Bibliometric Mapping of Energy Literacy and Public Participation in Energy Transition: A Visual Analysis of Thematic Structure and Conceptual Linkages

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Abstract
This study aims to map the thematic structure and conceptual linkages within the literature on energy literacy and public participation in the context of energy transition. Using a bibliometric approach, publication data were collected through an automated extraction process from open-access sources using a Python script designed to retrieve metadata from titles and abstracts. The analysis was conducted using the VOSviewer software to identify co-occurrence relationships among terms and to assess thematic relevance levels.The visualization results reveal two major clusters. The first cluster represents an educational approach, encompassing terms such as "energy literacy", "student", "curriculum", and "pedagogy". The second cluster reflects a participatory approach characterized by terms such as community, public participation, awareness, and project. The term "energy literacy" emerges as a central node connecting both clusters, indicating its strategic role in shaping public understanding and engagement with renewable energy issues. The findings contribute to strengthening conceptual understanding within the field of sustainable energy studies and open new opportunities for developing policy evaluations based on thematic data and bibliometric visualization.
Keywords: *bibliometric analysis, energy literacy, public participation, energy transition, VOSviewer, thematic mapping*

Abstrak
Penelitian ini bertujuan untuk memetakan struktur tematik dan keterkaitan konseptual dalam literatur mengenai literasi energi dan partisipasi publik dalam konteks transisi energi. Dengan menggunakan pendekatan bibliometrik, data publikasi dikumpulkan melalui proses ekstraksi otomatis dari sumber akses terbuka menggunakan skrip Python yang dirancang untuk mengambil metadata dari judul dan abstrak. Analisis dilakukan dengan perangkat lunak VOSviewer untuk mengidentifikasi hubungan kemunculan bersama antar istilah dan menilai tingkat relevansi tematik.
Hasil visualisasi menunjukkan dua kluster utama. Kluster pertama menggambarkan pendekatan edukatif, mencakup istilah seperti energy literacy, student, curriculum, dan pedagogy. Kluster kedua merepresentasikan pendekatan partisipatif dengan istilah seperti community, public participation, awareness, dan project. Istilah energy literacy muncul sebagai simpul sentral yang menghubungkan kedua kluster, menunjukkan perannya yang strategis dalam membentuk pemahaman dan keterlibatan publik terhadap isu energi terbarukan. Temuan ini berkontribusi pada penguatan pemahaman konseptual dalam studi energi berkelanjutan serta membuka peluang baru untuk pengembangan evaluasi kebijakan berbasis data tematik dan visualisasi bibliometrik.
Kata Kunci: *analisis bibliometrik, literasi energi, partisipasi publik, transisi energi, VOSviewer, pemetaan tematik.*

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INTRODUCTION

Over the past two decades, the transition toward cleaner and more sustainable energy systems has emerged as a pressing global agenda. Rising greenhouse gas emissions, dependence on fossil fuels, and the intensifying impacts of climate change have compelled countries to adopt renewable energy and energy efficiency policies as key strategies for sustainable development (IEA, 2021). Within this context, public engagement has become a crucial component, positioning citizens not only as energy consumers but also as active participants in local decision-making and the implementation of energy policies (Sovacool, 2016).

The energy transition cannot be separated from its social and educational dimensions. Energy literacy, which encompasses knowledge, attitudes, and behaviors related to energy issues, serves as a critical foundation for cultivating public awareness and responsiveness toward future energy challenges (DeWaters & Powers, 2013). In addition, public participation in renewable energy projects and energy efficiency initiatives has been shown to enhance policy legitimacy and improve the success of implementation across various regional contexts (Devine-Wright, 2007).

Accordingly, scholarly inquiry into energy literacy and public participation within the framework of energy transition is both academically relevant and strategically significant. A bibliometric approach can offer a comprehensive overview of how these two concepts have evolved and interrelated within the scientific literature.

Energy literacy is a multidimensional concept encompassing individuals' knowledge, attitudes, and behaviors toward energy issues, including understanding energy sources, environmental impacts, efficiency, and consumption choices (DeWaters & Powers, 2013). In educational contexts, energy literacy serves not only as a tool for knowledge transfer but also as a transformative approach to developing critical awareness and sustainable action (Lee et al., 2020). Enhancing energy literacy among students and the general public is thus a key strategy for supporting the transition toward low-carbon energy systems.

On the other hand, public participation refers to the active involvement of citizens in energy-related planning, decision-making, and policy implementation processes. Such participation can take the form of consultations, collaborations in renewable energy projects, or local policy advocacy (Irvin & Stansbury, 2004). Energy literacy and public participation are functionally interdependent: sufficient understanding of energy issues encourages more meaningful engagement, while public involvement reinforces the legitimacy and effectiveness of energy policies (Petts, 2008).

In the scientific literature, both concepts are increasingly positioned as integral elements within transdisciplinary approaches to sustainability. Bibliometric analysis of these terms can reveal thematic patterns, conceptual evolution, and potential integration points across education, technology, and energy policy domains.

Although energy literacy and public participation have been widely discussed in educational and policy studies, systematic analyses mapping their conceptual interlinkages within the literature remain limited. Most existing research tends to be descriptive or case-based, employing qualitative approaches that emphasize local contexts and program outcomes (Cotton et al., 2015; Park, 2018). As a result, there is a lack of comprehensive understanding of how key concepts such as "energy literacy," "public

participation," and "curriculum" interact and evolve within the academic discourse.

A bibliometric approach offers a methodological solution to address these limitations. By leveraging co-occurrence analysis, bibliometrics enables the identification of thematic structures, conceptual nodes, and term evolution within scientific publications (van Eck & Waltman, 2010). Bibliometric visualization not only illustrates the frequency of terms but also reveals their semantic relationships and thematic distributions. These insights can inform future research directions and support evidence-based policy evaluation.

The urgency of this study is further underscored by the growing need for cross-sectoral and interdisciplinary perspectives in addressing energy transition challenges. Visual mapping of the literature allows researchers and policymakers to identify thematic gaps, potential collaborations, and intersections among education, technology, and community participation. Therefore, this study seeks to fill the existing gap through a structured and data-driven bibliometric approach.

Based on the conceptual background and methodological gap described above, this research aims to map the thematic structure and conceptual linkages within the literature on energy literacy and public participation in the context of energy transition. Using bibliometric analysis based on term co-occurrence, the study seeks to identify dominant terms, thematic clusters, and patterns of conceptual relationships that have emerged in academic discussions.

The main contribution of this study lies in providing bibliometric visualizations that can serve as a foundation for developing policies, educational curricula, and participatory strategies within the energy sector. Furthermore, this research offers a methodological framework that can be replicated for thematic analysis in other transdisciplinary fields. By integrating energy literacy and public participation into a unified visual analytical framework, the study enhances understanding of the role of society in supporting a sustainable energy transition

METHOD

This study employed a bibliometric approach to identify the thematic structure and conceptual relationships within the literature on energy literacy and public participation in the context of energy transition. Bibliometric analysis is a quantitative method that enables a systematic examination of publication metadata, including patterns of term occurrence, conceptual linkages, and thematic evolution within a given field (Donthu et al., 2021). Given the multidisciplinary nature of the energy transition discourse, this approach is particularly relevant as it allows for the visual and structured identification of intersections among education, technology, and policy.

Unlike traditional narrative literature reviews that rely on selective interpretation, bibliometric analysis provides an objective, data-driven understanding of the literature landscape. Techniques such as co-occurrence analysis and conceptual network mapping facilitate the identification of dominant terms and thematic clusters that shape the academic discourse (van Eck and Waltman, 2010). The resulting visualizations can be used to assess research directions, detect thematic gaps, and develop evidence-based strategies for future studies or policy formulation.

In this study, bibliometrics served both exploratory and evaluative functions. It was used not only to map the conceptual structure of the literature but also to assess how energy literacy and public participation have been positioned and interconnected within scholarly discussions. The method thus bridges conceptual analysis and practical needs in supporting an inclusive and sustainable energy transition

Data Collection and Preprocessing

Bibliometric data were obtained through automated extraction from Google Scholar, selected for its broad multidisciplinary coverage and accessibility to relevant scientific publications. The extraction process was conducted using a modular Python script designed to execute queries based on thematic keywords such as *"energy literacy," "public participation,"* and *"renewable energy education."* The script was configured to collect metadata including publication titles, abstracts, and author keywords, and to store results in a CSV format compatible with VOSviewer.

To ensure ethical data handling, only publicly available metadata were used. No data from paid or restricted-access systems were included, and the extraction process avoided any aggressive scraping behavior that could violate platform terms of service (Gusenbauer and Haddaway, 2020). The script incorporated deduplication and data validation routines to ensure the consistency and reliability of the resulting corpus.

Following extraction, the dataset was manually curated to remove non-academic publications, duplicates, and entries lacking abstracts. The preprocessing stage also involved the cleaning of non-alphabetic characters, normalization of term formats, and consolidation of semantically equivalent terms. These steps were essential for improving the precision of the visual analysis and preventing noise in the bibliometric mapping.

A manually constructed thesaurus file in CSV format was used to standardize terms and merge variants such as *"renewable energy"* and *"renewable energy source."* Generic or non-thematic terms such as *"keyword"* or *"abstract"* were excluded to preserve conceptual relevance. The final dataset was validated for structural integrity, ensuring that each record contained properly formatted title, abstract, and keyword fields ready for import into VOSviewer.

Data Analysis and Visualization

Bibliometric visualization was performed using VOSviewer (latest version), a software tool specifically designed for constructing and exploring bibliometric maps. The analysis employed co-occurrence analysis of terms using a full counting method, which ensures that every instance of a term is counted equally, independent of the number of documents in which it appears (van Eck and Waltman, 2010).

Parameter optimization was conducted based on preliminary trials examining the term frequency distribution. The minimum occurrence threshold was set at five, to exclude sporadic terms while retaining thematic diversity. A relevance threshold of 60 percent was applied to refine term selection, allowing the inclusion of both dominant and contextually relevant supporting terms. The curated thesaurus file was used during import to unify similar expressions and remove analytically insignificant words.

The visual outputs consisted of two main types of maps:

(1) Network visualization, which highlights clusters and the relational structure among terms; and
(2) Density visualization, which indicates the relative frequency and centrality of key concepts such as *"energy literacy"* and *"public participation."*

Interpretation of the maps considered node size, color, and link thickness as indicators of term prominence, thematic proximity, and the strength of conceptual relationships (Perianes-Rodriguez et al., 2016). These visualizations provided an empirical foundation for identifying core thematic areas and conceptual linkages within the field of sustainable energy research.

RESULT AND DISCUSSION

The bibliometric analysis was conducted on a total of sixty publications extracted automatically from Google Scholar, focusing on the themes of energy literacy, energy

awareness, public participation, and sustainability education. The identified documents included journal articles, conference proceedings, and academic reports published between 2006 and 2025. Temporal distribution analysis revealed a consistent upward trend in publication volume since 2015, peaking in 2022 and 2025. This surge reflects growing academic attention to energy transition and public engagement in sustainability-oriented energy education.

1.1 Temporal Distribution of Publication

The corpus was classified into six time periods based on dominant thematic characteristics. Publications prior to 2010 generally emphasized technical education and the development of basic energy literacy. Between 2011 and 2014, studies began to incorporate competition- and project-based learning strategies to enhance students' energy awareness. The 2015–2017 period marked a shift toward evaluation instruments and the mapping of misconceptions among learners. Between 2018 and 2020, research increasingly addressed public awareness and behavioral aspects of renewable energy adoption. The years 2021–2022 indicated a growing focus on public participation and energy policy literacy, while publications from 2023–2025 demonstrated an integration of educational, social, and policy-oriented approaches within the green transition framework.

This temporal pattern indicates that energy literacy has evolved from a pedagogical construct into a strategic instrument that supports public participation and energy transition policy. Such temporal dynamics form the foundation for the subsequent visual analysis, which aims to identify thematic structures and conceptual linkages within the literature

Table 1. Annual Distribution of Publication

Time Range	Number of Publications	Dominant Thematic Focus	Example Publication Title
≤ 2010	2	Basic Energy Education	*Promoting STEM to Young Students by Renewable Energy Applications*
2011–2014	6	Energy Literacy and Competition	*The Kukui Cup: A Dorm Energy Competition Focused on Sustainable Behavior Change*
2015–2017	10	Literacy Scales and Evaluation	*Analysis of Energy Literacy and Misconceptions of Junior High Students in Taiwan*
2018–2020	12	Public Awareness and Energy Behavior	*Consumer Awareness of Renewable Energy Sources: The Case of Poland*
2021–2022	18	Public Participation and Policy Literacy	*Study on the Policy Literacy of the Republic of Korea Regarding Nuclear Energy*
2023–2025	12	Energy Transition and Sustainability Education	*Energy Literacy and Education: The Viewpoint of Stakeholders to Promote Energy Literacy*

1.2 Conceptual Network Structure

Co-occurrence analysis conducted in VOSviewer generated a conceptual network consisting of two primary thematic clusters. The visualization was based on the curated corpus of sixty publications, with a minimum occurrence

threshold of five and a relevance threshold of sixty percent. The resulting map displayed a well-defined pattern of interrelated terms forming two overlapping but distinct thematic areas.

The first cluster (red) represents the educational approach to energy literacy. Dominant terms within this cluster include *energy literacy, student, curriculum, pedagogy,* and *awareness.* The interconnections among these terms suggest that energy literacy is positioned as an integral component of formal education, emphasizing the development of assessment instruments, curriculum design, and project-based pedagogical strategies.

The second cluster (green) represents the participatory and social approach to energy issues. Terms such as *community, public participation, project, citizen,* and *policy* appear prominently. The relationships among these terms indicate that public participation in renewable energy projects and local policy initiatives has become an increasingly central theme in recent literature.

The term *energy literacy* functions as a central node bridging both clusters, underscoring its strategic role as a conceptual link between educational and participatory dimensions. The strong connection between *energy literacy* and *public participation* suggests that public understanding of energy directly contributes to more meaningful engagement in the energy transition process

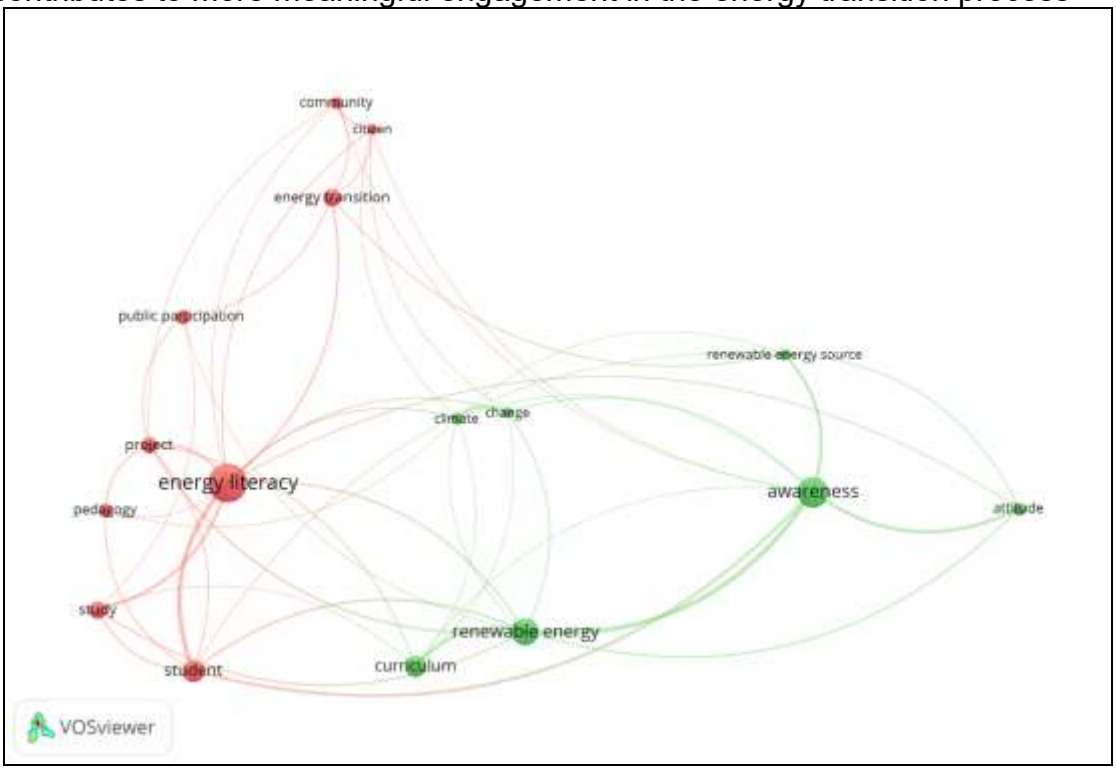

Figure 1. Conceptual Network Visualization

1.3 Frequency and Centrality of Key Terms

Frequency and connectivity analyses revealed that *energy literacy* is the most dominant and strategically central term in the corpus. It not only appears most frequently but also serves as the main linkage between the two thematic domains of energy education and public participation. This central position indicates that energy literacy is broadly conceptualized as the cognitive and behavioral foundation of public engagement in the energy transition.

Terms such as *student, curriculum,* and *awareness* appear consistently within the educational cluster, highlighting the literature's emphasis on learning instruments and conceptual understanding in formal education settings. Meanwhile, *public participation, community,* and *project* dominate the participatory cluster, emphasizing community involvement in decision-making and implementation of energy policies

Table 2. Most Frequent and Central Terms

Key Term	Frequency	Thematic Cluster	Position in Network
energy literacy	22	Educational & Participatory	Central Node
student	15	Educational	Supporting Node
public participation	13	Participatory	Connected Node
curriculum	11	Educational	Supporting Node
community	10	Participatory	Connected Node
awareness	9	Educational	Supporting Node
project	8	Participatory	Connected Node

1.4 Density Visualization of Co-occurrence Map

A complementary density visualization was performed to examine the spatial distribution of term frequency and intensity. The map displays color gradients representing term concentration, with yellow areas indicating high intensity and blue areas representing low intensity

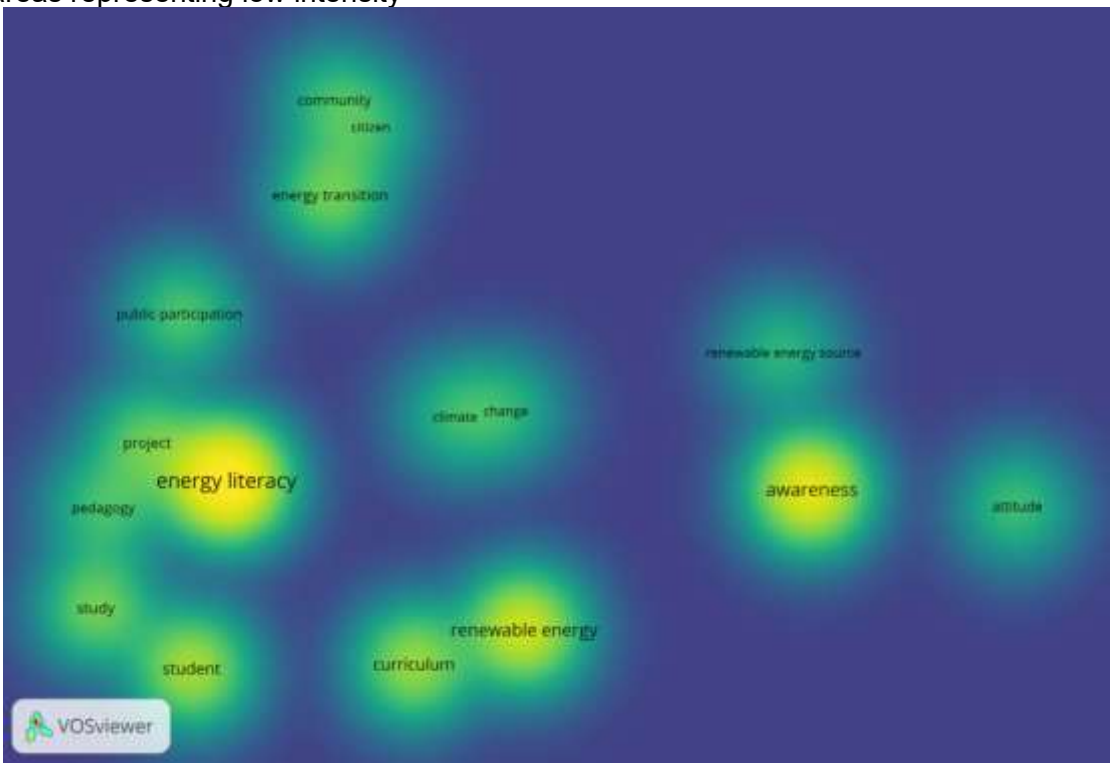

Figure 2. Density Visualization of Co-occurance Map

The visualization shows that *energy literacy* and *awareness* occupy areas of highest intensity, suggesting that these terms form the thematic gravity centers of the field. Terms such as *student, curriculum,* and *pedagogy* appear in the yellow–green range, indicating strong frequency and close conceptual association with energy education. In contrast, *public participation, community,*

and *citizen* appear in green–turquoise zones, reflecting moderate frequency but substantial thematic relevance.

This spatial distribution reinforces previous findings that energy literacy serves as a conceptual bridge between educational and participatory domains. Moreover, the intensity map indicates that educational approaches dominate the literature, while policy and social participation perspectives have recently gained momentum as complementary components of the broader energy transition discourse.

1.5 Interpretive Insights and Strategic Implications

The bibliometric findings demonstrate that energy literacy and public participation are not separate constructs but are intertwined within the broader ecosystem of sustainable energy transition. *Energy literacy* emerges as the conceptual nexus connecting educational theory with social action, emphasizing that energy understanding is both a cognitive foundation and a practical driver of collective engagement.

The combined network and density analyses yield three strategic implications:

1. Curriculum Development
   The close association of *curriculum* and *pedagogy* with *energy literacy* underscores the importance of embedding energy topics in formal education. Interdisciplinary and project-based pedagogical approaches should be adopted to enable learners not only to comprehend energy concepts but also to translate them into socially and environmentally responsible actions.
2. Community Program Design
   The prominence of *community* and *project* highlights opportunities for integrating energy literacy into community-based initiatives. Such programs can enhance local legitimacy, increase awareness, and strengthen community capacity to engage with renewable energy projects and sustainability policies.
3. Energy Policy Evaluation
   The connected position of *public participation* in the conceptual network indicates that public engagement must be supported by adaptive literacy strategies. Energy literacy can serve as an evaluative indicator for assessing policy effectiveness and public acceptance of emerging energy technologies.

Overall, the findings suggest that energy literacy functions not merely as an educational tool but as a strategic instrument for building a conscious, critical, and participatory society. The bibliometric approach applied in this study provides both visual and conceptual evidence to support the design of integrated, data-driven interventions in education and energy policy.

CONCLUSIONS

This study revealed the thematic structure and conceptual interconnections within the literature on energy literacy and public participation through a bibliometric approach. The analysis shows that energy literacy serves as a central conceptual node bridging the domains of education and social participation. Its high frequency and network centrality indicate its pivotal role in linking cognitive understanding with public engagement in energy transition processes. The network and density visualizations demonstrate that educational approaches to energy still dominate the academic discourse, although public engagement and policy-oriented perspectives are gaining increasing attention.

The main contribution of this study lies in the provision of a visual and conceptual framework that can inform curriculum development, energy communication strategies, and community-based policy evaluation. The bibliometric approach applied here not only provides a comprehensive overview of the literature dynamics but also highlights

opportunities for cross-sectoral integration in promoting an inclusive and sustainable energy transition.

Future research may expand the data scope by incorporating indexed databases such as Scopus or Web of Science, and by applying temporal and geographical bibliometric analyses to capture the evolution and regional distribution of the field. Furthermore, integrating bibliometric mapping with Natural Language Processing (NLP) and sentiment analysis techniques could enrich the understanding of public narratives and societal perceptions surrounding energy issues.

In conclusion, this study contributes not only to the advancement of academic knowledge but also provides strategic insights for policymakers, educators, and energy communities. The findings offer an evidence-based foundation for designing educational, communicative, and participatory interventions that can strengthen collective awareness and accelerate the transition toward a sustainable energy future.

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