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A BIBLIOMETRIC STUDY ON ENERGY LITERACY AND EDUCATION: MAPPING TRENDS, FOCUS AREAS, AND RESEARCH GAPS

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ABSTRACT

Energy literacy, encompassing knowledge, awareness, and responsible energy-related behaviors, is increasingly acknowledged as essential for addressing global challenges such as climate change, resource depletion, and the transition to renewable energy. Education is pivotal in fostering energy literacy across various levels, from primary to higher education. Despite growing initiatives to integrate energy-related topics into curricula, the research landscape on energy literacy education remains fragmented, with scope, methodology, and geographical focus inconsistencies. This study undertakes a bibliometric analysis to map global research trends in energy literacy over the past decade, identify the most influential publications, and highlight the underexplored areas. Using data from the Scopus database, this analysis focuses on articles published between 2015 and 2024. Key findings reveal a steady increase in research output, driven by heightened awareness and policy focus, with a peak in 2023. Additionally, the study identifies the most-cited works, key contributors to the field, and emerging themes, such as the integration of technology in energy literacy education. However, significant gaps remain, particularly in understanding the impact of cultural, contextual, and digital learning environments on long-term behavioral change. The study concludes with recommendations for a more holistic research approach that integrates cognitive, affective, and behavioral dimensions, and emphasizes the need for broader, more inclusive research platforms to promote diversity and innovation in the field.

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INTRODUCTION

Energy literacy, encompassing knowledge, awareness, and responsible energy-related behaviors, is increasingly recognized as a critical educational goal for addressing global energy challenges, such as climate change, resource depletion, and the transition to renewable energy (Papavasileiou et al., 2022; Zakaria et al., 2019). Understanding energy systems and their environmental, economic, and societal impacts is essential for fostering sustainable energy consumption patterns and promoting informed decision making among individuals and communities (Martins et al., 2020).

Education plays a pivotal role in developing energy literacy, starting with primary education and extending through secondary and higher education. Efforts to integrate energy-related topics into curricula have increased in recent years, with schools and universities implementing various initiatives aimed at raising energy awareness and promoting sustainable behaviors (Castañeda-Garza & Valerio-Ureña, 2022). However, despite this growing focus, the field of energy literacy education is characterized by fragmented research, with studies varying in scope, methodology, and geographical focus (Santillán & Cedano, 2023).

While the importance of energy literacy is widely acknowledged, its integration of energy literacy into formal education systems remains inconsistent and underexplored, particularly across different educational levels and contexts. Research in this area is often fragmented, with studies addressing different dimensions of energy literacy—cognitive (knowledge), affective (attitudes), and behavioral (practices)—but lacks a comprehensive approach that ties these dimensions together (DeWaters & Powers, 2011).

Moreover, the impact of various teaching methods, curricular designs, and cultural contexts on energy literacy development has not been adequately studied. For example, while many educational programs have successfully increased students' energy knowledge, translating this knowledge into long-term energy-saving behaviors remains a significant challenge (Rohmatulloh et al., 2023). There is also limited research on the role of digital and virtual learning environments in enhancing energy literacy, particularly considering the global shift towards online education (Ji et al., 2023).

To address these gaps, a comprehensive analysis of the existing literature is required. Such an analysis can help identify key trends, influential publications, and underexplored areas in energy literacy education research, providing valuable insights for educators, policymakers, and researchers aiming to promote sustainable energy behaviors.

OBJECTIVES

The primary aim of this bibliometric study was to answer the following questions:

1. In what manner have global research trends in energy literacy progressed over the past ten years?
2. What are the most cited articles?
3. What are the trends in document production by country?
4. What are the popular keywords related to the study and have they evolved?
5. What are the patterns of co-authorship within the country?
6. Which sources are most popular among researchers for publishing work related to energy literacy and education?

LITERATURE REVIEW

The literature review includes the definition of Creativity, SEN Students with Learning Disabilities, and 21st Century Learning.

ENERGY LITERACY: CONCEPTS AND SIGNIFICANCE

Energy literacy is broadly defined as the understanding of energy-related concepts, ability to make informed decisions about energy use, and adoption of behaviors that contribute to energy conservation and sustainability

(DeWaters & Powers, 2011). It includes three key dimensions: cognitive (knowledge), affective (attitudes), and behavioral (practices). Research has shown that individuals with higher levels of energy literacy are more likely to engage in energy-efficient behaviors and support policies aimed at reducing carbon emissions (Lee et al., 2015).

ENERGY EDUCATION IN DIFFERENT CONTEXTS

Energy education has been integrated at various educational levels, from primary schools to universities, with the goal of enhancing students' understanding of energy issues and promoting sustainable energy behaviors. In primary and secondary education, energy literacy is often incorporated into science, technology, and environmental studies curricula (Castañeda-Garza and Valerio-Ureña 2022). At the higher education level, specialized programmes aim to prepare students for careers in energy-related fields by providing in-depth knowledge of energy systems and sustainability challenges (Martins et al., 2019).

Despite these efforts, the integration of energy literacy into educational systems remains uneven across regions and educational levels. Furthermore, the effectiveness of different teaching methods, such as hands-on learning, experiential learning, and digital learning environments, in promoting energy literacy has not yet been fully explored (Ji et al., 2023).

CHALLENGES IN BEHAVIORAL CHANGE

One of the critical challenges in energy education is the gap between knowledge and behavior. While educational programs often succeed in increasing students' energy knowledge, translating this knowledge into concrete, long-term energy-saving actions remains a significant challenge (Rohmatulloh et al., 2023). Research has emphasized the need for a more holistic approach to energy education that goes beyond cognitive learning to include affective and behavioral dimensions. Programs that incorporate real-world applications and community involvement have shown promise in bridging this gap by engaging students in practical energy-saving initiatives (Merritt et al. 2019).

EMERGING TRENDS AND GAPS IN RESEARCH

Despite a growing body of research on energy literacy and education, several gaps remain. There is limited research on how cultural and contextual factors influence energy literacy outcomes, particularly in non-Western settings (Rohmatulloh et al. 2023). Additionally, while much of the existing literature focuses on the cognitive aspects of energy literacy, less attention has been paid to the affective and behavioral dimensions, especially in relation to long-term behavior change (Santillán & Cedano, 2023). Moreover, the role of digital and virtual learning environments in enhancing energy literacy is an emerging area of interest, particularly given the increasing shift towards online education (Ji et al., 2023).

This bibliometric analysis aimed to address these gaps by providing a systematic review of the literature on energy literacy and education. By identifying key trends, influential studies, and underexplored areas, this study seeks to contribute to ongoing efforts to improve energy literacy education worldwide and inform future research and policy initiatives.

METHODOLOGY

Bibliometrics refers to the collection, management, and analysis of bibliographic data derived from scientific publications (Verbeek et al. 2002). Beyond basic descriptive statistics, such as publication years, journal sources, and author classifications (Wu & Wu, 2017), bibliometrics also involves more sophisticated methods like document co-citation analysis. For an effective literature review, bibliography creation, and reliable research outcomes, an iterative process of keyword selection, literature search, and data analysis is crucial (Fahimnia et al., 2015).

The following section describes the process for selecting keywords, screening initial search results, and refining them. To ensure the study is indexed and has an academic level, data from Scopus was utilized. This study focuses on top-tier journals to gain theoretical insights into the evolution of the research domain. Scopus offers a wide range of articles and many options for obtaining them, which is why it was chosen for this study (Ibda et al., 2023 ; Mwita, 2022). The study covers articles published between 2015 and December 2024, which is a 10-year period used to examine trends and performance in energy literacy and education research. Recent studies have continued to emphasize the importance of bibliometrics for understanding the development of research domains. For example, a 2023 study on Green Energy Literacy used bibliometric methods to evaluate trends and collaboration networks in this field, demonstrating the utility of bibliometrics for mapping academic progress and identifying key research areas (Gudiman et al., 2023).

DATA SEARCH STRATEGY

The study employed a systematic process to identify search terms for article retrieval. Initially, Scopus was queried using the search string: TITLE-ABS-KEY (("energy literacy" OR "energy education" OR "energy awareness" OR "energy knowledge") AND (education OR school* OR curriculum OR teach* OR learn* OR train* OR instruct*)), resulting in 1,080 articles. The query was then refined to focus on specific research types, including articles, conference papers, and book chapters, narrowing the results to 600 articles. These were further filtered to include only research articles in English and final stage of publications within 10 years duration. Ultimately, a total number of articles was identified for a 10-year period, from 2015 to 2024. As of December 2023, all articles related to energy literacy and education from the Scopus database were included in the study. This 10-year span was selected to ensure consistent data on research trends involving the energy literacy and education.

DATA ANALYSIS

Data sets, including publication year, title, author, journal, citation counts, and keywords, were retrieved in PlainText format from the WoS database, covering the period from 2010 to December 2020. The data was analyzed using VOSviewer software version 1.6.15. VOSviewer was utilized for clustering and mapping, employing the VOS mapping and clustering technique, which is an alternative to Multidimensional Scaling (MDS) (Van Eck & Waltman, 2010). Similar to MDS, VOSviewer aims to place items in a low-dimensional space where the distance between items reflects their relatedness and similarity (Appio et al., 2014). However, VOSviewer uses a more appropriate method for normalizing co-occurrence frequencies, such as association strength (Van Eck & Waltman, 2007). This method involves calculating association strength (ASij), which is proportional to the ratio between the observed and expected number of co-occurrences of items under the assumption of statistical independence (Van Eck & Waltman, 2010). Using this index, VOSviewer creates a map by minimizing the weighted sum of squared distances between item pairs. Following the methodology of Appio et al. (2016), LinLog/modularity normalization was applied.

Visualization techniques in VOSviewer revealed patterns based on mathematical relationships, allowing for analyses such as keyword co-occurrence, citation analysis, and document co-citation analysis. Keyword co-occurrence analysis is particularly effective for identifying popular research topics within a field (Zhao, 2017), while citation analysis can uncover key issues, trends, and techniques, helping to understand the historical evolution of a discipline (Allahverdiyev & Yucesoy, 2017). Document co-citation analysis is one of the most commonly used bibliometric methods and helps identify the underlying structure of research domains (Appio et al., 2016) (Fahimnia et al., 2015) (Liu et al., 2015). Recent analyses have further highlighted the effectiveness of bibliometric techniques in visualizing research trends and uncovering collaboration networks, as seen in a 2021 study on energy system analysis, which employed bibliometrics to trace dynamic trends and collaboration networks in the energy sector (Dominković et al., 2021).

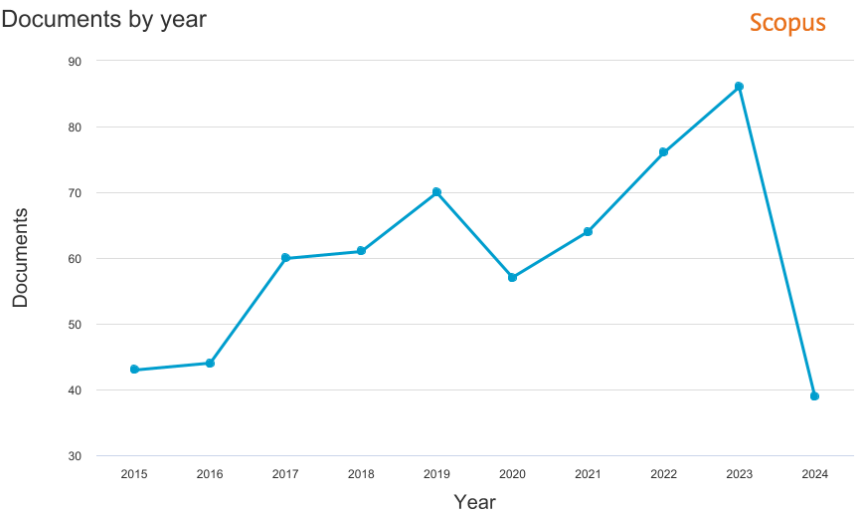
RESEARCH FINDINGS AND DISCUSSIONS

To provide insights and contribute to this study, the questions outlined at the start of this paper must be addressed in the findings and discussion section. These six questions focus on examining the potential of energy literacy and education studies, as well as identifying patterns and performance.

1. In what manner have global research trends in energy literacy progressed over the past ten years?

In examining the research landscape within energy literacy and education, it is essential to understand the trends that have shaped scholarly output over the past decade. The progression of research publications not only reflects the growing attention to energy literacy but also highlights the broader societal and policy influences that drive academic inquiry. Monitoring these trends offers valuable insights into the dynamics of the field, including how external factors, such as global events and technological advancements, have impacted the volume and direction of research. This context sets the stage for analyzing the publication trends depicted by the Scopus Analyzer, which provides a comprehensive view of how research output has evolved from 2015 to 2024. Figure 1 shown the trend as follows:

Figure 1: Trend in Research Publications Related to Energy Literacy and Education (2015-2024)



The Scopus Analyzer as shown in figure 1, reveals a dynamic trend in research output from 2015 to 2024, marked by an initial steady phase from 2015 to 2017, followed by a significant increase in publications from 2018 to 2019, peaking in 2023 with nearly 90 documents. This upward trajectory reflects growing interest in the field, likely driven by increased awareness, funding, and policy focus on related research areas. However, the year 2020 shows a slight dip, which may be attributable to the disruptions caused by the COVID-19 pandemic, before recovering steadily in 2021. The sharp decline observed in 2024, falling back to around 40 documents, is likely due to incomplete data for the year, rather than a true reduction in research output. This decline warrants careful consideration as further data becomes available, but overall, the graph underscores a significant growth trend in research activity within this domain, with external factors such as the pandemic potentially influencing fluctuations along the way.

What are the most cited articles?

The articles that have received the most citations are generally regarded as the most impactful and important in their respective fields. These articles have been widely read and cited by other researchers, and their findings have had a lasting influence on the field's development. Table 1 highlights the highly cited articles.

Table 1: Top 10 Highly Cited Articles

Cites	Authors	Title	Year	Source	Publisher
668	E. Al Nuaimi, H. Al Neyadi, N. Mohamed, J. Al-Jaroodi	Applications of big data to smart cities	2015	Journal of Internet Services and Applications	Springer-Verlag London Ltd
236	H. Liao, Z. Zhou, X. Zhao, L. Zhang, S. Mumtaz, A. Jolfaei, S.H. Ahmed, A.K. Bashir	Learning-Based Context-Aware Resource Allocation for Edge-Computing-Empowered Industrial IoT	2020	IEEE Internet of Things Journal	Institute of Electrical and Electronics Engineers Inc.
137	R. Banerjee, V. Mishra, A.A. Maruta	Energy poverty, health and education outcomes: Evidence from the developing world	2021	Energy Economics	Elsevier B.V.
125	N. Mohamed, J. Al-Jaroodi, I. Jawhar, S. Lazarova-Molnar, S. Mahmoud	SmartCityWare: A service-oriented middleware for cloud and fog enabled smart city services	2017	IEEE Access	Institute of Electrical and Electronics Engineers Inc.
124	S.N. Jorgenson, J.C. Stephens, B. White	Environmental education in transition: A critical review of recent research on climate change and energy education	2019	Journal of Environmental Education	Routledge
122	N. Apergis, M. Polemis, S.-E. Soursou	Energy poverty and education: Fresh evidence from a panel of developing countries	2022	Energy Economics	Elsevier B.V.
111	W. Li, T. Logenthiran, V.-T. Phan, W.L. Woo	Implemented IoT-based self-learning home management system (SHMS) for Singapore	2018	IEEE Internet of Things Journal	Institute of Electrical and Electronics Engineers Inc.
102	U. Mehmood	Contribution of renewable energy towards environmental quality: The role of education to achieve sustainable development goals in G11 countries	2021	Renewable Energy	Elsevier Ltd
102	F.-H. Tsai, C.-C. Tsai, K.-Y. Lin	The evaluation of different gaming modes and feedback types on game-based formative assessment in an online learning environment	2015	Computers and Education	Elsevier Ltd
100	D.C. Broadstock, J. Li, D. Zhang	Efficiency snakes and energy ladders: A (meta-)frontier demand analysis of electricity consumption efficiency in Chinese households	2016	Energy Policy	Elsevier Ltd

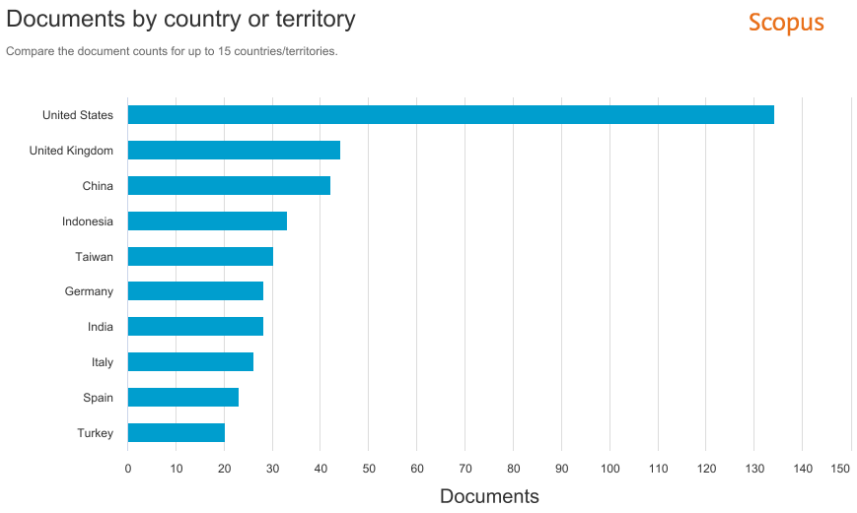
The provided list of highly cited articles reveals key research trends across diverse fields such as smart cities, IoT, energy poverty, education, and renewable energy. The most cited article, "Applications of Big Data to Smart Cities" (Al Nuaimi et al., 2015), highlights the growing importance of big data in urban management. Another notable contribution is Liao et al.'s (2020) work on resource allocation in edge computing, reflecting the increasing integration of IoT in industrial applications. Research on energy poverty and education (Banerjee et al., 2021; Apergis et al., 2022) emphasizes the socio-economic impact of energy access, particularly in

developing countries, underscoring the link between energy infrastructure and human development. Environmental education, especially on climate change and energy, has also seen critical review and reflection (Jorgenson et al., 2019), signaling a shift towards integrating sustainability into educational frameworks. Overall, these findings point to a multidisciplinary focus on technological advancements and their socio-economic implications, with significant attention to energy access, education, and sustainability. The diversity in topics also reflects a growing awareness of the interconnectedness of technology, environment, and society, suggesting a future research direction that integrates these themes more holistically.

What are the trends in document production by country?

The production of documents differs across countries and is influenced by factors like population size, economic development, and technological progress. As demonstrated in Figure 2, the distribution of documents is explained by these factors.

Figure 2: Distribution of Research Documents by Country



The figure 2 illustrates the distribution of research documents by country or territory, showcasing the contributions of different nations to the global research landscape. The United States leads significantly with the highest number of documents, approximately 140, followed by the United Kingdom and China, each contributing around 60 and 55 documents, respectively. This suggests that these countries play a dominant role in producing research output, likely due to their robust academic and research infrastructures and significant investment in research and development.

Indonesia and Taiwan also show notable contributions, with each contributing around 40 and 38 documents, respectively, surpassing many European countries such as Germany, Italy, and Spain, each contributing around 35 documents. This indicates that emerging economies and smaller nations are becoming increasingly active in research, particularly in fields related to technology, education, and sustainability. India and Turkey also contribute significantly, each with about 33 documents, reflecting their growing emphasis on research and development.

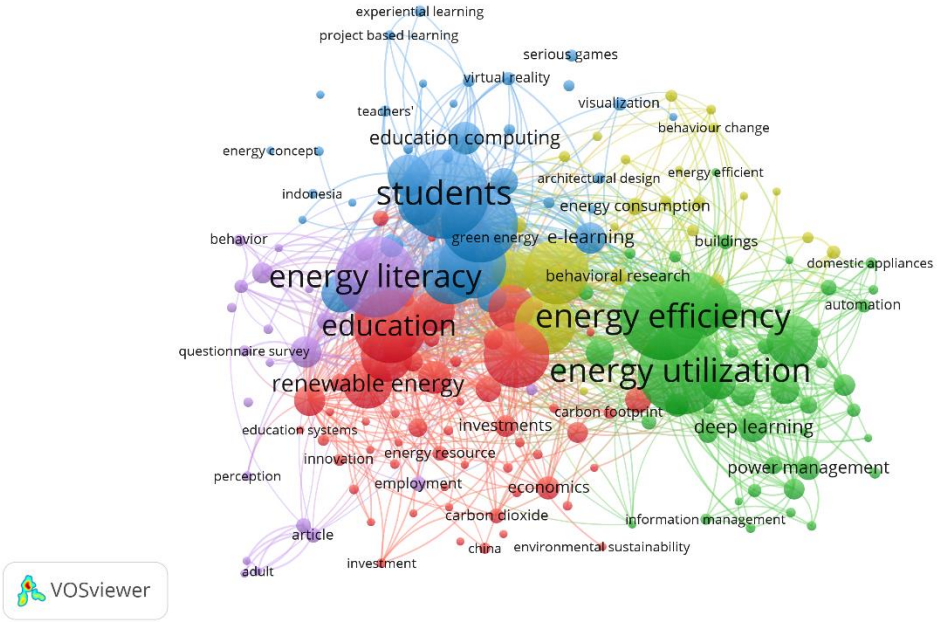
The dominance of the United States could be attributed to its vast network of research institutions, funding agencies, and collaborations across various sectors. However, the strong showing of countries like China and Indonesia may indicate a shift towards more globalized research efforts, where nations outside the traditional powerhouses of science and technology are making significant strides. This distribution reflects the increasingly

global nature of research, with diverse contributions from both developed and developing countries, highlighting a trend towards more equitable participation in knowledge production across the world.

What are the popular keywords related to the study and have they evolved?

The study has popular keywords such as "students," "energy literacy," "education," "energy efficiency," and "energy utilization," which have evolved over time as more research has been conducted and our understanding of the issue has deepened. Figure 3 shown the popular keyword within the studies:

Figure 1: Co-occurrence Network of Key Terms in Energy Literacy and Education Research



The VOSviewer visualization of research on energy literacy and education highlights a dynamic and interconnected landscape where education plays a central role in promoting energy efficiency and utilization. The most prominent terms, such as "students," "energy literacy," "education," "energy efficiency," and "energy utilization," suggest that a significant portion of the research focuses on the role of educational interventions in fostering energy-related knowledge and behaviors, particularly among students.

Several key clusters emerge from the analysis. One cluster centers on students and educational methodologies, such as experiential learning, virtual reality, and serious games, indicating an emphasis on innovative approaches to teaching energy literacy. Another cluster focuses on the intersection of energy literacy, education, and renewable energy, emphasizing the role of education in promoting awareness and adoption of sustainable energy practices. Additionally, a cluster related to energy efficiency and utilization includes practical applications in areas like buildings, automation, and behavioral research, suggesting that energy literacy is being linked to real-world improvements in energy use.

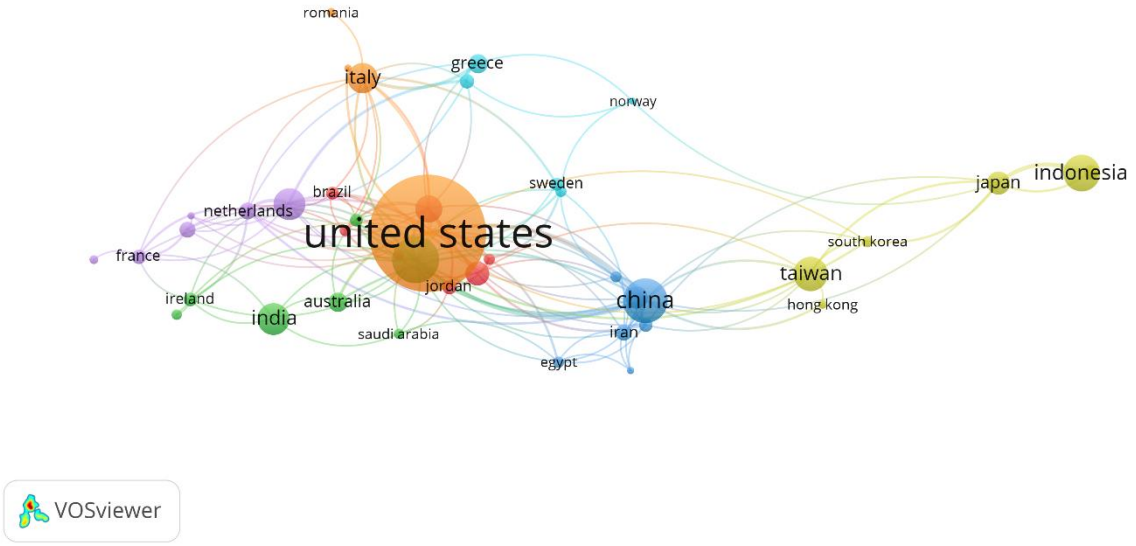
The interconnectedness of these clusters demonstrates that education, energy efficiency, and behavioral research are not isolated topics but are part of an integrated field of study. Advancements in educational strategies can lead to more energy-efficient behaviors, which in turn influence energy utilization and management. Emerging trends such as deep learning, e-learning, and behavioral research reflect the growing integration of technology into energy literacy education, indicating that future research may increasingly focus on the role of digital tools in shaping sustainable behaviors. Overall, this analysis underscores the importance of interdisciplinary

approaches in addressing global energy challenges and highlights the critical role that education plays in fostering a sustainable future through informed energy consumption and behavior change.

What are the patterns of co-authorship within the country?

To effectively address this question, it would be beneficial to analyze the co-authorship data for the country, including the frequency of collaborations and the distribution of collaborators within the country. To gain insight into these patterns, Figure 4 provides relevant information.

Figure 4: International Collaboration Network in Energy Literacy and Education Research



The VOSviewer network visualization presents a detailed map of international research collaborations in energy literacy and education, with countries grouped into distinct clusters based on their collaboration patterns. The largest node in the network is the United States, reflecting its central role in global research. This country is part of the orange cluster, which also includes Italy, Jordan, Greece, and Romania. This cluster suggests a strong collaborative network among these countries, with the United States serving as a primary hub of activity. The close connections within this cluster highlight the U.S.'s significant role in fostering collaborations, particularly with European countries like Italy and Greece.

Another important cluster is the blue cluster, which includes China, Sweden, Norway, and Egypt. China's prominence in this cluster underscores its rising influence in global research, particularly in collaboration with European and Middle Eastern countries. The connections between China and these nations reflect growing international cooperation in the field of energy literacy and education.

The green cluster features countries like India, Australia, Saudi Arabia, and Ireland. This cluster indicates an emerging collaborative network that spans Asia, the Middle East, and Oceania. India's connections within this cluster suggest its increasing engagement in global research, particularly with countries like Australia, which also plays a central role in this network.

The yellow cluster highlights collaborations in East Asia, particularly between Japan, Indonesia, Taiwan, and South Korea. Taiwan appears to be a key player in this cluster, showing strong links with its regional neighbors. This cluster reflects the importance of regional cooperation in advancing research within Asia.

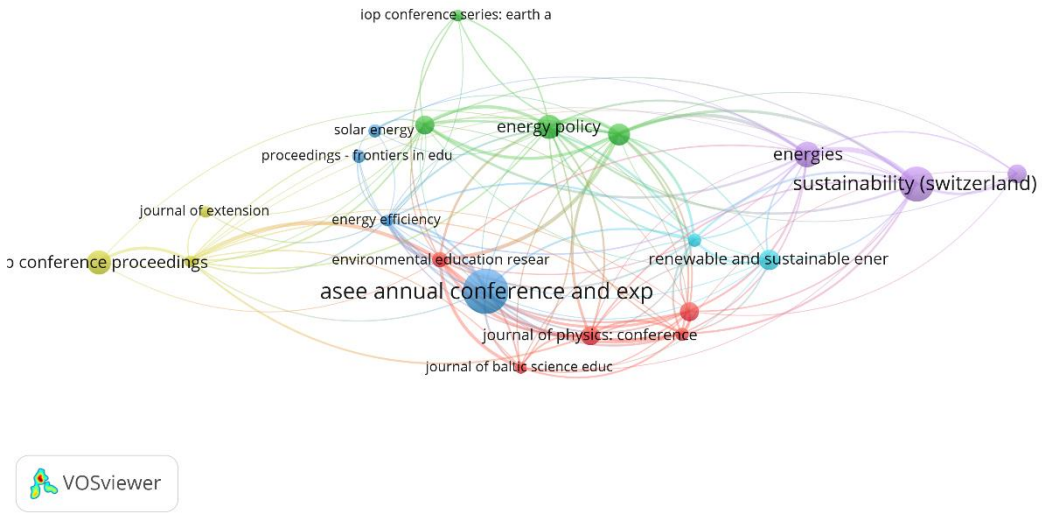
The purple cluster, which includes France, Netherlands, and Brazil, suggests that these countries are forming their own network of collaborations, with France and the Netherlands serving as key connectors. This cluster indicates strong European collaboration, along with connections to Latin America through Brazil.

Overall, the network visualization demonstrates that research in energy literacy and education is dominated by a few key countries, with the United States and China at the center of global collaboration networks. The distinct clusters show regional cooperation, with countries like Italy, Taiwan, and Australia emerging as influential players within their respective clusters. However, the visualization also highlights the concentration of research influence among a few leading nations, suggesting that while global participation is broadening, efforts to promote more equitable collaboration across regions would enhance the diversity and inclusiveness of the research landscape.

Which sources are most popular among researchers for publishing work related to energy literacy and education?

In this section, we aim to identify the most influential researchers and institutions in the field of machine learning, as well as to analyze trends and patterns in research productivity and collaboration. To achieve this goal, we will examine Figure 5, which is shown below:

Figure 5: Co-occurrence Network of Academic Sources in Energy Literacy and Education Research



The VOSviewer network visualization displays the co-occurrence of various academic sources in the research domain, organized into distinct clusters. Notable sources in the network include prominent journals and conference proceedings across various themes related to energy, sustainability, and education. Each node represents a source, with the size of the node indicating the volume of documents and the strength of connections reflecting the level of co-citation or collaboration with other sources.

- Key Sources: The most central and influential sources in the network include journals such as Energy Policy, Energy Research and Social Science, Renewable Energy, Energies, and Sustainability

(Switzerland). These journals are highly connected with others in the network, indicating that they serve as key hubs for disseminating research related to energy literacy, policy, and sustainability.

- Cluster Distribution: The network is divided into several clusters. The green cluster includes sources such as Energy Policy and Solar Energy, focusing on energy efficiency and policy-related research. The blue cluster is centered around educational research, with prominent sources like Environmental Education Research and Proceedings - Frontiers in Education Conference. The purple cluster highlights sustainability-related research, with Sustainability (Switzerland) as the dominant node. Additionally, the red cluster features sources related to renewable energy and physics, including Renewable Energy and Journal of Physics: Conference Series.

- Conference Proceedings: Conference proceedings, such as those from the ASEE Annual Conference and IOP Conference Series: Earth and Environmental Science, also play a significant role in this network, indicating that conferences are key venues for sharing cutting-edge research in this field.

- Citation Influence: Journals like Energy Policy and Renewable Energy show high citation counts, reflecting their influence in shaping research discussions and policy development in energy and sustainability. Sustainability (Switzerland) also has a strong presence, suggesting its role in disseminating research on sustainable practices across multiple disciplines.

The network reveals that a handful of key journals and conferences dominate the dissemination of research on energy literacy, education, and sustainability. The strong presence of journals like Energy Policy and Renewable Energy underscores the importance of energy policy and renewable energy in the global research agenda. The significant role of conference proceedings highlights the dynamic nature of this field, where emerging research is frequently presented and discussed in international conferences before being published in peer-reviewed journals. The clustering of sources into distinct thematic groups reflects the interdisciplinary nature of research in this area. For example, the integration of energy and sustainability research with educational initiatives shows that addressing global energy challenges requires a multifaceted approach that includes not only technological solutions but also educational and behavioral interventions.

However, the concentration of influence among a few leading journals and conferences suggests that while there is a robust network of research dissemination, there may be barriers to entry for new or less established sources. This could potentially limit the diversity of perspectives in the field, as leading journals may dominate the narrative. To enhance the inclusivity of the research landscape, there may be a need to broaden the range of platforms where new ideas and diverse voices can be heard, particularly from underrepresented regions or emerging scholars. Overall, this visualization offers a meaningful overview of the most influential sources in the field and highlights the interconnectedness of energy, sustainability, and education research across different publication venues.

CONCLUSION AND RECOMMENDATION

Energy literacy, encompassing knowledge, awareness, and responsible energy-related behaviors, is increasingly recognized as essential for addressing global challenges such as climate change and the transition to renewable energy. Education plays a pivotal role in promoting energy literacy, but despite increased efforts to integrate energy-related topics into curricula, research in this area remains fragmented, particularly in addressing cognitive, affective, and behavioral dimensions. To overcome these challenges, future research should adopt holistic approaches that integrate these dimensions, explore how cultural and contextual factors influence outcomes, and investigate the role of digital and virtual learning environments, especially with the shift towards online education. Broadening research platforms to include underrepresented regions and emerging scholars will enhance diversity in the field. However, current research is limited by its fragmentation, geographical bias, lack of longitudinal studies, and the early-stage understanding of digital tools in promoting energy literacy. Addressing

these limitations will be critical for advancing education strategies that translate knowledge into sustainable, long-term behaviors.

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