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Article

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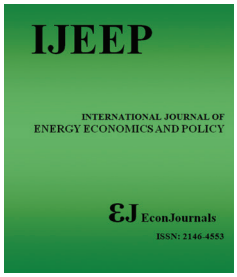

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Trends in Research Focused on Hydrogen Production Based on the Web of Science

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ABSTRACT

In the present research, a bibliometric analysis is performed on the trends of research focused on hydrogen production. The analysis was performed through an electronic search of the Web of Science database for publications between the years 2010-2019. HistCite software was used for the bibliometric analysis and VOSviewer software was used to create correlation graphs. The results obtained show that the number of publications has increased exponentially during the period 2010-2019. The research focused on hydrogen production is mainly driven by developed countries, of which China, the United States, and South Korea stand out. The predominant topics are focused on fuel energy (16.9%), electrochemistry (9.6%), and multidisciplinary materials science (8.69%). The most common keywords found in the analysis are "performance," "water," "generation" and "nanoparticles."

Keywords: Hydrogen, Bibliometric Research, Production, Literature Review
JEL Classifications: Q42

1. INTRODUCTION

The latest research shows that there is a need to transition energy from traditional systems to sustainable sources with lower environmental impact (Shafiei et al., 2017). Hydrogen has some economic, social, and energy advantages that can be harnessed to combat global energy demand and reduce environmental problems such as climate change and global warming (Dutta, 2014).

Hydrogen is considered a promising source to realize the energy transition, as they have a high potential to reduce global warming and pollutant emissions generated by traditional systems (Zhang et al., 2016). Table 1 describes some of the main advantages of using hydrogen as an energy source (Dincer and Acar, 2016).

Hydrogen systems facilitate the energy transition due to their possibility of large-scale integration with traditional energy infrastructures, adaptability, clean transportation, ability to integrate into multigenerational systems, clean feedstock, and affordability in all regions. Research shows that hydrogen has a wide variety of uses and can easily penetrate the renewable energy market (Singh et al., 2016; Kalinci et al., 2015). In addition, hydrogen can be used as an energy storage system, which is an important step toward the greening of energy systems (Cipriani et al., 2014). The literature indicates that the use of hydrogen as an energy source can cover 18% of the energy demand and reduce CO_2 emissions by 6 gigatons tons per year (Uyar and Beşikci, 2017). In addition, hydrogen could be used to power approximately 20-25% of the transportation industry (Mostafaeipour et al., 2016). Among the advantages of hydrogen is the ability to utilize the natural gas infrastructures currently in use (Gong et al., 2016; Valente et al., 2018). In addition, the methods used for hydrogen production are becoming more affordable, efficient, less fossil-fuel related, and environmentally friendly (Salvi and Subramanian, 2015).

To establish hydrogen fully in the energy market, research and investment are needed to develop hydrogen production systems (Chintala and Subramanian, 2015). This research should be focused on the creation of more affordable, reliable, and safe hydrogen production systems that can be applied depending on the needs of each user (Joshi et al., 2016). This implies improving the capacity of current hydrogen production systems and reducing costs.

To analyze research trends focused on hydrogen production, a bibliometric study is conducted to evaluate the historical and current growth of research in the last 10 years (from 2010 to 2019), identify the distribution of research, publication percentages, and main thematic areas. The above facilitates and informs future research trends focused on the topic of hydrogen production.

2. METHODOLOGY

To identify trends and changes in research, a technique called bibliometric analysis is used to determine different patterns related to institutions, topics, countries, and fields, among others. In addition, academic research focused on a specific topic can be quantified over time (Comino et al., 2012). The technique consists of the development of a statistical analysis involving variables such as authors, distribution of journals, keywords, and references. For this purpose, certain tools are available such as Network WorkBench (Isci and Demirer, 2007), VOSviewer (Elango et al., 2007), HistCite (Solé-Bundó et al., 2019), and CiteSpace (Chen et al., 2009).

In the present work, the HistCite tool was used to perform the statistical analysis, because it has excellent visualization capabilities and is freely available software. In addition, this tool is directly focused on the study of trends related to scientific research (Prabir et al., 2011). For the data collection used in the bibliometric analysis, the Web of Science site was used, since it is one of the main databases used in this type of study.

The collected data were downloaded from the Web of Science on October 22, 2020. The search was performed using the following search equation TS = (“hydrogen production” AND (“biomass” OR “electro*” OR “thermal process” OR “methane decomposition” OR “hydrocarbon reforming” OR “alcohol reforming”)). The publications span the years 2010 to 2019. The Web of Science yielded a total of 17,385 publications.

Table 1: Advantages of using hydrogen as an energy source

Descriptions	Advantages
Decarbonization of energy systems	Reduced contamination of industrial processes Renewable raw material Increased sustainability Reduced environmental impact
Integration with other renewable energy sources	Flexible systems Multigenerational options Improved efficiency Increased accessibility Improved resilience

Once the information was collected, a statistical analysis was performed considering production, language, authors, institutions, and keywords. For the construction and visualization of bibliometric networks, the complementary tool Vosviewer was used, which is a free software normally implemented in bibliometric studies. (de la Cruz-Lovera et al., 2017). Figure 1 describes the process of data search, collection, and analysis.

3. RESULTS AND DISCUSSION

3.1. Language of Research

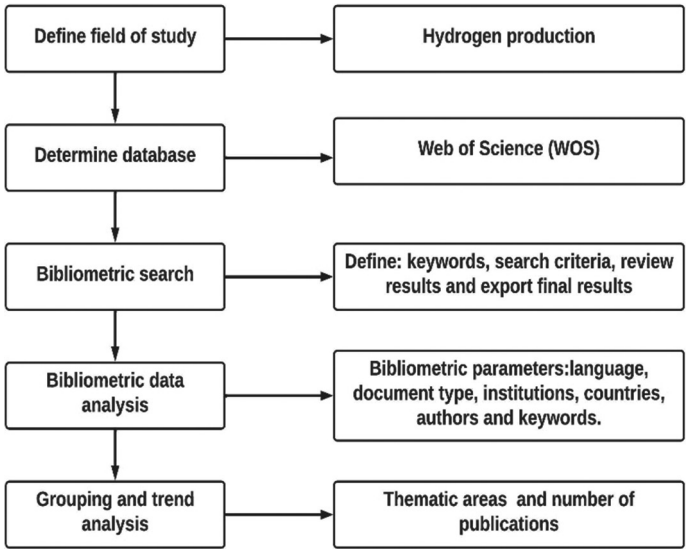
For the period analyzed (2010-2019), a total of 17,385 publications focused on hydrogen production were obtained. The main language of the research is English, which represents a total of 99%. The remaining 1% is mainly dominated by Chinese (0.65%), Korean (0.075%), Polish (0.058%), German (0.04%), Portuguese (0.04%), Japanese (0.035%), Spanish (0.029%) and others (0.058%). Figure 2 shows the distribution of languages obtained from the bibliometric analysis (except English).

The results obtained indicate that, of the 17,385 documents, 14,947 were published in scientific articles, 1311 in review articles, and 966 in proceedings documents. The remaining documents correspond to abstracts, books, and experimental data, among others. Scientific articles comprise approximately 86% of the research focused on hydrogen production. Figure 3 shows the distribution of document types during the period 2010-2019.

Figure 4 shows the trend in scientific production over the last 10 years. In general, an increase in the number of publications was observed each year. 17.65% of the publications are located in the year 2019. From the year 2015, there is a significant increase in the number of publications, which represents an increase of 18% compared to the year 2014.

By performing an exponential mathematical fit to the curve shown in Figure 4, a correlation coefficient of r^2 =0.99 was obtained,

Figure 1: Methodological flow diagram



which implies that the trend can be considered exponential growth. This demonstrates the relevance of hydrogen as a potential raw material for energy production.

Figure 2: Language of publications for the period 2010-2019

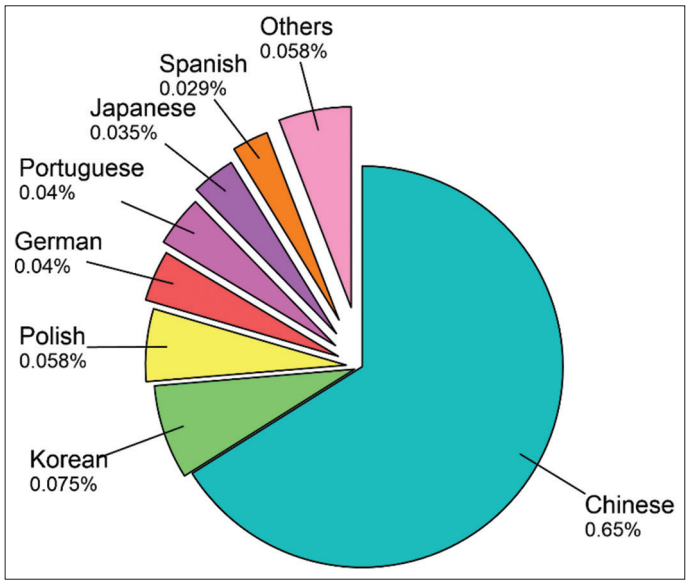


Figure 3: Types of publications

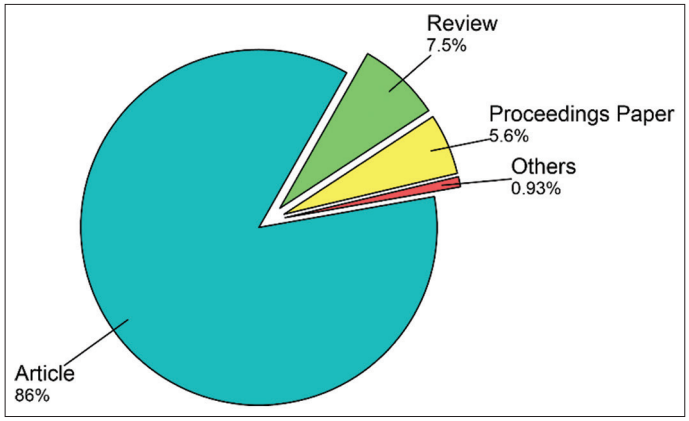
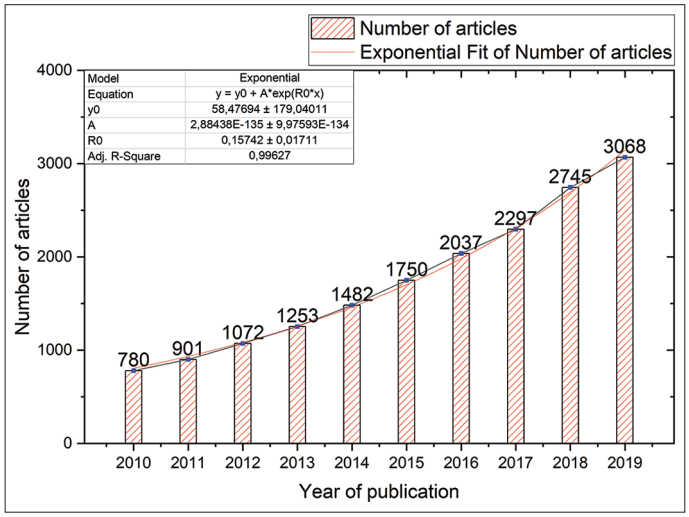


Figure 4: Trend of publications during the period 2010-2019



3.2. Contributing Countries and Institutions

Table 2 shows the top 10 academic institutions that have contributed the most to hydrogen production research.

Table 1 shows that the highest number of published research comes from the Chinese Academy of Sciences with 1243 publications, followed by the United States Department of Energy Doe with 549 publications and Centre National De La Recherche Scientifique CNRS with 359 publications, respectively. In general, the main universities focused on hydrogen production research are located in the country of China and the United States. In addition, low research productivity focused on hydrogen for developing countries was observed.

Figure 5 shows the scientific production related to hydrogen production at a global level.

The results indicate that the largest number of research articles are produced in China (3972), followed by the United States (2490), South Korea (1000), and Japan (897). In general, there is a high concentration of research results in developed countries. In Europe, the largest contributors are Germany (787), Spain (631), and England (610).

The low research productivity in developing countries may be a consequence of the weak collaboration between developed and developing countries, as indicated in Figure 6. This collaboration network between the different countries was extracted from the VOSviewer software, which uses the information obtained from the Web of Science search and downloaded as a.txt file.

Table 2: Academic institutions with the most research on hydrogen production

Institution	No. of publications
Chinese Academy of Sciences	1243
United States Department of Energy Doe	549
Centre National De La Recherche Scientifique CNRS	359
University of Chinese Academy of Sciences Cas	305
Xi An Jiao tong University	271
Harbin Institute of Technology	247
University of Science Technology of China Cas	238
University of California System	227
Council of Scientific Industrial Research Cir. India	225
Tianjin University	223

Figure 5: Worldwide scientific production of hydrogen production

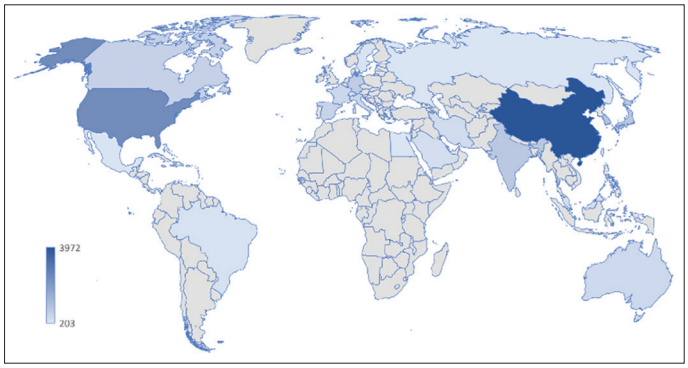


Figure 6: Collaborative work between countries

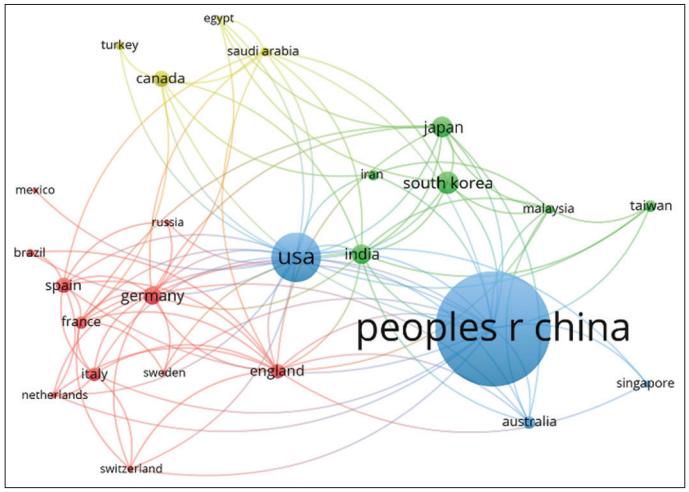
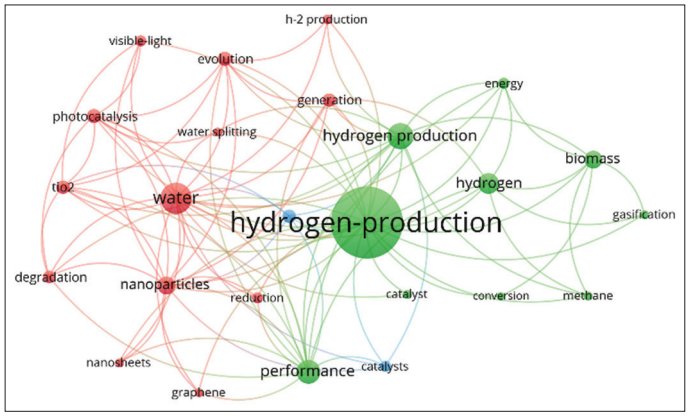


Figure 7: Keywords related to hydrogen production



3.3. Keyword Network Analysis

The keyword network analysis is a bibliometric indicator that allows the generation of clusters to provide a broader view of the research foci associated with hydrogen production. For the construction of the network, the keywords of each publication are extracted using the VOSviewer software. The 24 most frequent keywords are presented in Figure 7. The size of the circle for each word indicates its importance in the period 2010-2019. Among the first keywords are "hydrogen," "production," "performance," "water," "generation" and "nanoparticles."

3.4. Main Thematic Areas and Scientific Communities

Figure 8 shows the main thematic areas focused on hydrogen production. The main subject areas include fuel energy (16.9%), followed by electrochemistry (9.6%), multidisciplinary materials science (8.69%), and chemical engineering (7.84%).

The thematic areas of lower publication are formed by research focused on agricultural engineering, chemical molecular physics, and biochemistry. Figure 9 shows the collaborative network of authors formed by the bibliographic linkage. The top authors in the collaborative network include Wang, X, Zhang, J, Wang, Y, and Zhang, Y.

Figure 8: Thematic areas of publications

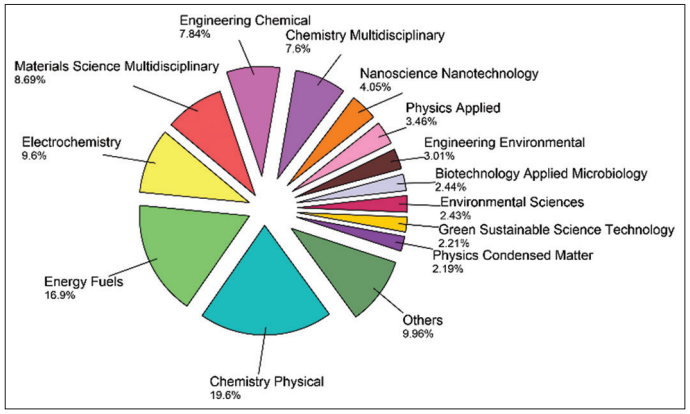
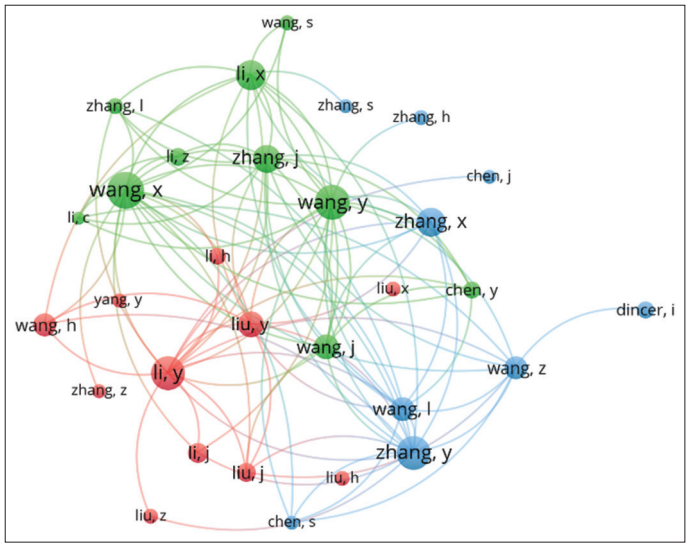


Figure 9: Scientific communities of authors related to hydrogen production



4. CONCLUSIONS

Hydrogen is a promising source of energy with the potential to reduce the negative impacts caused to the environment. For the sustainable use of this energy source, it is necessary to make certain technological advances to ensure its affordability, safety, reliability, security, and efficiency. To analyze the trends focused on hydrogen production, bibliometric analysis has been carried out in this research, which involves the evaluation of data related to the language of research publications, type of document, number of publications, main institutions and countries, keywords, and thematic areas. The following findings emerged from the bibliometric analysis:

The analysis of the scientific production shows that the growth in the number of publications has increased exponentially during the period 2010-2019. Therefore, it is concluded that the topic of hydrogen production will continue to be of interest and the number of publications will probably increase in the coming years.

The research focused on hydrogen production is mainly driven by developed countries, among which China, the United States, South Korea, and Japan stand out. This shows that collaboration networks with developing countries should be strengthened.

Regarding the thematic areas of publication, it was found that the predominant topics are focused on fuel energy (16.9%), electrochemistry (9.6%), and multidisciplinary materials science (8.69%). The most common keywords found in the analysis are "performance," "water," "generation" and "nanoparticles."

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