systems as a common practice in Turkey approximately in 2033, in parallel to the world economic growth expectations.

A simplified system overview of the current and potential hydrogen economy presented by the Energy Information Administration is shown in Fig. 5. The essential system elements include supply, production, distribution, dispensing, and end use (http://www.eia.doe.gov/oiaf/servicerpt/hydro/hydrogen.html). According to the participants of the Delphi survey, hydrogen production will be carried out by using different materials, methods and in different industrial scales between 2015 and 2045. On the other hand, hydrogen storage technology is foresighted to be developed in around 2020–2030.

Advanced technologies for hydrogen are also being explored in bilateral meetings [5] and especially, hydrogen based membrane biofilm reactors, thermochemical reactions, such as those using photosynthesis, fermentation, landfill gas recovery, and municipal waste reformation were stated. However, the likelihood of the technological and economic success of these advanced technologies was not guaranteed. But according to the results of Delphi survey, both hydrogen production and storage has become economical and performed in industrial scale approximately at the beginning of the 2020.

EurEnDel (http://www2.izt.de/eurendel) research project standing for ''European Energy Delphi Technology and Social Visions for Europe's Energy Future a Europe-wide Delphi Study'' is funded by EU. According to the EurEnDel project results, hydrogen produced solely from renewable and used as an energy carrier constitutes a significant part of the energy system towards 2035, whereas 3% of hydrogen is foresighted to be produced from renewables in Turkey by around 2020. Additionally, the occurrence of the statement ''biological production of hydrogen in practical use'' is expected to be

Table 2 – Impact ranking of hydrogen technology statements.

No	Statements	Round	Wealth creation	Environment impact	Quality of Life	Security of Supply	Overall Impact Index
6	Hydrogen is used in energy systems as a common practice.	1	1.46	1.61	1.43	1.29	2..90
		2	1.53	1.71	1.53	1.39	3.09
		E	1.77	1.92	1.85	1.69	3.62
9	Continuous bioprocesses have been developed for hydrogen production via microorganisms and solar energy.	1	1.22	1.41	1.24	1.13	2.51
		2	1.29	1.49	1.33	1.20	2.66
		E	1.8	1.93	1.87	1.53	3.58
10	Hydrogen production from biomass has been realised in industrial scale.	1	1.28	1.41	1.24	1.20	2.57
		2	1.35	1.47	1.22	1.20	2.63
		E	1.82	1.82	1.65	1.65	3.48
3	Industrial scale hydrogen production has started in Turkey.	1	1.53	1.70	1.30	1.33	2.95
		2	1.63	1.78	1.47	1.39	3.15
		E	1.78	1.89	1.70	1.52	3.45
17	H_2 Fuel Cell manufacturing technology know-how is available in Turkey.	1	1.48	1.60	1.42	1.31	2.91
		2	1.50	1.72	1.46	1.33	3.01
		E	1.71	1.86	1.76	1.48	3.42
1	National Industry has been operating in the field of hydrogen distribution, transmission and storage technologies.	1	1.55	1.68	1.52	1.35	3.06
		2	1.59	1.74	1.56	1.35	3.13
		E	1.70	1.81	1.74	1.52	3.4
14	First hydrogen-fueled internal combustion vehicle is produced by Turkish Automotive industry.	1	1.46	1.60	1.37	1.29	2.86
		2	1.50	1.67	1.50	1.33	3.01
		E	1.68	1.86	1.73	1.45	3.38
2	In Turkey, % 3 of hydrogen produced from renewables) About 3% of hydrogen is produced from renewables in Turkey.	1	1.27	1.53	1.32	1.29	2.71
		2	1.32	1.60	1.34	1.30	2.79
		E	1.61	1.87	1.57	1.48	3.27
18	H_2 is used in residential buildings for cogeneration of heat and electricity.	1	1.40	1.46	1.31	1.15	2.67
		2	1.46	1.57	1.39	1.22	2.83
		E	1.70	1.85	1.55	1.40	3.27
19	Hydrogen (gained by electrolysis in solar or wind parks) is stored for electricity generation.	1	1.35	1.54	1.29	1.29	2.74
		2	1.39	1.59	1.33	1.30	2.81
		E	1.62	1.76	1.62	1.43	3.22
15	Boron-based hydrogen storage mechanism has become feasible.	1	1.48	1.52	1.40	1.42	2.91
		2	1.48	1.52	1.37	1.39	2.88
		E	1.63	1.71	1.50	1.54	3.19
8	The biological production of hydrogen has become economical and performed in industrial scale.	1	1.05	1.20	1.05	1.04	2.18
		2	1.14	1.26	1.10	1.06	2.28
		E	1.65	1.65	1.47	1.35	3.07
11	Nanostructures for hydrogen storage has been developed for industrial usage.	1	1.26	1.34	1.21	1.26	2.54
		2	1.27	1.44	1.23	1.27	2.61
		E	1.41	1.64	1.41	1.50	2.98
12	Methane–hydrogen hybrid fuel mixtures have been provided for catalytic combustion process.	1	1.15	1.23	1.21	1.08	2.33
		2	1.11	1.21	1.17	1.02	2.26
		E	1.37	1.47	1.53	1.42	2.9
5	High efficiency hydrogen production has been realised by hydrogen based membrane biofilm reactors.	1	1.07	1.23	0.95	1.04	2.15
		2	1.10	1.29	0.98	1.10	2.25
		E	1.44	1.67	1.11	1.39	2.83
4	Hydrogen is used in gas turbines manufactured by the know-how created through national technologies.	1	1.18	1.27	1.07	1.07	2.30
		2	1.18	1.33	1.06	1.10	2.34
		E	1.43	1.62	1.24	1.24	2.78
13	Nanocomposite catalysts developed for hydrogen generation by methane reforming processes are manufacture in industrial scale.	1	0.94	1.06	0.92	0.96	1.95
		2	0.96	1.09	0.96	1.00	2.00
		E	1.39	1.44	1.28	1.28	2.7
7	Hydrogen production from natural gas using reformer method has been utilised in industrial scale.	1	0.98	1.11	1.02	0.84	1.98
		2	0.98	1.20	1.04	0.82	2.04
		E	1.32	1.50	1.32	1.09	2.63
16	Nanotechnology-based hydrogen sensors have been developed & manufactured.	1	1.02	1.06	1.00	1.06	2.07
		2	1.02	1.15	0.98	1.09	2.12
		E	1.22	1.39	1.17	1.28	2.53

realised by around 2030. According to another statement, the first hydrogen-fueled internal combustion vehicle is expected to be produced by the Turkish Automotive industry in 2021, while widespread use of gasoline engines will be fuelled with hydrogen in Europe by 2019 (http://www2.izt.de/eurendel).

Actions needed were evaluated on the basis of the Delphi results for all statements (Fig. 6). The four items with the highest degree of consensus among the respondents were ‘‘Development of R&D infrastructure’’, ‘‘Strengthened industry-academic-government collaboration’’, ‘‘Increase in

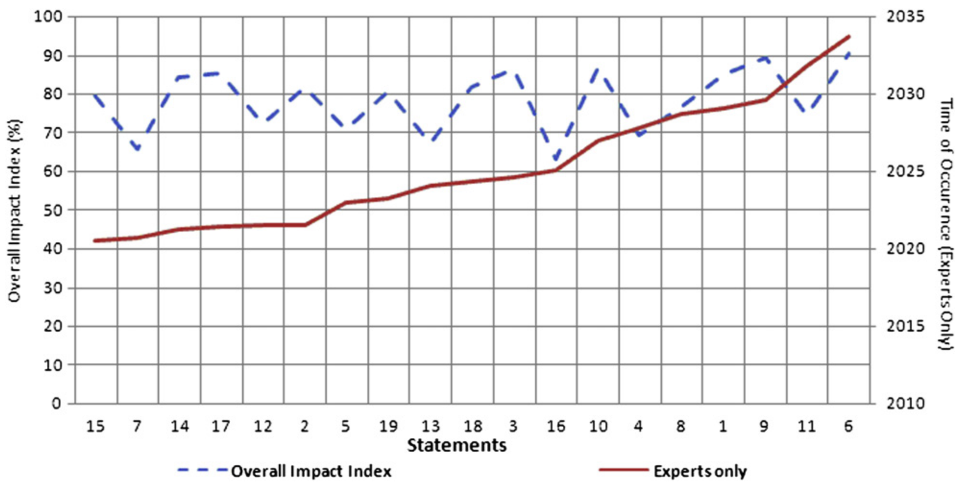

Fig. 7 – Overall impact index as a function of time of occurrence.

applied R&D and innovation" and "Supported interdisciplinary studies", whereas, "Increase in social awareness activities" has been pointed out by few respondents. According to these results, research efforts, collaboration, interrelationship and R&D infrastructure must be increased at least on the world level in order to play a major role in the energy system by 2030, otherwise the time frame will not be realistic. The recommended actions are quite similar with almost all the statements concerning hydrogen production, storage and distribution. The following statements, "Development of R&D infrastructure", "Strengthened industry-academic-government collaboration" and "Increase in applied R&D and innovation" were backed by approximately 87% of the respondents and likewise "Supported interdisciplinary studies " was recommended by 80%.

For each Delphi statement, the respondents were asked to give an assessment of the impact it would have, if the statement came true. Assessed was the impact on; wealth creation, environment, quality of life and security of supply. Hydrogen technologies were considered to be overall the most beneficial in the four areas. The statements were ranked according to their impact on these four impact measures. The ranking list is shown in Table 2. The evaluation of the impact assessments of the 19 Delphi statements was based on an overall impact index calculation. The overall impact index ranged from 1 for an adverse impact until 4 for a highly beneficial impact.

According to overall impact index, the statement namely "National industry has been operating in the field of hydrogen distribution, transmission and storage technologies" had a strong impact in the first round, whereas the statement "Industrial scale hydrogen production has started in Turkey" had a strong impact in the second round and the statement "Hydrogen is used in energy systems as a common practice" had the most significant impact on the hydrogen systems, whereas the statement "Nanotechnology-based hydrogen sensors have been developed & manufactured" had been assigned the minimum impact value according to expert opinions as the outcome of bilateral meetings. Likewise the statement "Nanocomposite catalysts developed for hydrogen generation by methane reforming processes are manufactured in industrial scale" received the minimum impact value as a result of both the first and second round Delphi survey.

Finally, the degree of importance of the statements to Turkey was reflected as a percentage breakdown of respondents who indicated "high," "medium," "low" or "unnecessary". The evaluation of the degree of importance of the statements to Turkey of the 19 Delphi statements was based on an importance index calculation. The overall importance index ranged from 0 for less importance to 1 for the most important. According to the degree of importance index, the top five statements were 1, 14, 17 calculated as 0.98, 9 and 10 calculated as 0.97. On the other hand, the five statements at the bottom of the list were 16 (0.68), 7 (0.75), 11 (0.86), 2 and 4 (0.87). In other words, there are no major differences between the statements ranked at the top and bottom of the list.

In terms of the impact, it should be noted that the statement "Nanocomposite catalysts developed for hydrogen generation by methane reforming processes are manufactured in industrial scale" had a very low wealth creation score compared to the statement "Hydrogen production from biomass has been realised in industrial scale" which was ranked with the highest score. However, the ranking based on environmental impact and quality of life differed somewhat from the total impact ranking. While the lowest ranked is the same statement of the total impact ranked, but the top ranked was different. On the other hand, the statement "Continuous bioprocesses have been developed for hydrogen production via microorganisms and solar energy" was ranked as the highest for both environmental impact and quality of life. Statements 6, 9 and 10 were all ranked higher in the ranking based on all impact measures. "Hydrogen is used in energy systems as a common practice" received the highest ranking in terms of security of supply. On the other hand, statement 13 was ranked very low for all impact measures except security of supply and Statement 7 was relatively low in regards to security of supply compared to the total ranking list.

Additionally, overall impact index has been plotted as a function of time of occurrence (Fig. 7) in order to investigate if any correlations exist and to have a holistic view. The overall impact index of the statements varies between 65 and 90%, whereas time of occurrence is predicted to be from 2020 to 2035. Although, there seems to be no direct correlation between the overall impact index and the time of occurrence, this is due to the structuring of the Delphi survey where assessments of realization of the statements by time of occurrence and overall impact have been presented separately to the participants. So if such correlations are of interest to researchers for future foresight studies, the structuring of the survey is recommended to be designed as a function of time of occurrence.

4. Conclusion

This study has explored the future hydrogen technologies in Turkey using expert opinions elicited from the bilateral meetings and a web-based survey developed and designed using PHP and MySQL databases in order to gather information for the two-round Delphi method. The participants chosen for the survey played key roles in the sector and the fact that all the actors such as academicians, policy makers, politicians, industrialists and representatives of civil society organizations were represented, the outcome was very fruitful.

In this paper, we looked for the most important hydrogen technologies and research priorities likely to be demanded by the Turkish energy industry. In this context, we investigated Turkey's hydrogen future and we believe that this foresight exercise may have contributed to the policy objective of fostering the diversity of technological options especially through the development of alternative hydrogen technology roadmaps that supported participants in their R&D activities.

According to this study;

- Hydrogen technologies are foresighted to have large socio-economic impacts in the future,
- And are currently a fast growing field for researches in multidisciplinary areas.
- Yet even more integration and collaboration among fields are needed to promote future hydrogen R&D studies.
- The Delphi statements "National Industry has been operating (operation) in the field of hydrogen distribution, transmission and storage technologies" and "H_2 fuel cell manufacturing technology know-how is available in Turkey" were highly prioritized by the experts and hydrogen community and there are great expectations for the development of these technologies.

The most important finding obtained from the Delphi survey can definitely not be summarized in one sentence. But the one of the most important message from the experts and hydrogen community was the fact that Turkey should strive towards a "hydrogen economy". All participants believed in the power of strengthened and increased collaboration between industry-academic-government collaboration. Additionally, it is obvious that the advancements in the mentioned hydrogen technologies in this publication are going to make an impact on environment, life quality and security of supply. Above all, the hydrogen economy *will bring* exciting innovations as well as economic prosperities and environmental benefits for the lives of Turkish people.

So, hydrogen is not a utopia for Turkey.

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