Biohydrogen Production from Effluents Using Anaerobic Bacteria: A Bibliometric Review

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This study investigates biohydrogen production from effluents using anaerobic bacteria through a bibliometric review supported by VOSviewer software. The potential of biohydrogen as a sustainable energy alternative is highlighted, as evidenced by growing academic interest. The analysis, focused on documents published between 2019 and 2024, reveals 141 publications that show trends, technical and economic challenges, and opportunities for process optimization and technological integration. Continued research is recommended to overcome barriers and promote biohydrogen's viability, also considering its large-scale production's environmental and social impacts.
Keywords: Biohydrogen. Anaerobic Bacteria. VOSviewer. Bibliometric Review.

Biohydrogen represents a promising frontier in the search for renewable energy sources, utilizing biological processes to convert organic compound-rich raw materials, such as biodiesel effluents, into clean energy. Recognized by ANEEL as biomass due to its organic origin and potential for energy generation through conversion processes, these residues offer a sustainable alternative to traditional fossil fuels [1]. By transforming wastewater into biohydrogen, we aim to significantly reduce CO_2 emissions and replace resources such as methane with more environmentally friendly solutions like biomethane or ethanol [2].

Hydrogen-producing bacteria, which inhabit water, soil, and sewage, play a crucial role in this biotechnological process, providing a less polluting route for energy production.

Fermentation, in particular, stands out as a practical and environmentally friendly approach for hydrogen production, promising efficiency and affordability with continued research progress in this area [3].

Among the bacteria studied for biohydrogen production, *Clostridium* and *Enterobacter* species are notable as strict anaerobes. These bacteria can synthesize and produce hydrogen due to the presence of hydrogenase enzymes, which catalyze the reversible oxidation of hydrogen, as shown in Equation 1 [4].

$$(2H^+ + 2e^- \rightarrow H_2.) \qquad \text{Eq 1}$$

This study aims to conduct a comprehensive bibliometric analysis of recent technologies, methods, and innovations in effluents, focusing on glycerol for biohydrogen production through anaerobic fermentation. The investigation seeks to contribute to advancing knowledge and developing more sustainable and efficient techniques for biohydrogen production, aligning with global sustainability goals and objectives for reducing environmental impact.

Materials and Methods

The study methodology centered on conducting a bibliometric analysis concerning hydrogen generation from industrial effluents. The research

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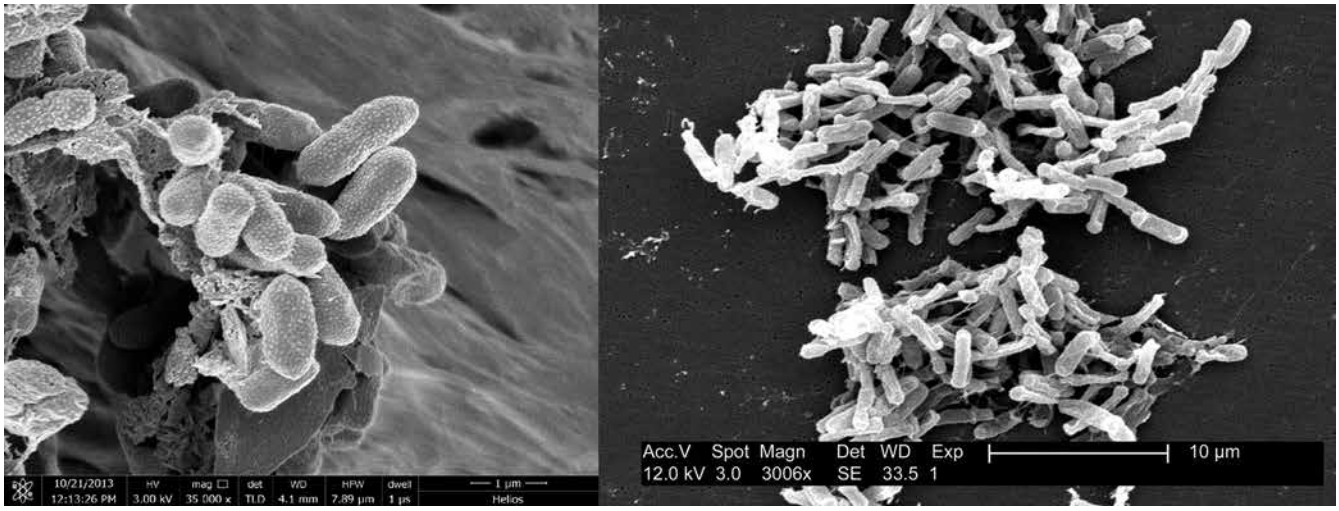
Figure 1. Bacteria of the genus *Enterobacter* sp. (left) and *Clostridium* (right).



Source: Tang (2014) [4].

involved searching for pertinent patents and articles and analyzing documents utilizing Web of Science, Derwent World Patents Index™ (DWPI), and Lens® along with the VOSviewer analysis tool. VOSviewer software played a crucial role in performing a detailed and visual analysis of the gathered data, facilitating the identification of trends and patterns in research through graphs and tables. This tool was instrumental in interpreting bibliographic results and examining patents and articles based on critical indicators such as Biohydrogen, Wastewater, Energy production, Fermentation, Glycerol, Reuse, and Anaerobic processes.

The selection process focused on documents published from 2019 to 2024, filtering out inactive or irrelevant patents and prioritizing recent articles. The rigorous bibliometric analysis concentrated on articles within the same timeframe, delving into prevalent themes and related keywords to evaluate advancements and trends in biohydrogen production from effluents.

Results and Discussion

The bibliometric analysis yielded results from approximately 171 documents analyzed and published between 2019 and 2024, focusing on keywords such as Biohydrogen, Wastewater, Energy production, Fermentation, Glycerol, Reuse, and Anaerobic processes (Figure 2). The analysis of these articles revealed a predominant theme, indicating a notable interest in research within this domain. Consequently, it became feasible to identify the primary trends and inquiries associated with biohydrogen production during the specified period.

By analyzing the articles selected as the foundation of the VOSviewer tool, we can discern the primary structural dynamics within the research field. Notably, 44 articles mentioned keywords like "Glycerol" and "Crude-Glycerol," indicating a substantial interest in this area. The keyword "Fermentation" also appeared in 44 articles, underscoring the enthusiasm for utilizing this fundamental process in biohydrogen production. These keywords serve as foundational pillars for the field, depicted by thicker lines that signify a robust correlation between the keywords and their frequency of occurrence in searches.

Connections between different clusters, as illustrated in Figure 3, such as "Anaerobic Digestion" and "Biodiesel Treatment," underscore the significance of interdisciplinary collaboration and how diverse processes contribute to the progress of biohydrogen technology. This

Figure 2. Annual scientific production.

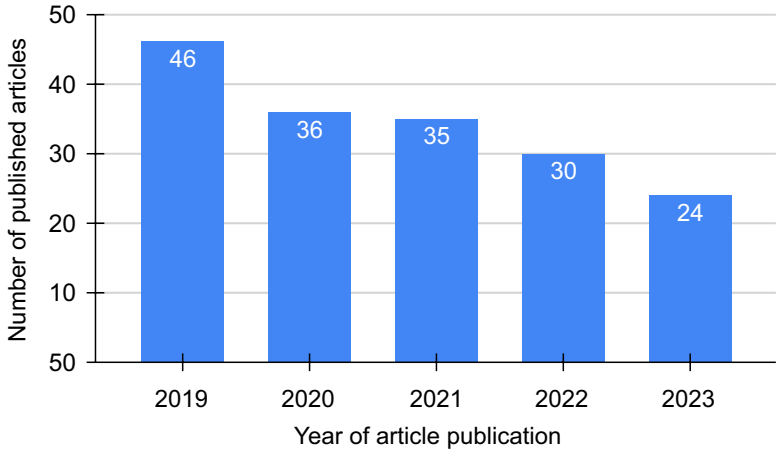
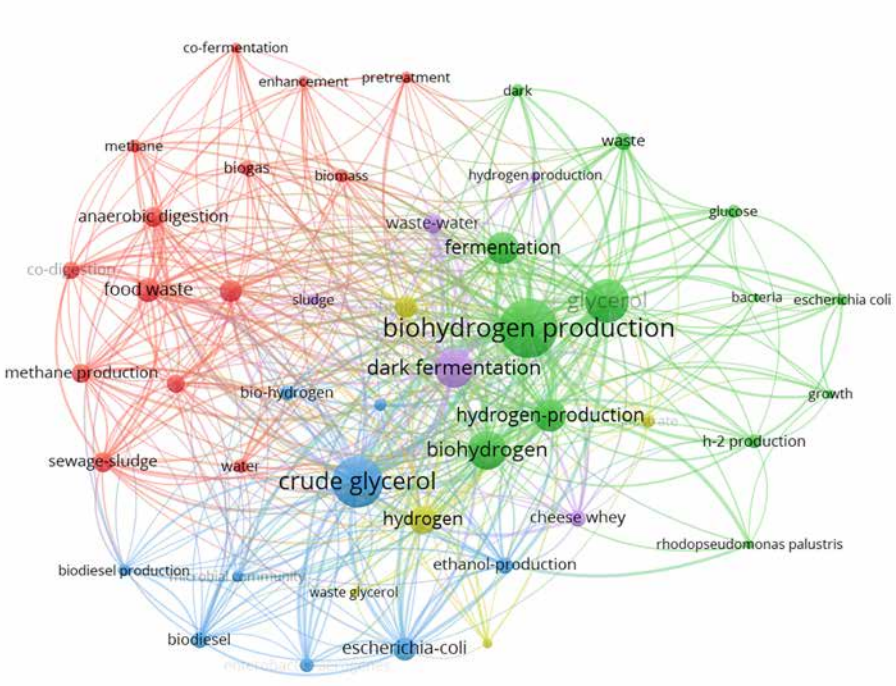


Figure 3. VOSviewer network map for related keywords.



emphasizes the substantial integration between waste treatment and renewable energy production, representing a promising domain for enhancing environmental sustainability and energy efficiency. At the map's periphery, terms like "*Escherichia coli*" and "*Rhodopseudomonas palustris*" denote specific niches within the field or emerging research frontiers. While these terms are less interconnected, they are crucial indicators of potential innovation and the direction of future investigations. Among the prominent studies conducted, the article by Adeknbi and colleagues (2023) reviewed advancements in biohydrogen production from wastewater, focusing on production techniques, technical challenges, and economic considerations. It explores various hydrogen production pathways,

including biophotolysis (direct and indirect), dark fermentation, and photofermentation. Additionally, the article delves into bioreactor design and the technical hurdles associated with utilizing biohydrogen from wastewater. It also provides an economic assessment of biohydrogen production from wastewater. It discusses the potential of this approach to address energy and environmental issues concurrently, particularly in developing regions such as Africa.

Conclusion

This study underscores the increasing relevance of biohydrogen as a sustainable energy alternative, as evidenced by the bibliometric analysis conducted. Although much of the research remains in the laboratory phase, as indicated by the significant number of scientific articles, it reflects a rapidly evolving field and holds considerable potential. Despite the existing technical and economic challenges, such as the need to enhance the implementation of hydrogen plants, the future of biohydrogen appears promising. For future research endeavors, exploring new optimization techniques, developing more efficient fermentation systems, and investigating strategies for integrating this technology into existing value chains is recommended. Additionally, assessing the environmental and social impacts of biohydrogen production on a large scale will be crucial to ensure its sustainability and garner public acceptance.

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