Global Trends in Hydropower Research: A Bibliometric Study

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Abstract*—The transformation of the global energy sector, driven by climate change, energy security and sustainability challenges, has increased attention to renewable energy, especially hydropower as a reliable and stable source. This study aims to analyze the development of hydropower research in sustainable energy systems using an integrated bibliometric approach. Descriptive quantitative methods were applied to 2,151 Scopus indexed documents, analyzed using VOSviewer and Bibliometrix, with a focus on publication trends, keyword co-occurrence, scientific collaboration and citation impact. The results show significant growth in hydropower publications, increasing from 246 documents in 2020 to more than 516 in 2025, indicating its increasing relevance in the global energy transition. The keyword "hydropower" was identified as a central node, which is closely related to renewable energy, decarbonization and sustainability. Furthermore, the findings highlight the multidisciplinary nature of hydropower research, encompassing technological, environmental and future energy innovation aspects, along with the predominance of contributions from a few leading countries and researchers. Overall, this study provides a comprehensive mapping of the scientific dynamics of hydropower and offers strategic insights to support future progress in sustainable energy development.

***Keywords*— bibliometric analysis, renewable energy, hydropower, sustainable energy systems, energy transition**

I. INTRODUCTION

The transformation of the global energy sector is being accelerated by the pressures of climate change, energy security and sustainability. Dependence on fossil fuels has become the main cause of increased greenhouse gas emissions as well as long-term environmental damage [1]. This drives the transition towards a low-carbon energy system based on renewable energy, efficiency and system resilience [2]. Apart from climate mitigation, the energy transition is also important to maintain global supply stability amidst increasing demand and geopolitical complexity [3].

In this context, hydropower has a strategic role as an established and reliable source of renewable energy [4]. Its advantages include high efficiency, long service life and major contribution to global electricity. Compared to solar and wind energy, hydropower is more stable through the provision of base load and pumped storage technology. However, its development faces challenges such as ecological impacts, water resource conflicts, and climate variability [2]. Therefore, hydropower needs to be understood as part of a complex energy system, influenced by geographical factors, scale of development, and integration with other renewable energy sources [5].

Hydropower research is growing rapidly, but is still dominated by technical aspects such as system design, efficiency, and environmental impact [6]. This approach does not fully describe the dynamics of science as a whole. Bibliometric analysis is a relevant method for studying the structure and evolution of research through publication trends, keyword co-occurrence, collaborations and citations [7]. Through analysis of publication trends, co-occurrence of keywords, collaboration networks, and citation analysis, this method is able to reveal patterns of knowledge development and scientific interaction. Visualization using Vosviewer and Bibliometrix allows more comprehensive mapping, although previous studies still tend to be partial and limited to certain aspects [8].

Based on this, there is still a gap in the form of a lack of comprehensive bibliometric studies based on large and integrated datasets. The connection between hydropower and sustainable energy systems is also still limited [9]. Therefore, this research analyzes 2,151 Scopus documents using an integrated bibliometric approach, including publication trends, conceptual structure, collaboration and citations. The results of this research are expected to contribute to the energy transition literature, the development of bibliometric methods, and the strategic direction of sustainable hydropower development.

II. METHODS

This study employs a descriptive quantitative approach based on bibliometric analysis to examine the global development of hydropower research. This method effectively captures publication trends, knowledge structures, and patterns of scientific collaboration [10]. Data were obtained from the Scopus database using the keywords "hydropower," "hydro energy," and "hydroelectric power," resulting in 2,151 relevant documents. The search was conducted across titles, abstracts, and keywords without time restrictions, and the initial results were refined through a screening process to ensure relevance.

The dataset then underwent a cleaning process, including the removal of duplicates, elimination of irrelevant documents, and standardization of author names and

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keywords to ensure consistency. The cleaned data were exported in CSV or RIS formats and analyzed using VOSviewer and RStudio with the Bibliometrix package [11], [12]. The analysis included descriptive analysis to identify publication trends, co-occurrence analysis to explore conceptual structures, co-authorship analysis to map collaboration networks, and citation analysis to assess publication impact. Additionally, co-citation analysis was applied to reveal the intellectual structure based on frequently co-cited references [13]

Visualization techniques, including network, overlay, and density maps, were used to illustrate relationships, topic evolution, and research intensity [14]. The research followed a systematic workflow from data collection and cleaning to analysis, visualization, and interpretation. Although limited to the Scopus database and keyword selection, which may exclude some relevant publications, this approach still provides a representative overview of global hydropower research trends.

III. RESULTS AND DISCUSSION

A. Development of Hydropower Use (Publication Trends)

Publication Trends per Year (2020–2026) The analysis of publication trends indicates a consistent increase in hydropower-related publications from 2020 to 2025. The number of documents rose from 246 in 2020 to more than 516 in 2025. This trend reflects the growing global attention to hydropower as part of renewable energy solutions and the transition toward low-carbon energy systems [15]. A significant rise is particularly observed after 2022, likely driven by the expansion of clean energy policies and international commitments to carbon emission reduction [16]

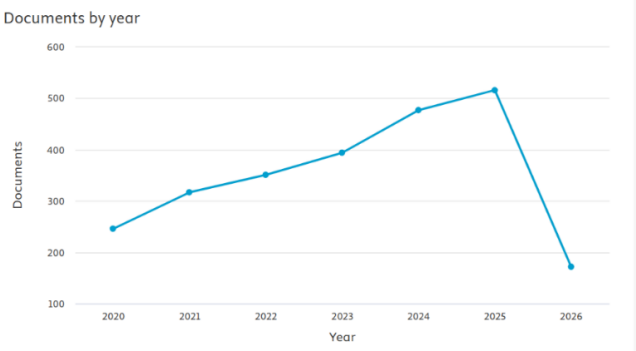

Fig 1. Hydropower Publication Trends 2020-2026

Overall, this trend indicates that hydropower remains a rapidly growing and highly relevant research topic within the global energy agenda, particularly in the context of renewable energy integration and energy security [17].

B. Keyword Network Map (Network Visualization VOSviewer Analysis)

The keyword network visualization shows that "hydroelectric power" serves as the central node in the research structure, characterized by the largest node size and high connectivity. This indicates that the topic is the dominant focus in global hydropower literature. Furthermore, its strong connections with keywords such as "wind power," "energy," "carbon dioxide," and "hydroelectric generators" suggest that hydropower research is not isolated but integrated within a broader energy system context, including energy transition and decarbonization issues [18]

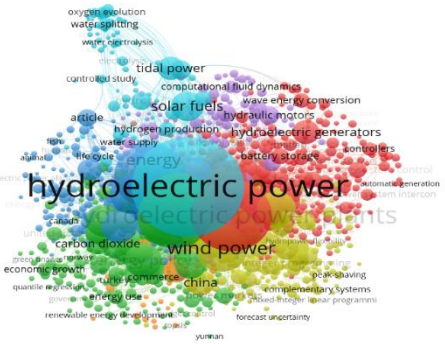

Fig 2. Network Visualization Keywords

In terms of clustering, several major groups represent the main research directions. The technology cluster (e.g., hydroelectric generators, hydraulic motors, controllers) focuses on system development and efficiency improvement. The renewable energy cluster (e.g., wind power, solar fuels, energy policy) reflects the integration of hydropower with other energy sources within sustainable energy systems. Meanwhile, the environmental cluster (e.g., carbon dioxide, climate-related terms) highlights the role of hydropower in emission mitigation [19]. Notably, the emergence of keywords such as battery storage and computational fluid dynamics indicates a trend toward integrating energy storage technologies and advanced simulation approaches in hydropower research[20].

As a complement to the visual network analysis, Table 1 supports the VOSviewer keyword visualization by presenting the conceptual structure of hydropower research based on keyword relationships. "Hydroelectric power" appears as the main node, while the identified clusters represent interconnected research themes within an integrated renewable energy system.

Based on the cluster analysis table, hydropower research demonstrates a strong multidisciplinary character. The red cluster emphasizes the dominance of engineering approaches in power generation technology development, particularly in efficiency, control, and automation, as also reflected in the VOSviewer visualization. Meanwhile, the blue and green clusters indicate that hydropower is studied within the context of energy systems and sustainability, including its relationship with energy, carbon emissions, and economic growth. The yellow cluster highlights the integration of hydropower with other renewable sources such as wind power, leading to hybrid energy systems. The purple and light blue clusters reflect advancements in numerical simulation and integration with future energy technologies such as hydrogen. Overall, these findings confirm the role of hydropower as a key component in an integrated low-carbon energy system.

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Table 1. Hydropower Research Cluster Based on Keyword Analysis

Cluster	Research Focus	Scientific Interpretation
Cluster 1 (Red)	Hydropower generation technology (hydroelectric generators, controllers, automation)	Focuses on engineering aspects to improve efficiency, performance, and control systems, showing dominance of engineering approaches.
Cluster 2 (Green)	Environment and sustainability (carbon dioxide, renewable energy, economic growth)	Highlights hydropower's role in carbon reduction and supporting clean energy-based economic growth.
Cluster 3 (Blue)	Energy systems and life cycle (energy, life cycle, environmental impact)	Represents integrated energy system analysis considering resource efficiency and long-term environmental impacts.
Cluster 4 (Yellow)	Renewable energy integration (wind power, hybrid systems)	Indicates integration with other renewables to enhance system flexibility and address intermittency.
Cluster 5 (Purple)	Simulation and modeling (computational fluid dynamics, modeling)	Emphasizes numerical methods for flow analysis and hydropower system optimization.
Cluster 6 (Light Blue)	Future energy innovation (hydrogen, electrolysis, solar fuels)	Shows linkage with future energy technologies and integration into clean energy systems.

Source: VOSviewer keyword data

C. *Thematic Map (Motor, Main, Basic, and Niche Emerging Themes)*

The thematic map provides deeper insight into the position and development of research themes based on two main dimensions: centrality (relevance) and density (level of development).

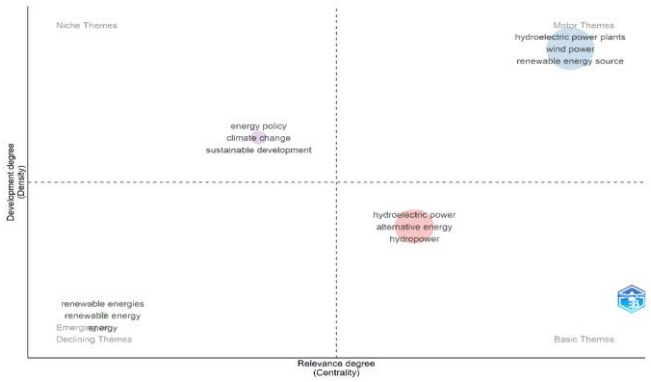

Fig 3. Thematic map of hydropower research

In the motor themes quadrant, topics such as hydroelectric power plants, wind power, and renewable energy sources exhibit high relevance and development, acting as the main drivers of hydropower research. In the basic theme's quadrant, topics such as hydroelectric power and alternative energy show high relevance but still require further development. Meanwhile, niche themes such as energy policy, climate change, and sustainable development are well-developed but less integrated, indicating opportunities to strengthen their linkage with the technical aspects of hydropower [9].

In the emerging or declining themes quadrant, topics such as renewable energy indicate either renewed development or a decline in focus. This suggests that research is becoming more specific, particularly toward technologies such as hydropower and their integration within energy systems [21]

D. *Most Relevant Sources*

The analysis of most relevant sources is conducted to identify the journals or proceedings that dominate hydropower research publications, thereby providing an overview of the main channels of scientific dissemination in the field of renewable energy.

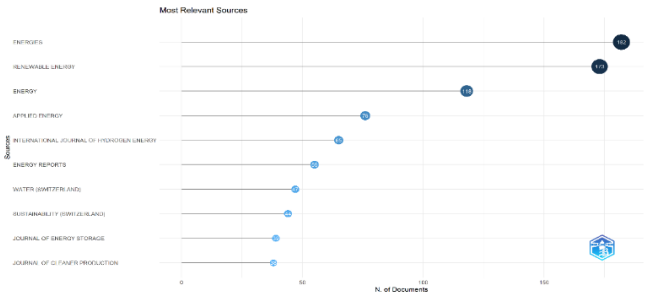

Figure 1. Relevant journal sources

Hydropower publications are dominated by reputable international journals, particularly *Energies* (182 documents) and *Renewable Energy* (173 documents), followed by *Energy* (118 documents) and *Applied Energy* (76 documents). Other journals such as *International Journal of Hydrogen Energy*, *Energy Reports*, and *Water (Switzerland)* also contribute significantly. The absence of conference proceedings

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dominance indicates that research is primarily published in journal articles, reflecting the maturity of the field with high scientific standards and rigorous peer-review processes [22].

E. Country Scientific Production

The analysis of scientific production by country shows the global distribution of hydropower research, dominated by countries with substantial energy capacity and water resources, as indicated by higher color intensity in regions with greater publication output.

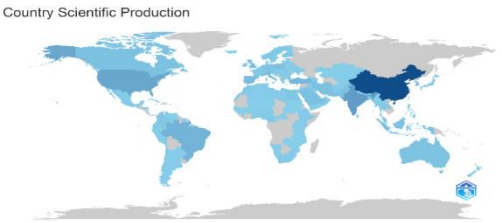
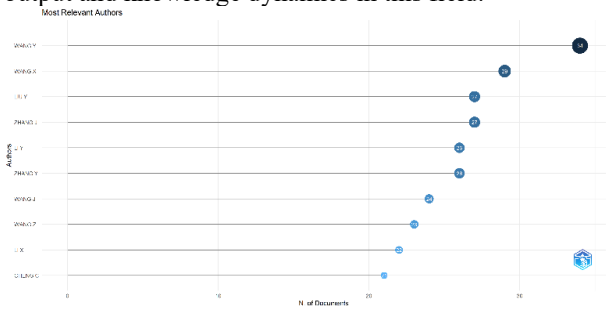


Figure 4. Countries with the most research

Hydropower research contributions are dominated by China as the global leader, followed by the United States, Brazil, and Europe, supported by strong research infrastructure and energy policies. Developing countries remain limited but are gradually increasing, particularly in Asia and Africa. This distribution indicates that scientific production is influenced by academic capacity, water resource potential, and national energy policies [20]. Countries with high hydropower potential tend to be more productive, while also highlighting opportunities for increased contributions from developing countries in the future.

F. Most Relevant Authors

The identification of the most productive authors is essential to reveal key actors in the development of hydropower research. This analysis provides insights into individual contributions and their roles in shaping scientific output and knowledge dynamics in this field.



Graph 2. Development of hydropower publications per year

Based on the data, the most productive author is Wang Y (34 documents), followed by Wang X (29), and Liu Y and Zhang J (27 each), while Li Y, Zhang Y, and Wang J also show high contributions with more than 20 documents. This pattern indicates the dominance of core authors with high productivity as key drivers of hydropower research. Furthermore, the recurrence of certain author names reflects a concentration of contributions within strong scientific collaboration networks [23]. This finding confirms that the development of hydropower research is influenced not only by geographic distribution but also by the strategic role of individual researchers.

The data on the most productive authors are presented in tabular form to facilitate readability and provide structured information on the number and types of publications in hydropower research.

Table 2 Most Prolific Author in Hydropower Research

No	Authors	Publication Source	Type	Number of Publication
1	WANG Y	Energies	Journal	34
2	WANG X	Renewable Energy	Journal	29
3	LIU Y	Energy	Journal	27
4	ZHANG J	Applied Energy	Journal	27
5	LI Y	Sustainability	Journal	25
6	ZHANG Y	Water (Switzerland)	Journal	23
7	WANG J	Energy Reports	Journal	24
8	WANG Z	Journal of Energy Storage	Journal	23
9	LI X	Journal of Cleaner Production	Journal	22
10	CHENG C	Applied Energy	Journal	21

Source: Graph from Hydropower Publications per Year at R studio

Based on the overall table results, hydropower research is dominated by publications in reputable international journals and is supported by the significant contributions of highly productive leading authors who serve as key actors in the development and dissemination of knowledge in this field.

IV. CONCLUSION

The conclusion of this study indicates that global hydropower research has increased significantly, reflecting its important role in the transition toward low-carbon energy systems. Through an integrated bibliometric analysis of 2,151 Scopus-indexed documents, this study identifies publication trends, conceptual structures, scientific collaboration, and citation patterns. The results confirm that “hydroelectric power” serves as the central node in the research network, closely linked to renewable energy, decarbonization, and sustainability. In addition, the research is multidisciplinary and dominated by countries and researchers with high research capacity, providing a comprehensive mapping of the scientific dynamics of hydropower.

This study also strengthens the energy transition literature through an integrated bibliometric approach that systematically reveals the relationships among themes,

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actors, and research trends. Its implications provide strategic insights for the development of sustainable hydropower and its integration with other renewable energy sources. Therefore, future research is recommended to integrate multiple databases, expand analytical variables, and examine the interconnections between technical, policy, and sustainability aspects more holistically to enhance scientific contributions in the field of hydropower.

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