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PERSPECTIVE

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A perspective on hydrogen energy research, development and innovation activities in Turkey

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Summary

Hydrogen can be considered as the most promising fuel towards the greenization. Developed and developing countries around the world have formed their research, investments and directives on hydrogen. The leading countries in this field can be cited as members of the European Union and the United States. Laws and regulations have been shared with the public under the aegis of the established policies. Additionally, determined targets for the short, medium and long term and their feedbacks are recorded by the reports of the competent authorities. Although the Republic of Turkey was aware of the importance of the issue, though there is no open source inventory as disclosed. In Turkey, governmental organization, General Directorate of Energy Affairs (YEGM), and foundations, such as the National Hydrogen Association (NHA), have been encouraging and supporting multidisciplinary studies and activities within the country and internationally. In this study, it is aimed to provide numerical analyses from 1970 to the present by considering hydrogen energy. Related information and data were compiled from online resources on scholarly publications, organizations, groups, books and book chapters, master and doctorate theses, patents received and completed projects. It is also aimed to create a unique information source to refer with respect to planning and activities.

1 | INTRODUCTION

Hydrogen is recognized as one of the most important energy solutions for sustainable future, and there have been significant attempts worldwide to make a primary focus on hydrogen energy research, development and innovation activities in almost every developed and fast developing country. Prof. Dr. Nejat Veziroğlu initiated the first formal hydrogen energy related activities in 1974 with a landmark conference in Miami, USA. Since then, he has been serving as a mastermind through conferences, journals, books, projects, outreach activities, society activities, etc. Because high leadership, more and more people are everyday joining these activities around the world with a great interest.

Last two decades, more affordable attractions have risen up scales about hydrogen all over the world. The main purpose of this positive quest is minimizing the emissions and carbon footprint. Although, there were carbon related hydrogen production methods (steam reforming of natural gas, coal gasification), there have been new production solutions of hydrogen which are relevant to renewable and alternative energy sources.

Hydrogen Council[1] was established on 17 January 2017 with 13 inaugural members, and by June 2019, it has reached 60 leading energy, transport and industry

companies. According to IEA's latest Hydrogen report[2], global hydrogen demand is 70 million tons. The energy sectors, which are in need of hydrogen energy most are listed as heat, industry, transportation, chemical industry and power systems. Hydrogen has a very important place in the transport sector, especially in minimization of emissions, resource size, availability and different production processes. Due to the development and cheapening of fuel cell technology, the use of hydrogen has been increasing in the last decade, in bicycles, forklifts, cars, busses, trucks, trains, and even marine and aircraft transportation sectors.

Hydrogen has taken a significant place in the energy policies of countries, especially in Japan, Germany, Canada and USA since 2000. In a speech of the USA President in 2003, hydrogen energy was defined as a liberty fuel. China, which produced 16 million tons of hydrogen in 2012 and 20-22 million tons of hydrogen in 2018, now has the largest hydrogen production capacity in the world.[3] Japan has adopted the usage of fuel cells that generate electricity using hydrogen for various means of transportation, and aims to strengthen the country's energy infrastructure. France supports and wants to push forward the hydrogen sector in all fields. Nicolas Hulot, France's environment minister, announced that the government would have invested in the hydrogen sector more than $100 million by 2019.[4] Additionally, according to EU Hydrogen report[5]; FCH JU projects were funded by Horizon 2020 in several sectors. Mentioned projects could be listed as:

- About transportation with 60 projects (926 M€).
- About de-carbonization on buildings with 66 projects (426 M€).
- About industry with 4 projects (43 M€).
- About hydrogen feedstock with 4 projects (46 M€).
- About hydrogen large demonstration with 56 projects (215 M€).

With this rising momentum, the number of active hydrogen refueling station increased to 325 in 2019.[6] Bezdek[7] discussed the current hydrogen economy and technologies and tented to show the necessity of identifying the unique occupational title and job scale with similar salaries. Bezdekstated that the global hydrogen market, which had been 122 billion dollars in 2018, would rise to 155 billion dollars in 2022. In addition, the American Solar Energy Association and Management Information Services (ASEA/MISI) estimated that the extensive hydrogen energy and fuel cell market would have created about one million new job opportunities only in the USA by 2030.

In addition to the developing hydrogen economy, technical, social and academic research on this subject is increasing, which proves the interest of academicians and researchers on hydrogen. Research, development and innovation activities in the hydrogen field in Turkey increased drastically towards the end of the 1900s and increased even further after the 2000s. In this regard, Turkey has been quite active in academia with many researchers through scholarly publications, projects, partnerships, conferences, etc. As a result of such activities over three decades, the National Hydrogen Technologies Association was established to play a critical role in moving into hydrogen era by bringing all parties together and mobilizing academia, industry and government agencies for a common goal, advocating for hydrogen economy, serving as a key shelter, coordinating the efforts, activities and events, reaching out to people and communities and serving them, liasoning for implementing hydrogen agreements, making a base in Turkey, and many more.

The demands of scientists and their desire to deepen their research clearly reveal the need to establish more hydrogen centers in the country. The Energy and Natural Resources Ministry of Turkey Republic regulates the state policy in the country in order to contribute to the development of new hydrogen technologies and provide awareness. Additionally, technology transfer and effectuate “know-how” are necessary for universities, research centers and national laboratories. Many protocols have been signed by universities, public institutions and organizations regarding the qualifications of the experts to be assigned to the evaluation, support, monitoring and finalization of project applications for research and development activities related to the domestic design and production in hydrogen energy and technologies.

In this perspective article, we present the results of comprehensive literature search through the online resources and data and information collection from various people, groups and organizations about hydrogen energy related research, development and innovation activities for a period of nearly 50 years (from 1970 to present). Such compiled data and information results cover scholarly publications, books and book chapters, master and doctorate theses, received patents, completed projects, etc. from 1970 to present inclusively. The results illustrated in the graphs appear to be interesting and show really how diverse they are. They provide a hopeful picture about hydrogen economy and its role in Turkey's energy road map.

2 | METHODOLOGY

With the information technologies and online resources available today, it is easy to reach the information day by day. A data analysis can be done much faster and faster than before. The main purpose of this study is to provide a compilation of studies on hydrogen, which are made in

Turkey between 1970 and 2020. Here are limitations and keyword listed below for each of the separate documents under the search:

- Articles, Conference Papers, Reviews and Article in Press = Search: "Hydrogen"; Affiliation: "Turkey", Time period: "1970-2020", Source: Scopus.
- Books, Book Chapters and Editorial = Search: "Hydrogen"; Affiliation: "Turkey", Time period: "1970-2020", Source: Scopus.
- Patents = Search: "Hydrogen"; Affiliation: "Turkey", Time period: "1970-2020", Source: Turkish Patent and Trademark Office.
- Projects = Search: "Hydrogen"; Affiliation: "Turkey", Time period: "1970-2020", Source: The Scientific and Technological Research Council of Turkey.
- Theses (MSc and PhD) = Search: "Hydrogen"; Affiliation: "Turkey", Time period: "1970-2020", Source: Turkish Council of Higher Education Thesis Center.

After these keywords and criteria selected; a lot of numerical data have been collected, analyzed and presented in the following section.

3 | RESULTS AND DISCUSSION

This section includes all of the presented charts on hydrogen studies done in Turkey between 1970 and 2020. Figure 1 covers all documents held by the Turks or Turkey. Notable fields within all disciplines have been the chemistry, physics and material sciences. These total numbers were obtained by neglecting any potential field conflicts. That is, if a single publication is interdisciplinary, it is attributed to the related fields more than once. Side effect of chemistry to biochemistry and molecular biology cannot be refused. These research areas are the main part of medicine and science faculties, which are the source of experiments, publications and books.

The number of articles, conference papers, reviews and article in press obtained in this research cover almost half of the total numbers of documents. Similarly, the

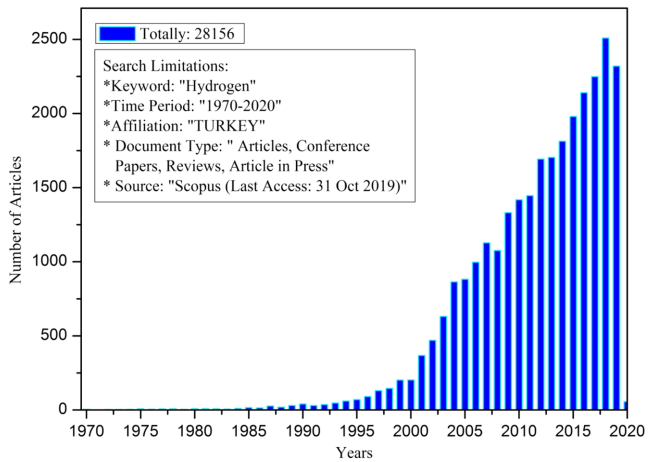

FIGURE 2 Turkey's hydrogen research outputs between 1970-2020 by considering the research articles. (Analyzed with Reference 8) [Colour figure can be viewed at wileyonlinelibrary.com]

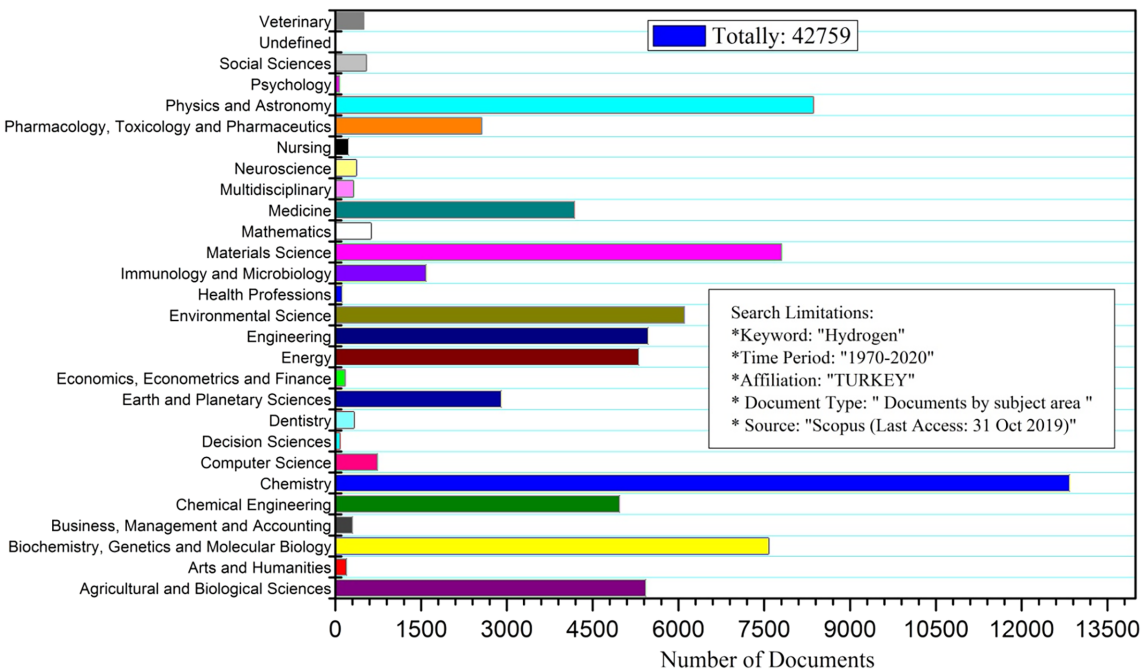

FIGURE 1 Turkey's hydrogen research outputs between 1970-2020 by considering the subject areas. (Analyzed with Reference 8) [Colour figure can be viewed at wileyonlinelibrary.com]

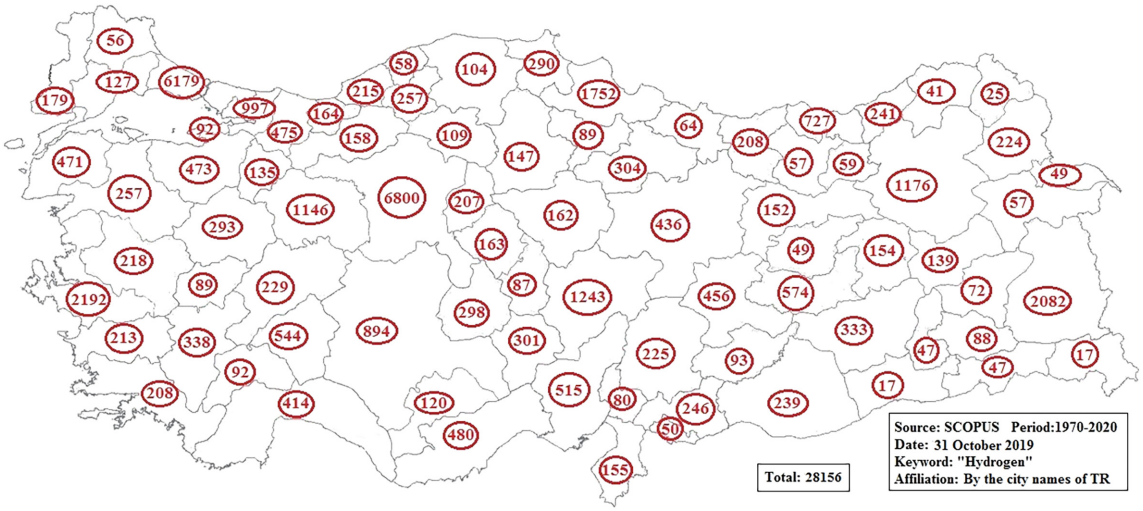

FIGURE 3 Hydrogen research distribution mapping of Turkey in terms of provincial perspective (Analyzed with Reference 8) [Colour figure can be viewed at wileyonlinelibrary.com]

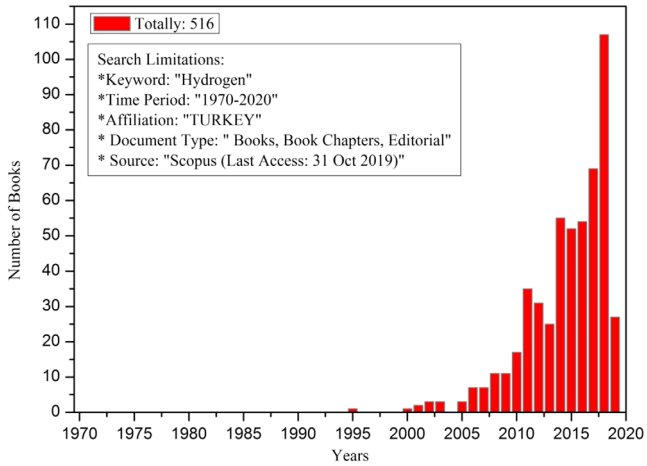

FIGURE 4 Turkey's hydrogen research outputs between 1970-2020 by considering the books. (Analyzed with Reference 8) [Colour figure can be viewed at wileyonlinelibrary.com]

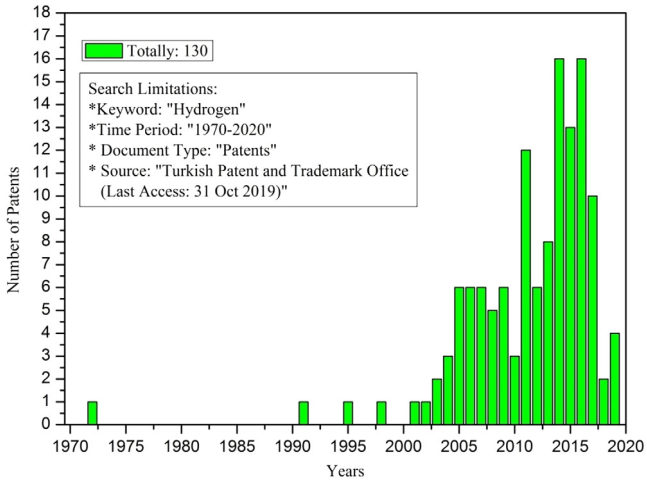

FIGURE 5 Turkey's hydrogen research outputs between 1970-2020 by considering the patents. (Analyzed with Reference 9) [Colour figure can be viewed at wileyonlinelibrary.com]

numbers started to increase in 2000s and continue to increase at present as seen in Figure 2.

The evaluation and mapping of hydrogen publications on the provincial basis are showed in Figure 3. This map is obtained with search limitations of Figure 2 except "affiliations". There are 207 universities in Turkey, as of today. It can be seen clearly in Figure 3 that the distribution of the publication is concentrated in three main provinces. These are listed as 6800 in Ankara, 6179 in Istanbul and 2197 in Izmir.

There are 21, 61 and 10 universities in these provinces, respectively. Seventy-nine percent of the total number of publications was realized in nine cities. By neglecting the population distribution, more than three-quarters of the work are carried out by 11% of cities. They are home to advance laboratories, medical schools related to chemistry, and a relatively larger number of academicians. Investments in other cities should be increased by providing governmental incentives for a balanced distribution and a more promising future.

In Figure 4, a total of 516 works were identified in the scope of books, book chapters and editors. When we look at the distribution according to years, 90% was realized after 2010. Patent studies seem better when compared to successful project number. The information and data provided by TPE (Turkish Patents Institute) show that there have been 130 patents so far. The number of projects is scarce when Turkey's technological level and the number of researchers are considered in this field accordingly. The number of projects supported by The Scientific and Technological Research Council of Turkey (TUBITAK) is 120 between 1970 and 2020. The patent and the project results are presented in Figures 5 and 6 respectively.

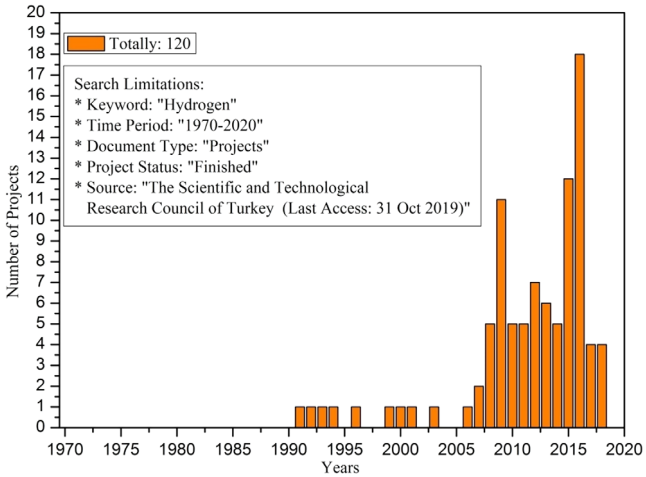

FIGURE 6 Turkey's hydrogen research output between 1970-2020 by considering the research projects. (Analyzed with Reference 10) [Colour figure can be viewed at wileyonlinelibrary.com]

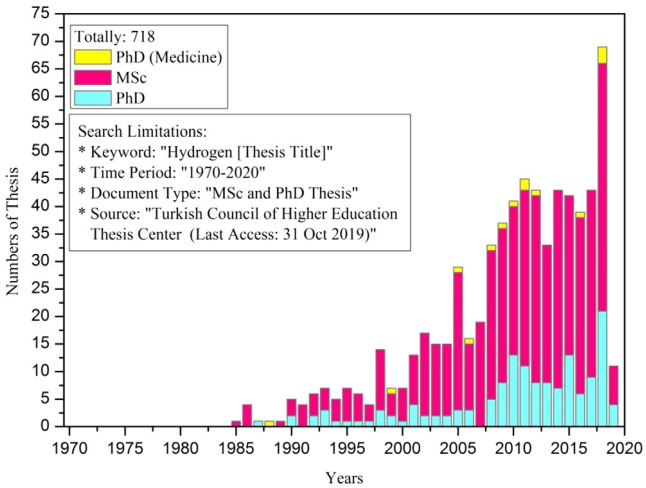

FIGURE 7 Turkey's hydrogen research outputs by considering the graduate theses completed. (Analyzed with Reference 11) [Colour figure can be viewed at wileyonlinelibrary.com]

In the last 50 years, a total of 718 graduate degrees have been granted in Turkey. In the last 50 years, a total of 718 graduate degrees have been completed. A significant percentage of 718 are MSc theses. However, also some studies have been completed in the health sciences during the same period. After 2010, the studies have been deepened and an increase has been observed in PhD studies. The numerical distributions of the prepared thesis are shown in Figure 7.

4 | CONCLUSIONS

In the scope of this work, in particular for the Republic of Turkey, hydrogen-related researches were compiled as numerical data. The main purpose is a compilation of the past to create a road map for the future. Limitations and keyword are listed and expressed detailed in methodology section. The prominent results of this study are:

- A total of 42759 documents were studied by scientists on 28 different "subject areas".
- A total of 28156 studies were performed by researchers in terms of articles, conference papers, reviews and article in press.
- In terms of "books, book chapters and editorial" part of studies in Turkey Hydrogen related publications were 516.
- According to Turkish Patent and Trademark Office; 130 patents were granted to the inventors.
- A total of 120 projects were completed as confirmed by the Scientific and Technological Research Council of Turkey.
- A total of 718 graduate theses were completed by investigators in various universities and institutions.

5 | FUTURE RECOMMENDATIONS

Here, some recommendations are made for a smooth switch to hydrogen economy with sustainable hydrogen energy options and hydrogen derived other potential options. The following state some of the points for consideration:

- Import energy depended countries have started to take steps for the transition to the use of hydrogen and biofuels instead of traditional energy sources, such as oil, natural gas, coal, and have supported many projects in this direction and established pilot energy plants. However, in order not to be inadequate in this process, the number of supported projects should be increased and nationwide facilities should be established. It should also place a significant meaning on hydrogen and allocate an important budget when developing long-term energy strategies.
- Turkey should be aware and evaluated the source of hydrogen with its high potential. Hydrogen sulfide, especially found in the Black Sea bottom waters, is an important resource for obtaining hydrogen. The idea of establishing hydrogen production facilities in the Black Sea should be accelerated.
- Importance should be given to fuel cells, which play an important role in converting hydrogen energy into electrical energy at universities, R&D institutions and so on. Their prototype fuel cells should be supported developed and mass production phases should be started.

- The application areas of the fuel cells should be expanded and used in automobiles, UAVs, ships etc. Use should be expanded and hydrogen-refueling stations should be established in this step.
- Industry-university cooperation and international cooperation with developed countries should be increased in order to accelerate the transition to hydrogen.
- "The Hydrogen Roadmap of Turkey" should be prepared by all stakeholders, together with the relevant ministries and government departments. Future predictions should be prepared in this context and should take their place in Turkey's energy policies.
- Not only production but also carriage and storage should be taken into consideration by authorized people, academicians and commercial companies.
- There is a great move in Europe to consider power to gas options in all sectors. Turkey needs to be part of these initiatives, ranging from multi-institutional projects to networks.
- Turkey should consider developing a nationwide hydrogen energy program and help develop economy activities around this.
- The Turkish Authorities need to closely work with the National Hydrogen Technologies Association for potential solutions for industry and more innovative education in the area of hydrogen technologies.

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