

Potential in Indonesia for Sustainable Energy Transition: A Bibliometric Study

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Abstract—Hydropower is a renewable energy source that has great potential in supporting the transition to a sustainable energy system, especially in Indonesia which has abundant water resources. This research aims to analyze the potential use of hydropower through a bibliometric approach with 2,151 Scopus publications analyzed using VOSviewer and RStudio (bibliometrix). The results show an increasing publication trend, indicating high global attention to hydropower. Co-occurrence analysis reveals close links with the energy system, renewable energy integration, and sustainability, confirming its role in maintaining energy stability. The thematic map shows that hydropower has a strategic position as a basic theme and driving force. Meanwhile, analysis of sources and authors shows the dominance of developed countries, especially China, which is correlated with research capacity. In developing national energy, Indonesia has great potential, but its utilization is not yet optimal due to limited research, technology and collaboration. Therefore, it is necessary to strengthen research capacity, international cooperation, and an integrated energy system approach to support national energy security and sustainability.

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

I. INTRODUCTION

The global energy crisis and the accelerating pace of climate change have created an urgent need to transition from fossil fuel-based energy systems to more sustainable renewable energy sources. To date, the dominance of fossil energy remains the primary driver of greenhouse gas emissions and environmental degradation [1]. This condition highlights the importance of developing low-carbon energy systems that are not only efficient but also capable of ensuring long-term energy stability and security. In this context, hydropower emerges as a strategic solution due to its high efficiency, mature nonology, and significant contribution to global electricity production [2]. Compared to intermittent sources such as solar and wind, hydropower offers advantages in maintaining grid stability through load balancing and energy storage capabilities [3]. However, its development also faces challenges, including environmental impacts and dependence on hydrological and climatic conditions[4].

From an energy systems perspective, hydropower is not merely a power generation ebut an integral component of a complex and interconnected energy system. Its development spans various scales, from large-scale to small and pico hydropower, and is highly influenced by geographical and climatic conditions. Beyond energy supply, hydropower supports the integration of other renewable energy sources and enhances system flexibility and reliability [5]. However,

a key issue remains the limited comprehensive understanding of global hydropower research development, particularly in relation to its strategic role in sustainable energy systems. Most existing studies still focus on technical aspects such as efficiency, design, and environmental impacts, and therefore fail to fully capture the structure of knowledge and research dynamics [6].

Several previous studies have applied bibliometric approaches to analyze renewable energy development, including hydropower, focusing on publication trends, sustainability issues, and topic mapping [7]. However, these studies are generally partial and fragmented, lacking the integration of multiple analytical dimensions such as conceptual structure (keyword co-occurrence), scientific collaboration networks (co-authorship), and citation analysis within a comprehensive framework. In addition, the use of limited datasets remains a constraint in producing a representative overview of global hydropower research development. This indicates a significant research gap, particularly in providing large-scale bibliometric analyses capable of linking research trends with the broader context of sustainable energy systems [8].

Based on these conditions, this study is both important and timely in providing a more comprehensive understanding of the hydropower research landscape. This study aims to analyze publication trends based on 2,151 Scopus-indexed documents, identify conceptual structures using VOSviewer, examine scientific collaboration networks, and evaluate publication impact through citation analysis. The significance of this study lies in its contribution to integrating various bibliometric approaches into a unified framework, enabling a deeper understanding of research development patterns [9]. Furthermore, this study offers practical relevance by providing strategic insights for researchers and policymakers in shaping future directions for hydropower research and development, particularly in supporting the transition toward sustainable energy systems [10]

II. METHODS

This study employs a descriptive quantitative approach based on bibliometric analysis to systematically examine the global development of hydropower research. This method is selected for its ability to identify publication patterns, map knowledge structures, and reveal scientific collaboration networks within a research field [11]. Data were obtained from the Scopus database, which offers broad coverage and high indexing quality. The search process was conducted using a combination of keywords such as “hydropower,”

“hydroelectric power,” and “renewable energy” in the title, abstract, and keyword fields without any time restrictions. The search results were then filtered, resulting in 2,151 relevant documents for further analysis.

The next stage involved data screening and cleaning to ensure the quality and consistency of the dataset. This process included removing duplicates, excluding irrelevant documents, and standardizing data such as author names, affiliations, and keywords. The cleaned data were exported in CSV and RIS formats to facilitate further analysis. Several analytical techniques were applied, including descriptive analysis to examine publication trends and research distribution, co-occurrence analysis to identify key themes and keyword relationships, co-authorship analysis to explore scientific collaboration patterns, and citation and co-citation analyses to evaluate publication impact and map the intellectual structure of hydropower research.

In its implementation, this study utilizes two main tools, namely VOSviewer and RStudio (Bibliometrix). RStudio is used for data processing and statistical analysis, while VOSviewer is employed to visualize bibliometric networks in the form of network, overlay, and density visualizations. The research workflow is carried out systematically, starting from data collection, cleaning, processing, and visualization to result interpretation. Although this study relies solely on the Scopus database and selected keywords, the use of a large dataset and integrated analytical methods provides representative results in describing global hydropower research trends and supports the development of sustainable energy systems [12].

III. RESULTS AND DISCUSSION

A. Development of Hydropower Use (Publication Trends)

The following figure presents the trend in the number of hydropower research publications, reflecting the dynamic development of studies over time. This trend serves as an important indicator in assessing the increasing scientific attention as well as the potential use of hydropower in supporting sustainable energy development in Indonesia [13].

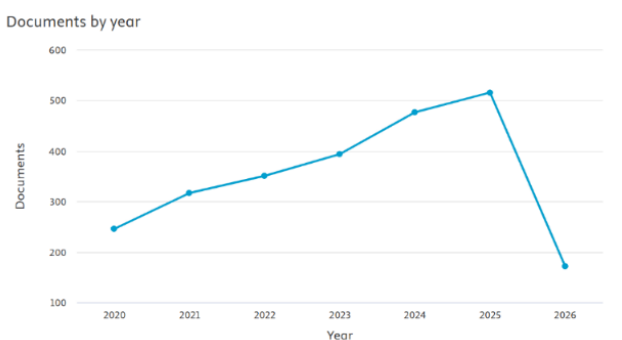


Fig 1. Hydropower Publication Trends 2020-2026

The analysis of publication trends within the bibliometric network shows a significant increase in hydropower research during the 2020–2025 period, reflecting the intensifying global scientific attention to the role of hydropower as a strategic solution in the energy transition [14]. This increase not only indicates quantitative growth in publications but also

demonstrates an expansion in the scope of research, encompassing technical aspects, energy system integration, and environmental sustainability. Although a decline appears in 2026, this phenomenon is more likely due to data limitations for the ongoing year rather than a substantive decrease in research interest [15]. Overall, this trend confirms that hydropower has strong long-term development prospects and remains relevant within the dynamics of global energy systems. In line with this condition, Indonesia has significant potential to develop hydropower as a key pillar in strengthening national energy security, particularly in supporting energy diversification and accelerating the transition toward a sustainable energy system [16].

B. Conceptual Potential of Hydropower Utilization (Co-occurrence)

The following figure presents a network visualization of hydropower research, illustrating the interconnections among topics within the scientific literature. This visualization serves as a basis for identifying the knowledge structure and the potential utilization of hydropower within energy systems, particularly in the context of sustainable energy development in Indonesia [7].

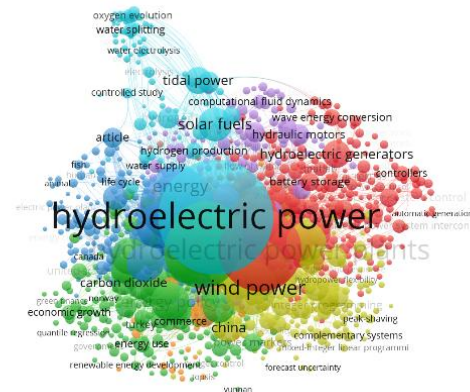


Fig 2. Network Visualization Keywords

The VOSviewer-based co-occurrence network analysis shows that *hydroelectric power* occupies a central node with high centrality and link strength, reflecting its dominant role in the conceptual structure of energy research. Its strong connections with keywords such as *energy systems*, *wind power*, and *battery storage* indicate that hydropower functions not only as a conventional energy source but also as a strategic component in integrated energy systems, particularly in maintaining system stability and flexibility in renewable energy–dominated systems characterized by intermittency [17], [18]. This relationship pattern confirms the role of hydropower as balancing power, supporting the reliability of modern energy systems. Based on these findings, the potential use of hydropower is highly significant, not only due to abundant water resources but also because of its capability to be optimized as a key element in renewable energy integration, grid stability enhancement, and the acceleration of the transition toward sustainable energy systems [5].

To strengthen the visual interpretation of the network map, keyword extraction and clustering were conducted to systematically identify the intellectual structure of the research field. The presentation of results in tabular form aims to highlight key research focuses, inter-topic relationships, and potential research gaps that may not be directly visible in the network visualization [19].

Table 1. Hydropower Research Cluster Based on Keyword Analysis

Cluster	Focus Area	Scientific Interpretation
C1 (Red)	Technical & operational (generators, control systems)	Mature technology improves efficiency and performance
C2 (Green)	Environment & policy (carbon, energy policy)	Supports decarbonization and sustainable energy
C3 (Yellow)	Energy system integration (wind, power systems, storage)	Balances renewable energy systems
C4 (Blue)	Energy systems & sustainability (life cycle, water resources)	Enhances system efficiency and water management
C5 (Purple)	Advanced technology (CFD, hydrogen)	Integrates with future energy technologies
C6 (Light Blue)	Water-based energy (tidal, electrolysis)	Enables diversification of water-based energy

Source: VOSviewer keyword data

Based on the cluster classification, each theme represents complementary dimensions in illustrating the potential use of hydropower. The technical cluster emphasizes the importance of technological development to improve power plant efficiency [20], while the environmental and policy cluster highlights its role in supporting decarbonization and energy transition. The energy integration cluster indicates the function of hydropower as a balancing system for intermittent energy sources [21]. In addition, the sustainability cluster underscores life-cycle efficiency and water resource management, whereas the advanced technology and water-based energy clusters point toward future technological innovations. Overall, hydropower has strong strategic potential in supporting sustainable energy systems in Indonesia [18].

C. Strategic Potential of Hydropower Utilization (Thematic Map)

The following figure presents a thematic map of hydropower research, illustrating the position and level of

development of themes based on the dimensions of centrality and density. This analysis is used to identify the strategic role of each theme and the potential development of hydropower in supporting sustainable energy systems in Indonesia [22].

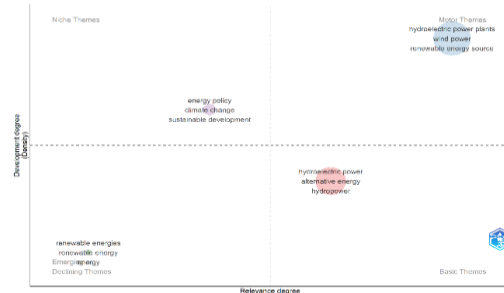
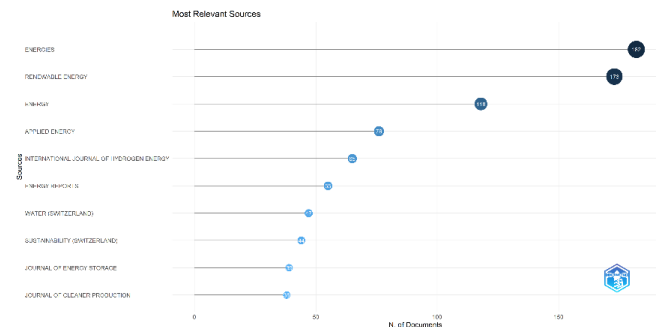


Fig 3. Thematic map of hydropower research

The thematic map analysis indicates that hydropower occupies a strategic position within the renewable energy research landscape, as reflected by the distribution of themes based on the dimensions of centrality and density. The thematic map analysis indicates that hydropower occupies a strategic position within the renewable energy research landscape, as reflected by the distribution of themes based on the dimensions of centrality and density [23]. On the other hand, the appearance of hydropower within the basic themes quadrant indicates that this technology has strong conceptual relevance as a research foundation, yet still requires further development to achieve optimal utilization [24]. Its association with issues such as climate change and sustainable development highlights that hydropower is not only positioned as a technical solution but also as a strategic instrument in supporting global sustainable development agendas. Based on these findings, Indonesia has significant potential to develop hydropower not only as a primary energy source but also as a key element in building an integrated, sustainable, and climate-resilient energy system for the future [5].

D. Most Relevant Sources

To obtain a more comprehensive understanding of the global development of hydropower research, an analysis of the most relevant sources was conducted as an approach to identify patterns of publication dominance, scientific research focus, and emerging topic trends within the international scholarly literature [25].



Graph 1. Relevant journal sources

The analysis results indicate that journals such as *Energies*, *Renewable Energy*, and *Energy* serve as the primary sources of hydropower publications, confirming that this field is dominated by high-impact journals focusing on renewable energy, energy systems, and sustainability. This is further supported by journals such as *Applied Energy* and *Journal of Cleaner Production*, which emphasize efficiency and environmental impact aspects [26]. These findings suggest that global research trends are directed toward the integration of hydropower into sustainable energy systems, improving efficiency, and reducing environmental impacts [27].

E. Country Scientific Production

The distribution of scientific production by country is used to identify hydropower research development centers and their relevance to potential utilization. The distribution of scientific production by country is used to identify the main centers of hydropower research development and their relevance to its utilization potential [28]. This analysis provides a basis for assessing a country’s research capacity in advancing technology, policy, and energy system integration [18].

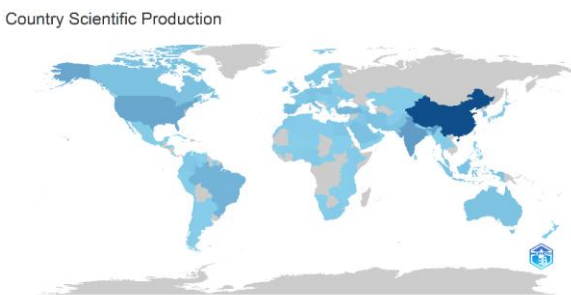
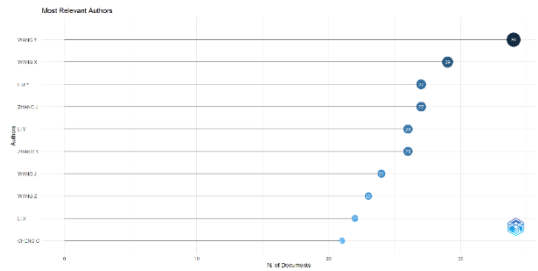


Fig 4. Countries with the most research

The visualization results indicate that countries such as China, the United States, Brazil, and Europe dominate hydropower scientific production, reflecting their strong research capacity and ability to optimize its utilization within energy systems [29]. The high intensity of research contributes to improvements in technological efficiency, system innovation, and integration with other renewable energy sources. This suggests that the potential use of hydropower is determined not only by water resource availability, but also by scientific and technological capacity [5].

F. Most Relevant Authors

To gain a deeper understanding of key actors in hydropower research, an analysis of the most relevant authors was conducted to identify scientific contributions, productivity patterns, and the direction of research development [30].



Graph 2. Development of hydropower publications per year

The analysis results indicate that the most productive authors are predominantly from Asia, particularly China, reflecting strong research capacity and a focus on hydropower technology, efficiency, and system integration [27]. This dominance suggests that scientific productivity contributes significantly to optimizing hydropower utilization through innovation.

To provide a more structured overview of researcher contributions in the hydropower field, a table of the most relevant authors is presented, including information on publication counts, primary publication sources, and each author’s scientific contribution focus [31]

Table 2 Most Prolific Author in Hydropower Research

No	Author	Pubs	Main Source	Contribution
1	Wang Y	34	Energies	Tech & system development
2	Wang X	29	Renewable Energy	System optimization & integration
3	Liu Y	27	Energy	Efficiency & performance
4	Zhang J	27	Applied Energy	Modeling & technical analysis
5	Li Y	25	Energy Reports	Sustainability analysis
6	Zhang Y	23	Journal of Cleaner Production	RE integration
7	Wang J	24	Int. Journal of Hydrogen Energy	Control & technology
8	Wang Z	23	Sustainability (Switzerland)	Energy performance
9	Li X	22	Water (Switzerland)	Optimization
10	Cheng C	21	Energy Policy	Policy analysis

Source: Graph from Hydropower Publications per Year at Rstudio

Based on the table, it is evident that the most productive authors predominantly publish in reputable international energy journals, such as *Energies*, *Renewable Energy*, and *Energy*. Each author demonstrates a relatively specific research focus, ranging from technological development and system optimization to efficiency, energy integration, and policy aspects [32]. This indicates that hydropower research is developing in a multidisciplinary manner, with a strong emphasis on system performance improvement and energy sustainability. The tabular presentation allows readers to easily understand each author's contributions and the main research directions within the hydropower field [33].

IV. CONCLUSION

Based on the bibliometric analysis of hydropower publications indexed in Scopus, there is a significant increase in research trends, reflecting strong global attention toward renewable energy development and energy system sustainability. The co-occurrence analysis reveals that key terms such as *hydroelectric power*, *renewable energy*, and *energy policy* dominate the research structure, indicating that hydropower studies have evolved from purely technical aspects toward a more integrated approach encompassing energy systems, policy, and sustainability issues. Furthermore, thematic mapping identifies topics such as hydropower plants, renewable energy, and energy system integration as motor themes, highlighting their strategic role and high level of development in the global research landscape.

From a geographical perspective, the dominance of countries such as China, the United States, Brazil, and European nations indicates that research capacity and energy policies play a crucial role in advancing hydropower research. These findings are also highly relevant to Indonesia, a country with abundant water resources, suggesting that this analysis can serve as a foundation for developing hydropower strategies as part of the national renewable energy mix. Moreover, the dominance of publications in high-reputation journals indicates that hydropower research has reached a high level of scientific maturity and can support evidence-based policymaking. Therefore, this study not only contributes theoretically but also provides practical implications for supporting sustainable energy transition in Indonesia, particularly in optimizing hydropower as a reliable and environmentally friendly energy source.

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