Hydrogen Production via SMR with Carbon Capture: A Bibliometric Analysis

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The global energy demand should double by 2030, reaching a peak of 80 to 120 million barrels of oil per day. Therefore, to mitigate climate change and reduce the high demand for oil imports, future energies must be clean (carbon-free), renewable and recyclable. A promising solution to reduce dependence on fossil fuels and meet future demands for sustainable energy is to use H_2 as an energy vector. In the literature, some works involve H_2 production via SMR and CO_2 capture. Therefore, a bibliometric analysis of this topic is developed to assess its level of maturity and map the publications most adhering to this research line. From the results obtained, it was observed that the focus of the research already has a particular maturity, but there are still many gaps to be addressed and developed.
Keywords: H_2 Production. Steam Methane Reforming. Carbon Capture. Bibliometrics.

Introduction

Fossil fuel's historic consumption has caused climate change and several environmental and health problems that threaten the global community because, in its combustion, there is significant greenhouse gas emission. In addition, the global energy demand is expected to double by 2030, reaching a peak of 80 to 120 million barrels of oil per day [1]. Therefore, to mitigate climate change and reduce the high demand for oil imports, future energies must be clean (carbon-free), renewable and recyclable [2].

Climate change mitigation is directly related to the circular economy concept, which is characterized as an economic model that proposes the efficient use of resources through the waste, costs, and raw materials reduction and the closed cycles development of products and materials to promote the sustainability and economic growth of activities without causing resource depletion and environmental degradation [3].

The circular economy concept is associated with green chemistry, which focuses on using (bio)renewable resources and the processes and product development that promote human health and environmental protection [4]. From a technological point of view, green chemistry is viable through integrating renewable and greener processes that aim to achieve high production efficiency and yield, using resources efficiently, and generating reduced waste streams [4]. However, the supply of CO_2-free or nearly CO_2-free energy is a big technological challenge that requires significant developments, government initiatives, and industrial innovations. A promising solution to reduce dependence on fossil fuels and meet future demands for sustainable energy is to use H_2 as an energy vector. Then its molecule is carbon-free and has a high energy content, being an essential pillar in the energy transformation that can contribute to global warming mitigation [1].

The hydrogen production route is a determining factor for its environmental feasibility. It can be produced by water electrolysis using renewable energy sources, known as green H_2, by steam methane reforming (SMR) from fossil fuels, gray H_2, by SMR associated with carbon capture and storage, blue H_2 [5], and alternatively can be produced by pyrolysis generating solid carbon as a by-product, turquoise H_2 [6]. With the blue H_2 production characterized by CO_2 capture, a potential for decarbonization of the energy scenario and compliance with climate goals is highlighted. It is expected that, in the long term,

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the investment and production costs of green hydrogen obtained by electrolysis will reduce due to large-scale applications, better production processes, and possibly new technologies [7].

However, in the short and medium term, blue H_2 (low carbon) can be supplied on a large scale from the optimization and improvement of existing technologies, being considered a transition route to the green H_2 exclusive consumption of the future.

In the literature, some works involve H_2 production via SMR and CO_2 capture. Therefore, a bibliometric analysis of this topic is developed to assess the maturity level and map the publications that most adhere to this research line.

Bibliometrics

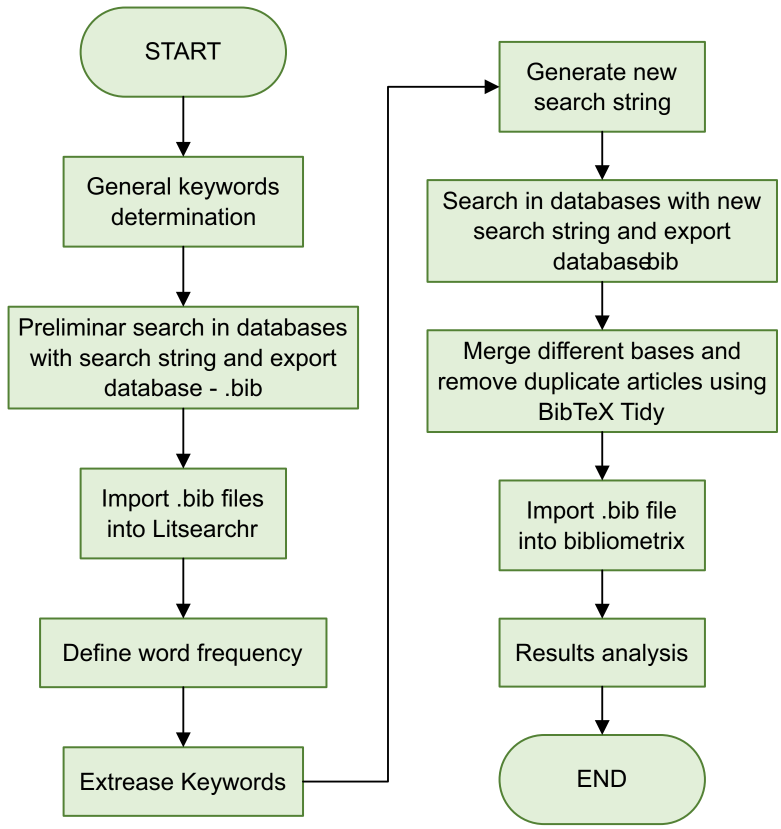
In the research bases, there is a constant increase in publications in the most several areas, so we observed the difficulty for authors to map publications adhering to their research, selecting them according to specific criteria, processing the data obtained, and then using the primary references obtained in the project development [8]. This way, bibliometric analysis tools can guide authors in their search for adherent works. Bibliometrics is a complex scientific mapping that is difficult to execute because it comprises multiple steps and uses different tools. Nevertheless, bibliometric analysis can assess the relevance of publications through indicators and guide the author in selecting references that are more adherent to the exciting topic in a quantitative way. Therefore, this methodology aims to develop a systematic, transparent and reproducible review process based on the statistical measurement of science, scientists, or scientific activity [9].

In the literature, there are several methodologies for bibliometrics development. According to Zupic and Cater [10], a systematic review is based on five steps: (1) Study design – the bibliometric analysis is performed at a specific time to represent a static image of a given research area. In this step, the time interval is defined as what the researcher wants to work on; (2) Data collection - step in which the databases selection of interest occurs, filtering the set of principal documents and exporting the data; (3) Data analysis – use of bibliometric or statistical software tools; (4) Data visualization: stage of choosing the visualization of the results obtained by the software; (5) Interpretation: evaluation and description of the data obtained at the bibliometric research end.Based on Qyyum and colleagues [1], Reis and do Vale [12] proposed the use of the Litsearchr tool to develop a more assertive search string from the development using text-mining and keyword co-occurrence networks to identify important terms to include in a search strategy, associated with the Bibliometrix methodology [13], with the objective of setting up a data matrices for co-citation, coupling, scientific collaboration analysis, and co-word analysis, a methodology known as the Bili Method. This way, Reis and do Vale [12] propose an open-source tool called bibliometrix. With this tool, it is possible to carry out comprehensive bibliometric scientific mapping analyses developed in the R language. Moreover, this tool is flexible and can be quickly updated and integrated with other statistical R packages and is therefore constantly changing, like bibliometrics. In this context, this work presents a bibliometric analysis methodology, based on Reis and do Vale [12], about the H_2 production via methane steam reforming with carbon capture. From the bibliometric analysis, it is possible to consolidate the results of previous research in order to effectively utilize the existing knowledge base and move toward a particular line of research [13].

Materials and Methods

Figure 1 represents the methodology flowchart used. First, a keyword set (string) is created using Boolean operators for the general research context. Then, from the words set, a preliminary search is carried out in the leading research bases, SCOPUS [14] and WEB OF SCIENCE [15], both available on the CAPES PERIODIC Portal. The results obtained in the two databases are exported in bibtex format and used in the Litsearchr platform.

Figure 1. Flowchart of the developed method.



Source: Authors based on Reis & Vale (2022) [12].

In this platform, it is possible to check the word frequency of the publications mapped in the search and generate a new, more specific boolean. At this stage, the user can enter other keywords that they consider relevant in that search, thereby making the set of terms even more specific to the topic at issue. Finally, a new search is performed in the databases from the new word set, and the obtained results are exported and submitted to an analysis for the existence of duplicates by RStudio (BibTeX Tidy) [16]. This way, a more specific database is generated without repeated documents on the exciting topic, so the bibliometric analysis can be performed using Bibliometrix, a tool available in RStudio.

Results and Discussion

From the proposed theme for the development of the bibliometric analysis, H_2 production via steam methane reforming with carbon capture, a general keyword set was elaborated: "hydrogen production" AND ("steam methane reforming" OR "blue hydrogen") AND (simulation OR modeling). The results obtained using these word sets were exported from the SCOPUS and WEB OF SCIENCE databases. It was found that both databases presented very adherent results, but is still necessary to refine the search to map more specific publications. With the ListSearch support and contributions from the authors, new keywords set was generated: ("methane reforming" OR "steam methane reforming process" OR "steam methane reforming" OR "methane conversion" OR "hydrogen Production") AND ("carbon capture" OR "CO_2 removal" OR "CO_2 capture" OR "CO_2 separation") AND (hydrogen OR "blue hydrogen") AND (simulation OR modeling) AND ("natural gas" OR methane).

Making a preliminary results evaluation was found that some publications were outside the interesting niche since the research objective is restricted to the H_2 production via steam methane reforming from natural gas. Therefore, we generate a new search string by inserting a boolean exclude term. The new keywords set is: ("methane reforming" OR "steam methane reforming" OR "methane conversion" OR "hydrogen Production") AND ("carbon capture" OR "CO_2 removal" OR "CO_2 capture" OR "CO_2 separation") AND (hydrogen OR "blue hydrogen") AND (simulation OR modeling) AND ("natural gas") AND NOT (biogas OR pyrolysis OR coal OR gasification OR renewable OR ammonia). After defining the new search strings, new results were obtained and analyzed. Table 1 presents the general results of the research, and it was verified that the results more adherent to the proposed theme appeared from 2005, highlighting that it is a relatively new theme and the annual growth rate and the production graph are in increasing development annually (Figure 2).

Figure 2 shows that this topic increased the number of publications in 2016, with peaks in 2018 and 2020. It was found that, even though the COVID-19 pandemic intensified in 2020, this year, there was a high number of publications in the area, but in 2021 there was a decline that can be justified by the economic crisis resulting from the pandemic.

The most relevant sources in the group of publications related to research were the International Journal of Hydrogen Energy, with 11 publications; Applied Energy, with 5 papers and Energy, with 5 publications. Among these three sources, the International Journal of Hydrogen stands out as the one with the most significant impact, according to the Bibliometrix. Thus, this is the most adherent and renowned journal to publish research on the topic addressed. When evaluating the region with the highest frequency, it was verified that Italy has 20 publications, followed by Norway (16), Spain (15), the United States (15), China (10), and the United Kingdom (9), indicating that Europe is leading the way in this research niche. Figure 3 shows the occurrence of keywords in the results. The carbon dioxide term is cited more often than hydrogen production, highlighting a global concern regarding CO_2 emissions when works in this niche are published since the steam reforming method emits a high amount of CO_2.

Table 1. General results.

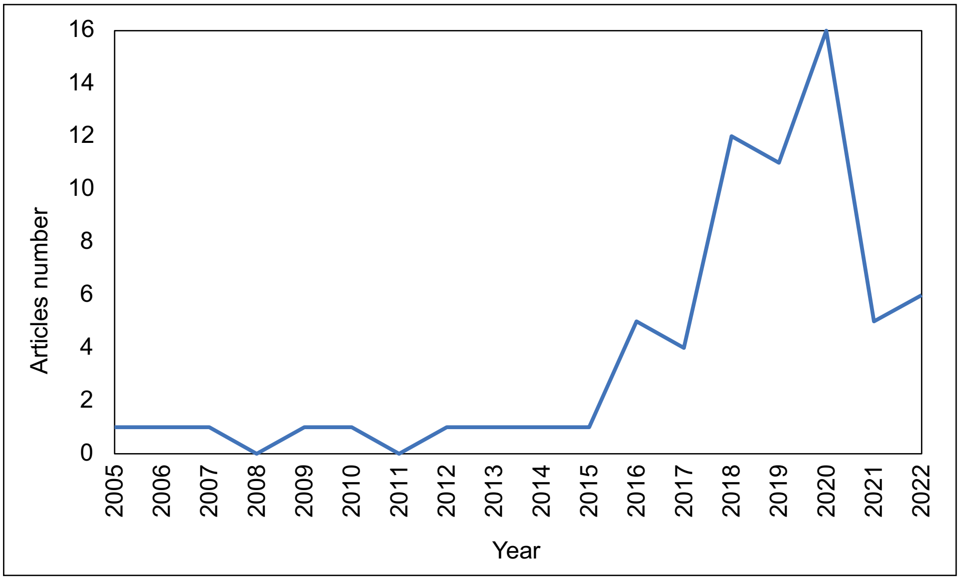
Description	Results
Timespan	2005:2022
Sources (Journals, Books, among others)	32
Documents	68
Annual Growth Rate %	11.12
Average citations per doc	14.75
References	2,927
Author's Keywords (DE)	217
Authors	206
Article; review; others	59; 3; 6

Source: BibTeX Tidy.

Conclusion

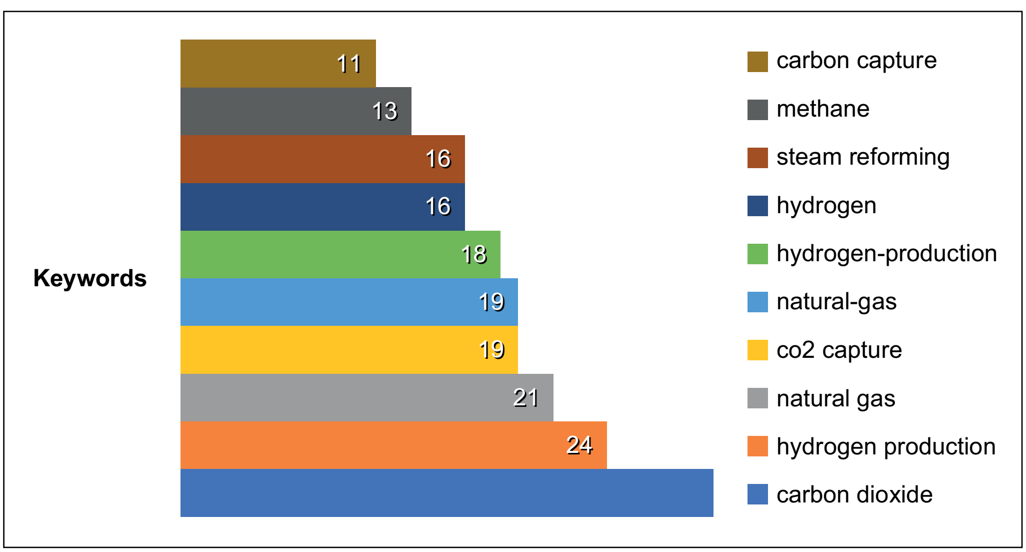
H_2 production is of significant relevance in the global energy challenge today. From the results obtained, it was observed that the research focus already has a particular maturity. However, there are still many gaps to be addressed and developed concerning the research expansion in offshore production, seawater desalinization for generating steam (raw material), and CO_2 compression and injection in mature wells. The SCOPUS and WEB OF SCIENCE databases provide an expressive amount of results (68 publications). However, new search strings must be used, and a manual analysis of the results (title, abstract, and keywords) should be executed to define and map the works even more adherent to the research focus. Was verified that Brazil does not have any representation on the discussed topic, reinforcing the importance of developing this investigation.

Figure 2. Annual Scientific Production.



Source: Bibliometrix.

Figure 3. Occurrence of keywords.



Source: Bibliometrix.

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