Technologies for green hydrogen production: Application of the PROKNOW-C method

Tecnologias para produção de hidrogênio verde: Aplicação do método PROKNOW-C

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1 INTRODUCTION

Hydrogen is the most abundant element in the universe, being found in compound form on planet earth (IEA, 2019). This element can be obtained by several routes, currently obtaining is dominated by the use of fossil fuels, but it can also be obtained from renewable sources. This energy vector can be produced through the separation of water (electrolysis, thermolysis and photolysis) and biomass mechanisms (biological and thermochemical), and hydrogen that is free of CO_2 is called green hydrogen.

Hydrogen stands out for its ability to store and supply large amounts of energy, being considered promising in the energy transition and decarbonization, since it can reduce greenhouse gas emissions, or neutralize them, contributing to the Sustainable Development Goals (SDGs) established by the United Nations (UN) (AGENDA, 2030).

The work is divided as follows, section 1 contemplates the introductory part, section 2 objective of this work, section 3 presents the theoretical framework for conducting the research based on the PROKNOW-C methodology (Knowledge Development Process - Constructivist), section 4 describes the obtaining of the bibliographic portfolio (BP), followed by section 5 that presents the bibliometric analyzes and the final considerations.

2 OBJECTIVE

The aim of this article is to present a systematic review on green hydrogen, from renewable energy sources, as well as production technologies, from the systemic and bibliographic analysis of articles obtained using the PROKNOW-C method.

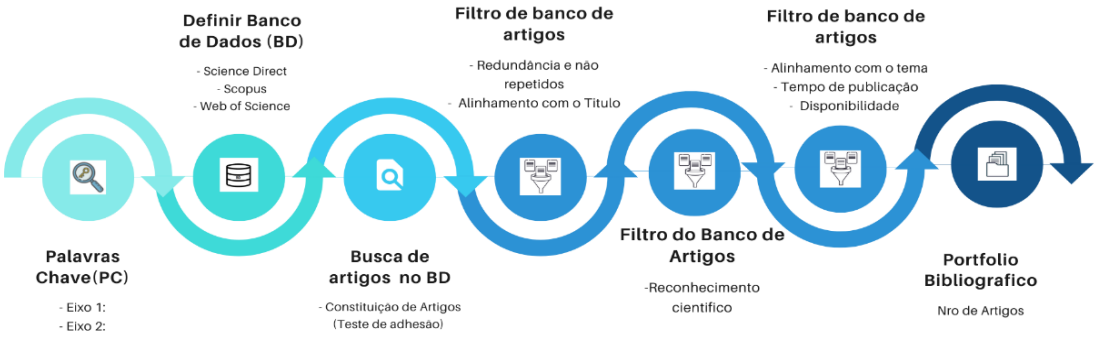
3 METHODOLOGY

To systematize the literature review of the theme, the PROKNOW-C (Knowledge Development Process Constructivist) method will be used, which aims to obtain a bibliographic portfolio relevant to the theme, identifying scientific articles in an efficient and structured way.

The structured steps are: 1) selection of the bibliographic portfolio that will provide the literature review; 2) bibliometric analysis of the bibliographic portfolio; 3) systemic analysis of the bibliographic portfolio; 4) elaboration of the research objectives. (Afonso et al., 2011).

In this work, the first two stages are carried out, selection and bibliometric analysis of the portfolio. For the selection of the portfolio, the search for scientific material is carried out in a systematized way, following a series of sequential procedures, which begin with the definition of the search mechanism for the scientific articles to be used, followed by a series of pre-established procedures until the filtering and selection phase of the relevant bibliographic portfolio on the subject, as shown in Figure 1

Figure 1: Selection of the Bibliographic Portfolio (BP).



Next, the bibliometric analysis of the bibliographic portfolio is carried out, evaluating i) the journals in the portfolio ii) the references, the degree of relevance of the authors, iii) the scientific recognition of the articles and iv) the keywords.

4 DEVELOPMENT

In the first step, the research question was considered: "what are the technologies for the production of green hydrogen?", defining the research axes, where axis 1 refers to green hydrogen and axis 2 refers to hydrogen production / obtaining technologies. Based on these axes, the keywords (PC) were selected, being for axis 1: *Green Hydrogen, Renewable Hydrogen and Low Carbon Hydrogen*, for axis 2, we have the terms

Production Technology, Energy Conversion Processes, Technological Routes. The Boolean operator "*and*" was used for the combination of CP, in addition to wildcard characters next to these operators. For the research axes and the selected CPs, 9 combinations were considered. The databases chosen were *Scopus, Web of Science, Science Direct*. Data collection was performed in three languages: English, Portuguese and Spanish. In order to collect updated information, articles published in the last 7 years were considered.

To verify that the CPs are within the scope of the work, the adherence test was performed, confirming that the CPs are in accordance with the scope of the research.

Until 04/07/2023, 7339 articles were found in the selected databases, which include the combinations and keywords, these results compile the raw article database (BAB).

As different databases were used, it was necessary to exclude duplicate articles from the BAB. For this, two filters were applied, the first to eliminate repeated articles. To manage the publications by exporting the articles from the databases, the *MENDELEY* software and *CAPES* platform were used, and it was possible to eliminate the duplicate articles, excluding 843 articles. The second filter is the alignment of the title, which consists of reading the titles and comparing them with the research theme, the result of this filter excluded 112 articles.

In the next step, the scientific recognition of the articles was coferred, for this the number of citations of the articles was used, which is an important metric for the evaluation of the articles. With the help of the Google Scholar platform, the number of citations is verified and the spreadsheet is created to verify the representativeness of these articles. This evaluation showed that the most cited article received 1900 citations, so to cover more articles, it was excluded from this step. Then it was established that the articles that accounted for 90% of all citations (except for the article with 1900 citations), and which are equivalent to 26 articles conformed to Repository K, with more than 15 citations. Another 36 articles received between 1 and 11 citations and 14 articles had no citations found. These articles (50) make up Repository P.

Then, for the articles that make up Repository K, the abstracts were read in order to verify the real alignment of the article with the scope of the research and 17 aligned articles were considered, being stored in repository A, with the elimination of 9 articles. In the next step, Repository P with lower scientific recognition was analyzed. In this step, factors such as publication period, abstract and alignment were considered, and if the

authors have scientific recognition, being present as authors of the articles in Repository A, establishing 5 articles stored in Repository B. After identification, these repositories are added together forming a single repository, called Repository C, with 22 articles.

In the last step, this repository was read, analyzing the relationship of alignment with the research theme and checking if these articles are available in full. After being identified and analyzed, the Bibliographic Portfolio (BP) is formed with 22 articles.

4.1 BIBLIOMETRIC ANALYSIS

The analysis of the portfolio was carried out, with respect to i) the journals of the portfolio ii) the references, degree of relevance of the authors, iii) the scientific recognition of the articles.

For the analysis of the portfolio, the journals where the articles that are part of the BP were published were considered. In

it is observed that the articles are published in 14 different journals, of which the *International Journal of Hydrogen Energy has* more than 6 articles, followed by the journal *Energies with* 3 articles and the other journals with 1 article.

Regarding the scientific relevance of the PB articles, the authors that stand out are Nikolaidis & Poullikkas, with more than 1900 citations followed by Acar & Dincer, with 524 citations, works published in 2018 and 2019 respectively, while the other articles remain with less than 200 citations, articles published in 2023 maintain citations between 2 and 5 citations. (Al-Orabi et al., 2023; Benghanem et al., 2023; Sarkar et al., 2021; Sarker et al., 2023; Tao et al., 2022). as shown in *Figure 2*:Journals that are part of the PB.

Figure 2:Journals that are part of the PB

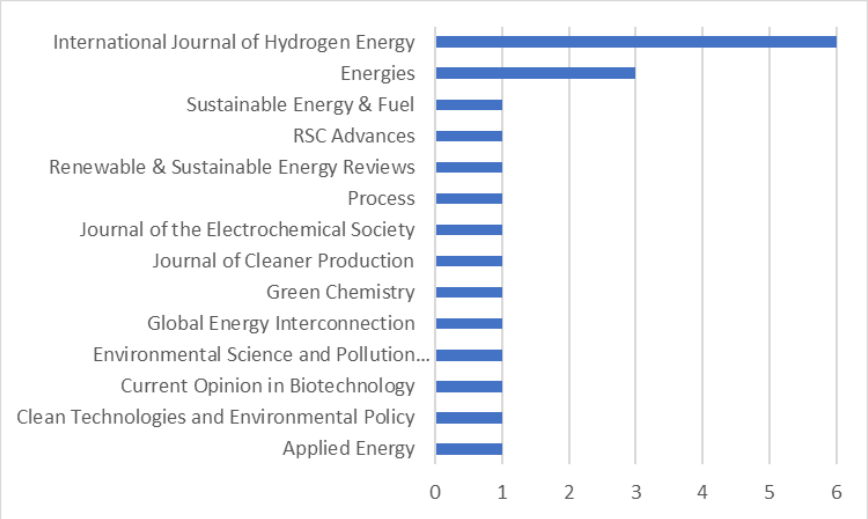
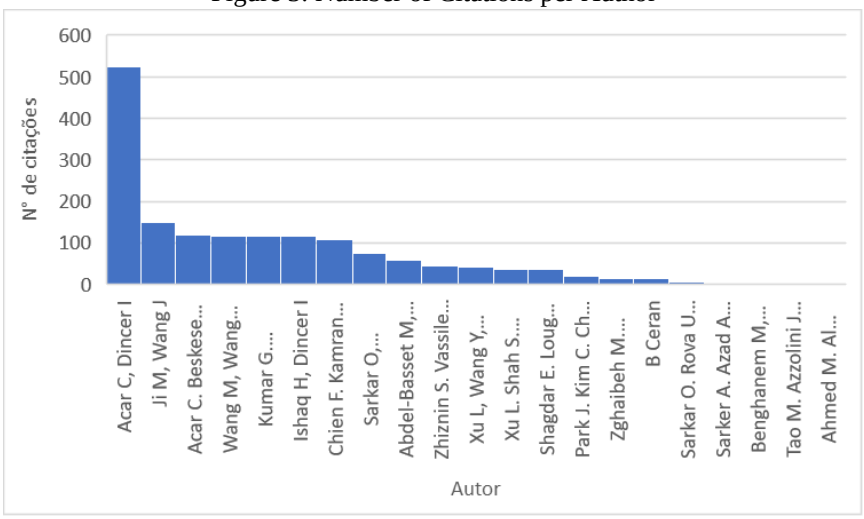
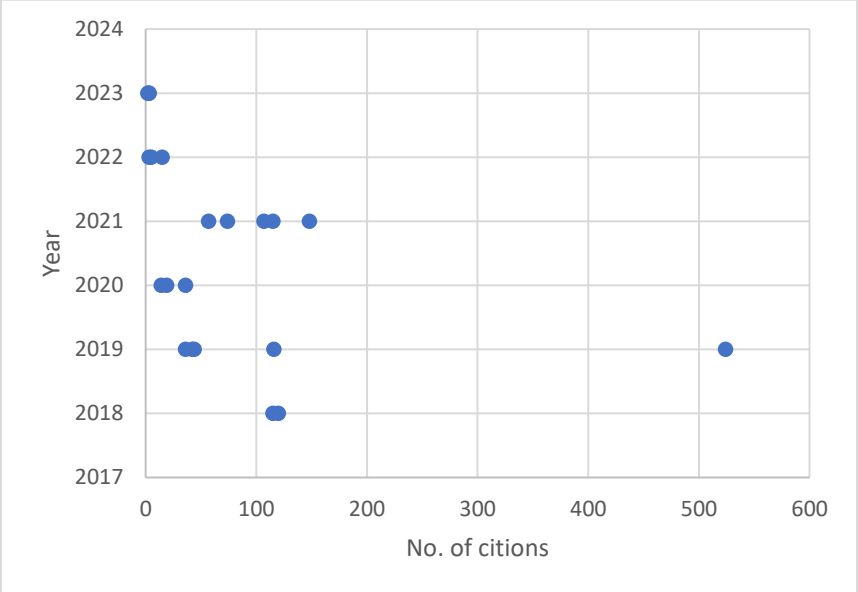


Figure 3: Number of Citations per Author



In order to contemplate the relevance of the articles, the number of citations per year was presented, as follows Figure 4 It can be seen that the publications start to be relevant from 2018 onwards.

Figure 4: Number of Citations per year



5 FINAL CONSIDERATIONS

The research aimed to survey technologies for hydrogen production. This systematic review of the literature was carried out using the Proknow-C method, which allowed obtaining articles relevant to the research topic, which will be used as a benchmark for the incorporation of hydrogen, promoting the energy transition in the energy sector aiming at carbon neutralization.

The process presented made it possible to select references aligned with the research in the last seven years, initially a large number of articles were obtained, and as the filters were applied, a PB with 22 scientifically relevant articles was obtained, including national and international research.

The bibliometric review allowed to visualize some characteristics of the scientific production in a clear way.

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