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Integrating Energy Literacy into Science Education through the STEM Approach: A Systematic Literature Review

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Abstract

Energy literacy is an essential competency for addressing global sustainability challenges, encompassing knowledge, attitudes, and behaviors related to the wise use of energy. Science education plays a central role in conveying energy as a unifying concept in science; however, students often struggle to develop a deep understanding of this concept. This literature review aims to analyze the current state of research and practices regarding the integration of energy literacy into science education through the STEM approach. The method used is a Systematic Literature Review (SLR), drawing from academic databases such as Scopus and Google Scholar. The findings of this literature review are as follows: 1) energy literacy is multidimensional, encompassing knowledge, attitudes, and behaviors related to energy use; 2) a non-fragmented STEM approach is effective in providing more relevant learning experiences; 3) innovative learning strategies, such as project-based learning and interdisciplinary approaches, have been shown to improve students' energy literacy; and 4) teacher professional development plays a crucial role in the successful implementation of this integration in the classroom.

Keywords: *Energy Literacy, STEM Approach, Science Education, SLR*

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INTRODUCTION

Rapid changes in the modern world require society to have a comprehensive understanding of critical global issues, one of which is energy. Energy is the backbone of the economy and societal sustainability, and is fundamental to human development (Santillán & Cedano, 2023). The growing scarcity and limited availability of energy make energy literacy essential for empowering students to make wise decisions and take responsible actions (Lee et al., 2015). Energy literacy generally encompasses knowledge and understanding of energy, as well as appropriate attitudes, values, intentions, and behaviors related to its use. Energy-literate individuals possess a basic understanding of energy consumption and its impact on the environment, as well as energy production and consumption (Sayarkhalaj & Khesal, 2022).

Energy literacy is not merely about theoretical knowledge; rather, it is a competency that is highly relevant to daily life, given that energy is an integral part of every aspect of modern life (Soto-Arriaza et al., 2021). Students need to understand how energy is generated, transported, stored, distributed, and used, as well as be aware of its environmental and social impacts, and possess the knowledge to use it efficiently (Santillán & Cedano, 2023). Energy literacy programs through the education system are a strategic effort to build students' awareness from an early age. This is expected to foster critical literacy—that is, the ability and engagement of individuals as citizens to use energy wisely (Rohmatulloh

et al., 2021).

Science education plays a central role in shaping students' understanding of natural phenomena, including those related to energy (Amadea, 2020). The concept of energy is a fundamental unifying concept in science (Nordine *et al*., 2010). The importance of energy in science education stems from the integrative nature of this concept; its economic, social, and environmental impacts; and its presence in everyday life (Soto et al., 2021). Although curricula worldwide have strengthened efforts to support the teaching of the concept of energy, most students still struggle to develop a deep understanding of energy (Mittenzwei et al., 2019). This indicates a need for more effective approaches in science education to convey the concept of energy comprehensively.

The *Science, Technology, Engineering, and Mathematics (STEM)* approach has emerged as a promising educational framework for addressing the complex challenges of the 21st century (Anning, 2024). STEM education not only integrates these four disciplines but also aims to equip students with problem-solving abilities, innovation skills, logical thinking, and technological literacy (ALFARISI, 2020). This interdisciplinary approach is crucial for developing key skills such as critical thinking and problem-solving (Marzuki et al., 2024).Studies show that integrated STEM learning can enhance cognitive performance, provide more entry points for academic learning, and offer a more complex understanding of authentic phenomena (Peters-Burton et al., 2022).

Integrating energy literacy into science education through a STEM approach offers strong synergy. Energy-related issues inherently involve STEM aspects. In science, students can study the physics of energy—such as the concept of energy transformation and how generators work—as well as environmental and ecological issues related to energy sources. The technology aspect can include the use of environmentally friendly technologies and renewable energy (Basuki et al., 2019). Engineering encourages students to engage in the design process to create energy-efficient products or design sustainable energy systems(Choudhury & Rodriguez, 2015; Goldstein et al., 2015; Zhang et al., 2021). Meanwhile, mathematics is used to analyze energy consumption data and perform modeling to optimize energy use (Boukarta & Berezowska-Azzag, 2018); Klyuev *et al*., 2022; Pujani *et al*., 2020). This interdisciplinary approach supports the development of the scientific literacy students need to understand and respond to complex real-world issues (Rusilowati et al., 2018)

Given the importance of energy literacy and the STEM approach, a systematic literature review is crucial for identifying the current state of research and best practices in integrating energy literacy into science education through the STEM approach. This review will help identify research gaps, effective teaching methods, as well as reported challenges and successes. A literature review can provide a comprehensive and balanced summary of primary research findings (Setyawati et al., 2022) This study aims to analyze various studies that have been conducted regarding the integration of energy literacy in the context of science education using the STEM approach. Thus, this study is expected to provide a roadmap for educators, curriculum developers, and policymakers in designing more effective and relevant learning programs. The results of this literature review will serve as the basis for practical recommendations to improve students' energy literacy.

METHODS

This study employs a qualitative approach in the form of *a* systematic literature review (SLR). This method was chosen to identify, evaluate, and synthesize all available information relevant to the predetermined research questions (Husamah *et al*., 2022). A systematic review allows researchers to obtain a comprehensive overview of the integration of energy literacy into science education through the STEM approach, based on published academic sources. The procedures in this systematic literature review follow the stages commonly used in SLRs.

Formulation of Research Questions

The first stage involved formulating the research questions (RQs) that guided the literature search and analysis process. The research questions were formulated as follows: (RQ1) How is the STEM approach integrated into science education to improve students' energy literacy? (RQ2) What are the

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impacts of STEM-based learning on students' energy literacy reported in previous studies? (RQ3) What challenges are encountered in implementing STEM-based learning to improve students' energy literacy?. These research questions served as the basis for determining the search strategy, selecting relevant studies, extracting data, and synthesizing the findings.

Identification of Data Sources

The literature search was conducted in relevant academic databases such as *Scopus* and *Google Scholar*. The use of various databases aims to ensure a broad and representative scope of the literature (Mohamad & Osman, 2022).

Search Strategy

The keywords used in the search included combinations of terms such as “energy literacy,” “STEM approach,” “science learning,” “integration,” “science curriculum,” “literature review,” and “energy education.” These keyword combinations were tailored to each database to obtain the most relevant results.

Inclusion and Exclusion Criteria

Strict eligibility criteria were applied to ensure the relevance and quality of the analysis presented in Table 1.

Table 1. Inclusion and Exclusion Criteria

Category	Inclusion Criteria	Exclusion Criteria
Field of study and focus	1. Articles published between 2018 and 2026 2. Focus on science education, environmental education, or the integration of STEM/STEAM approaches in science learning.	1. Articles published outside the 2018–2026 timeframe. 2. Non-science fields or general education that do not specifically address the natural sciences or STEM integration.
Study Types	Empirical research involving interventions or classroom practices (qualitative, quantitative, or *mixed-methods*), as well as systematic literature review articles	Non-empirical articles not based on systematic data, such as opinion pieces, essays, or textbooks
Subjects/Population	Includes elementary (SD), middle (SMP/SMA), and high school levels, as well as educators or *pre-service teachers*.	Studies that do not directly involve learners or education practitioners (industry or community sectors)
Substantive Relevance	Explicitly applies, evaluates, or discusses the concepts of *energy literacy*, energy-related science literacy, or active learning models (such as PjBL and POE) in the context of STEM/science.	Articles that discuss purely technical aspects of energy (laboratory science/engineering) without an educational context, or that merely use the term “STEM” in a general sense without referring to literacy or learning indicators.

The selection of articles based on research type, the data analysis methods used, and a focus on educational research in schools resulted in 15 articles.

Screening and Quality Assessment

Preliminary search results were screened based on titles and abstracts for relevance. Articles that passed the initial screening underwent a full-text review to determine their eligibility. Subsequently, each study was assessed using a quality assessment (QA) rubric adapted for systematic literature reviews.

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The assessment included five criteria: (1) clarity of the research objectives, (2) appropriateness of the research methodology, (3) relevance to the topic of STEM-based science education and energy literacy, (4) clarity of the reported findings, and (5) contribution of the study to the objectives of this review. Each criterion was scored as Yes (1) or No (0). Only studies achieving a minimum score of 4 out of 5 were included in the final synthesis.

Data Extraction

Relevant data from the selected articles will be extracted. This data includes research methodology, key findings related to the integration of energy literacy into STEM education, the instructional models used, challenges, and implications.

Data Analysis

The extracted data will be analyzed thematically or by content to identify patterns, trends, gaps, and relationships among concepts. This analysis aims to present a comprehensive synthesis of the existing literature and answer the research questions (Mohamad & Osman, 2022). Thus, the final number of articles analyzed in this systematic review is summarized in the PRISMA Flow Diagram (Hebebci, 2023; Indah & Ahmad, 2025) in Figure 1.

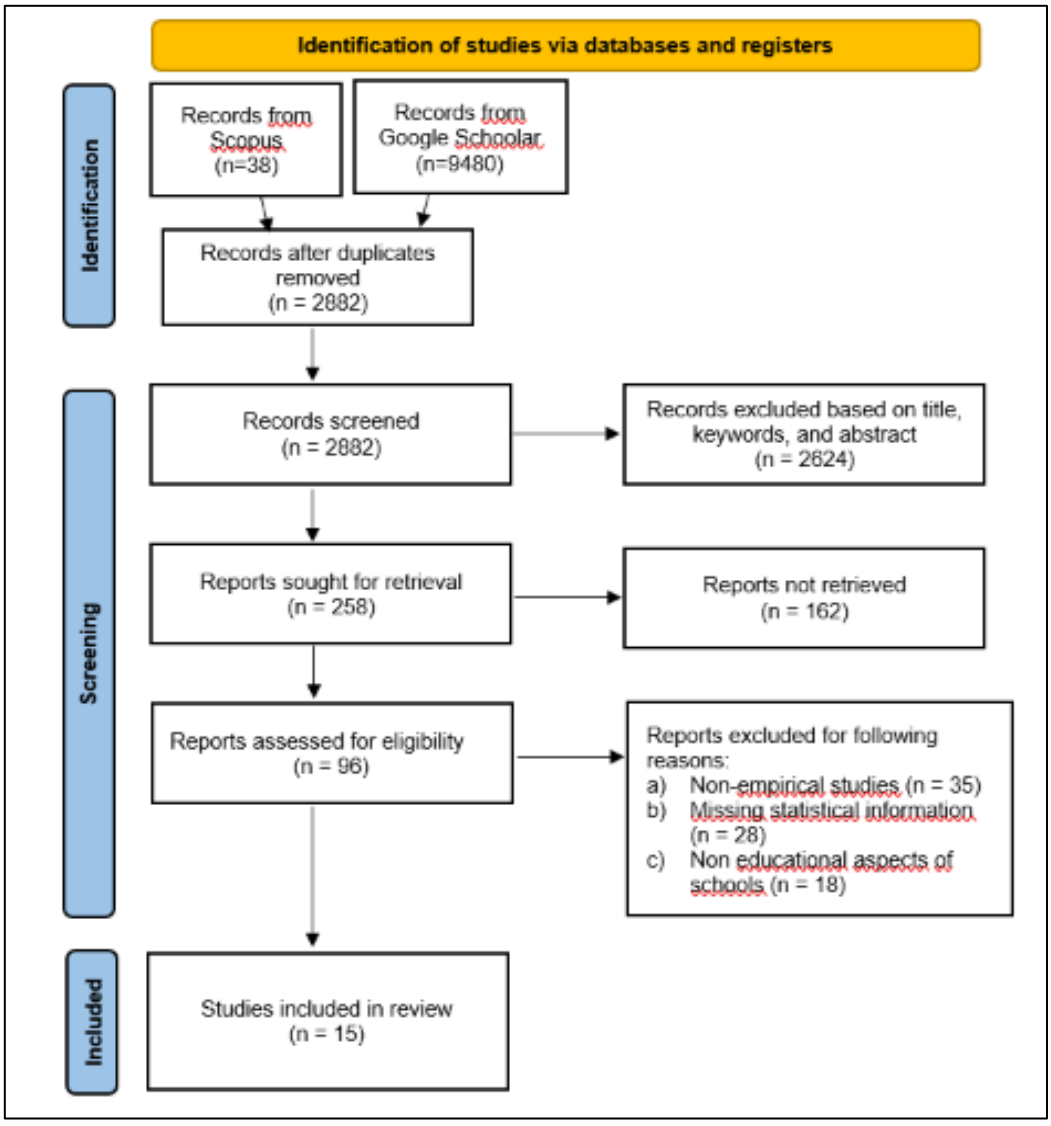


Figure 1. PRISMA Flowchart

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Figure 1 presents the PRISMA (*Preferred Reporting Items for Systematic Reviews and Meta-Analyses*) flowchart, which illustrates the article selection stages in this study. The literature search process began by collecting articles from two databases: *Scopus* (38 articles) and *Google Scholar* (9,480 articles), resulting in a total of 9,518 articles. After reviewing and removing articles identified as duplicates, the number of articles eligible for the next stage was 2,882.

All of these articles then underwent an initial screening process to assess the relevance of their titles, keywords, and abstracts to the research topic. The screening results showed that 2,624 articles did not meet the research focus and were therefore excluded from the selection process. Consequently, 258 articles were selected for full-text retrieval. However, of that number, 162 articles could not be obtained in full-text form and thus could not proceed to the evaluation stage.

The next stage involved assessing the eligibility of the 96 articles for which full-text versions were successfully obtained. These articles were reviewed based on the previously established inclusion and exclusion criteria. The evaluation results showed that 81 articles did not meet the research requirements and were therefore eliminated. The excluded articles consisted of 35 articles that were irrelevant to the research topic, 28 articles that did not meet the inclusion criteria, and 18 articles with insufficient data or full-text versions that could not be analyzed further.

After all selection stages were completed, 15 articles that met all research criteria were identified and subsequently used as the primary sources in the analysis process. The application of the PRISMA procedure in this study ensured that the literature selection process was conducted systematically, objectively, and accountably, so that the analyzed articles possessed a level of relevance and quality consistent with the research objectives.

RESULTS AND DISCUSSION

The development of energy literacy is an essential prerequisite for fostering responsible citizens who are capable of contributing to global sustainability solutions (Santillán & Cedano, 2023). Strong energy literacy can empower communities to support the transition to a low-carbon energy system and achieve the Sustainable Development Goals (SDGs), particularly SDG 7 on clean and affordable energy (Anastasya & Putri, 2024). Thus, integrating energy literacy into science education through a STEM approach can be viewed as a strategic investment in future sustainability.

Results

This section presents relevant findings from previous studies published in academic journals to provide an overview of existing research related to the topic. The selected studies are reviewed based on their publication titles, authors and years of publication, research methods, and main findings. This review aims to identify key trends, compare research approaches, and establish the theoretical and empirical foundations for the present study. A summary of the relevant previous research is presented in Table 2.

Table 2. Relevant Previous Research

Publication Title	Author, Year	Method	Description of Findings
Energy Literacy: A Systematic Review of the Scientific Literature	Santillán & Cedano, 2023	*Systematic Literature Review* (SLR)	This systematic review shows that most research on energy literacy focuses on evaluating energy literacy in various groups (primarily students) as well as the development, implementation, and evaluation of tools to improve energy literacy.
Learning- -effectiveness of energy education in junior high schools:	Wang & Wang, 2023	*Action Research*	This study designed an interdisciplinary energy education course using the *predict-observe-explain* model within a

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Publication Title	Author, Year	Method	Description of Findings
Implementation of action research and the POE model in a STEM course			STEM context for teaching the topic of wind power.
Energy Literacy and Education: Stakeholders' Perspectives on Promoting Energy Literacy in Education	Rohmatulloh et al., 2021	Qualitative Research (*Stakeholder* Analysis/ Interviews)	This study reveals that energy literacy programs are educational initiatives aimed at raising awareness among energy users, with the goal of fostering understanding, attitudes, and behavioral changes in science education.
Integration of STEAM and Project-Based Learning to Improve Elementary School Students' Scientific Literacy in Alternative Energy	(Adriyawati et al., 2020)	*Quasi-Experimental*	This study aims to determine how the integration of STEAM-Project-Based Learning is implemented to develop students' scientific literacy, demonstrating that this integration can enhance the scientific literacy of elementary school students.
Integrated STEM Education: A Systematic Review of Instructional Practices in Secondary Education	Thibaut et al., 2018	*Systematic Literature Review* (SLR)	This systematic review highlights that an integrated STEM curriculum provides a more relevant, less fragmented, and more stimulating learning experience for students.
Making Connections: Elementary Students' Ideas About Electricity and Energy Resources	Merritt et al., 2019	Qualitative Study (*Case Study*)	An exploration of energy literacy development in fourth grade, in which the research team developed a curriculum on energy sources aligned with *the Next Generation Science Standards*.
An Interdisciplinary Renewable Energy Education: Investigating the Influence of STEM Activities on Perception, Attitude, and Behavior	Hiğde, 2022	*Quasi-Experimental*	This study aims to examine the effects of design-based STEM activities developed for renewable energy sources on the perceptions, attitudes, and behavioral orientations of prospective science teachers.
The Energy Concept and Its Relation to Climate Literacy	Mittenzwei et al., 2019	*Conceptual Analysis*	This study concludes that an understanding of energy concepts is crucial for addressing climate change in education, and highlights the challenges in developing a deep understanding of energy.
Interdisciplinary Approach-Based Energy Education	Sulun & Guven, 2019	*Quasi-Experimental*	This study aims to investigate the effects of an interdisciplinary, energy-based learning approach on the academic achievement and conceptual understanding of prospective science teachers
Project-Based Learning: MaS WaWi Electric Power Plant Model (biomass, sun, water, and wind) to Improve Students' Energy Literacy	Ilmi et al., 2021	*Research and Development* (R&D)	This study demonstrates that efforts to improve students' energy literacy skills are carried out by implementing project-based learning through a STEM approach on physics topics related to energy sources.

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Publication Title	Author, Year	Method	Description of Findings
Fostering Active Engagement in Pre-Service Teachers in STEM Education: A Comprehensive Systematic Literature Review	Kamarrudin et al., 2023	*Systematic Literature Review* (SLR)	This systematic literature review demonstrates that active engagement in STEM education is a powerful pedagogical approach that enhances students' interest, motivation, and achievement in STEM subjects.
Innovating Education: A Comprehensive Review of STEM Education Approaches	Marzuki et al., 2024	*Case Studies*	Presents case studies of successful STEM programs at various educational levels and compares international STEM education models, providing insights into effective strategies.
Integrating Literacy into STEM Education: Changing Teachers' Dispositions and Classroom Practice	Feng et al., 2020	*Mixed Methods*	This paper presents the results of a study on teachers' dispositions and classroom practices related to the integration of literacy into STEM subjects, where literacy is one of the key focuses in integrated STEM to enhance teachers' content knowledge and student success.
Analysis of the Concept of Energy in the Spanish Curriculum for Secondary Education and the Baccalaureate	(Martínez-Borreguero et al., 2019)	*Sustainable* Perspective	This study found that teaching and learning concepts within the science, technology, society, and environment (STSE) approach—such as the "concept" of energy—are key elements in enhancing student competencies.
Enhancing High School Students' Creativity Through a Project-Based Learning Model with a STEM Approach on Optical Instruments	Alfarisi, 2020	*Quasi-Experimental*	This study found that the application of the STEM approach in integrated learning encourages students to produce tangible products as solutions to identified problems, and requires students to be active learners who think and act creatively.

Discussion

The following discussion synthesizes these fifteen studies into three main themes: the urgency of energy literacy as a 21st-century competency, the contribution of the STEM approach to energy education, a variety of innovative learning strategies that have been tested, and the role of teacher professional development in supporting its implementation.

The Urgency of Energy Literacy as a 21st-Century Competency

Energy literacy is inseparable from efforts to foster citizens capable of making wise decisions regarding their daily energy consumption. Santillán and Cedano (2023), through a systematic review of the scientific literature, found that the majority of research in this field focuses on two areas: evaluating the level of energy literacy among target groups (primarily students) and developing instruments to improve it. This mapping is important because it shows that energy literacy as a field of study has not yet made significant progress toward full curricular integration but remains largely confined to the measurement and diagnostic stages.

This urgency is reinforced by the findings of Mittenzwei et al. (2019), which highlight the close relationship between conceptual understanding of energy and climate literacy. This study concluded that a deep understanding of energy is a prerequisite for students' ability to address climate change issues scientifically; however, in practice, students still struggle to achieve this level of understanding. These findings align with those of Rohmatulloh et al. (2021), who identified energy literacy programs as

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educational initiatives aimed at fostering awareness among energy users—manifesting as measurable changes in understanding, attitudes, and behaviors within the context of science learning. Together, these three studies confirm that energy literacy is not merely a mastery of physics concepts related to energy, but rather a multidimensional competency that encompasses the cognitive, affective, and psychomotor domains.

The Contribution of the STEM Approach to Energy Education

The second theme is how the STEM approach provides a framework that allows energy concepts to be taught in an integrated manner. Thibaut et al. (2018), through a systematic review of STEM instructional practices in secondary school education , found that an integrated STEM curriculum yields more relevant and stimulating learning experiences compared to traditional approaches that separate academic disciplines. This argument aligns with the findings of Kamarrudin et al. (2023) in their systematic literature review on pre-service teachers' engagement in STEM education, which showed that active engagement in STEM learning correlates with increased student interest, motivation, and academic achievement.

At the implementation level, Hiğde (2022) directly tested the impact of design-based STEM activities—specifically developed for the topic of renewable energy—on the perceptions, attitudes, and behavioral orientations of science teacher candidates. The results of this study are relevant because they demonstrate that the STEM approach is not only effective at the student level but can also be used to build teacher candidates' readiness to teach energy-related issues. Meanwhile, Alfarisi (2020) demonstrated, from the perspective of learning outcomes, that the STEM approach in integrated learning—in this case applied to the topic of optical instruments—encourages high school students to produce tangible products as solutions to the problems they encounter, while simultaneously requiring students' active engagement in creative thinking and action. Marzuki et al. (2024), through a comprehensive review of various STEM education approaches, complement this picture by comparing case studies of successful STEM programs at various educational levels internationally, thereby providing insights into which strategies are consistently effective across geographical contexts and educational levels.

Innovative Learning Strategies for the Integration of Energy Literacy

The third theme groups studies that specifically examine particular learning models or strategies in the context of integrating energy literacy and STEM. In the realm of *project-based learning*, Adriyawati et al. (2020) implemented *STEAM-Project-Based Learning* with the aim of developing elementary school students' scientific literacy in the study of alternative energy, and found that this approach was effective in developing scientific literacy at that level. These findings are reinforced by Ilmi et al. (2021), who implemented project-based learning through a STEM approach on physics topics related to energy sources (biomass, solar, hydro, and wind power plant models) and demonstrated an improvement in students' energy literacy skills. Although these two studies were conducted at different educational levels (elementary school in the study by Adriyawati et al., and a higher level in the study by Ilmi et al.), they consistently show that project-based learning provides students with hands-on experience in designing energy solutions, rather than merely studying them theoretically.

In the realm of interdisciplinary approaches, Güven and Sülün (2019) investigated the effects of energy-based interdisciplinary learning on the academic achievement and conceptual understanding of pre-service science teachers, while Wang and Wang (2023) designed an interdisciplinary energy education course using the *predict-observe-explain* model within a STEM context for the topic of wind power among middle school students. Both studies demonstrate that an interdisciplinary approach can be applied both at the pre-service teacher education level and directly with students, with the *"predict-observe-explain"* model serving as a concrete pedagogical strategy that bridges abstract energy concepts with observations of real-world phenomena.

In the realm of curriculum development, Merritt et al. (2019) developed a curriculum on energy sources and electricity aligned with *the Next Generation Science Standards* for fourth-grade students, tracing how students' ideas about electricity and energy sources develop through the curriculum. In line

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with this, Martínez-Borreguero et al. (2019) analyzed the concept of energy in Spain's secondary and baccalaureate education curricula from a sustainability perspective and concluded that teaching concepts—such as energy—through a science-technology-society-environment approach is a key element in enhancing students' competencies. Both studies confirm that the successful integration of energy literacy depends not only on classroom teaching methods but also on the alignment of curriculum design with applicable national standards.

Overall, the synthesis of these fourteen studies underscores that the integration of energy literacy into science education through a STEM approach is an evolving field of study with great potential for shaping citizens who are better informed and more responsible regarding energy. This approach has consistently been found to support the development of deep conceptual understanding (Mittenzwei et al., 2019; Martínez-Borreguero et al., 2019), practical skills through tangible products (Alfarisi, 2020; Ilmi et al., 2021), and a proactive attitude toward energy issues (Hiğde, 2022; Rohmatulloh et al., 2021), with its success ultimately depending on the readiness of the teachers implementing it (Feng et al., 2020; Kamarrudin et al., 2023).

Although various studies have demonstrated the effectiveness of the STEM approach in improving energy literacy, there are still a number of *research gaps* that require attention. Most previous studies have focused on testing the effectiveness of specific instructional models—such as *Project-Based Learning*, *Predict–Observe–Explain*, or interdisciplinary approaches—without providing a comprehensive synthesis of how these various strategies contribute to the development of energy literacy. Furthermore, existing research tends to treat energy literacy as merely a learning outcome, while discussions regarding the interrelationships among the dimensions of knowledge, attitudes, behavior, and the implementation of STEM learning are still conducted in isolation. Differences in research contexts, educational levels, and student characteristics have also prevented the formation of a complete picture of the patterns of energy literacy implementation in STEM-based science education. Therefore, a study is needed that can integrate these various empirical findings to provide a more comprehensive understanding of research trends, effective learning strategies, and the future direction of energy literacy development in STEM-based science education.

CONCLUSION

This systematic literature review indicates that energy literacy—a multidimensional competency encompassing knowledge, attitudes, and behaviors—can be effectively developed through a STEM approach using various strategies such as Project-Based Learning, the Predict-Observe-Explain model, an interdisciplinary approach, and curriculum development, with success being significantly influenced by teacher readiness. Nevertheless, there are still limitations in studies regarding the integration of energy literacy into digital teaching materials, such as STEM-based e-modules, as well as a lack of long-term research measuring changes in students' attitudes and behaviors. Therefore, future research needs to develop and evaluate digital teaching materials that integrate energy literacy with a STEM approach to support sustainable science learning that is relevant to the demands of the 21st century.

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Conflict of Interest

The authors declare that they have no conflict of interest related to this study.

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Author Contributions

V.M., R., and N.I.S. contributed to the conceptualization, methodology, literature search, data analysis, and synthesis of findings. All authors contributed to the preparation and revision of the manuscript, reviewed and approved the final version, and agreed to be accountable for their respective contributions.

Data Availability Statement

The data supporting the findings of this study are available from the corresponding author upon reasonable request, subject to applicable confidentiality and ethical considerations.

Ethics Approval and Consent to Participate

Ethical approval and informed consent were not required for this study because it was a systematic literature review based exclusively on previously published research and did not involve direct participation by human subjects or the collection of new data from participants.

Generative AI Declaration

The authors did not use generative artificial intelligence (AI) tools in the preparation of this manuscript.

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