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Systematic Literature Review of Renewable Energy Concepts in High School Physics

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Abstract

Renewable energy has become a strategic topic in high school physics education due to its relevance to energy transition, technological development, and sustainability issues. This study aims to systematically review how essential physics concepts are applied, what instructional approaches are used, and how renewable energy education is integrated into high school physics curricula. A Systematic Literature Review (SLR) was conducted following PRISMA procedures, including identification, screening, eligibility assessment, and qualitative synthesis. A total of 210 articles were identified from three databases (Scopus, Web of Science, and Google Scholar) for the period 2021–2025. After duplicate removal and eligibility screening, 15 empirical studies met the inclusion criteria and were analyzed. The synthesis indicates that the dominant physics concepts addressed include energy conservation, energy conversion, electrical power, and system efficiency, typically contextualized through solar panels, wave energy, and alternative energy systems. In terms of pedagogy, approximately two-thirds of the studies employed Project-Based Learning (PBL), frequently integrated with STEM or STEAM approaches. More than half incorporated digital media such as e-worksheets, digital modules, augmented reality (AR), or interactive simulations to support conceptual visualization. The findings also reveal a growing alignment between renewable energy instruction and Education for Sustainable Development (ESD), particularly in fostering energy literacy and environmental awareness. Overall, renewable energy functions not only as contextual content but also as a conceptual and pedagogical bridge connecting physics principles, engineering design, and sustainability education. However, most studies focus on short-term instructional outcomes, with limited longitudinal evidence regarding sustained improvements in students' energy literacy. Future research should expand cross-context implementation and examine long-term curricular integration of renewable energy within physics education.

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INTRODUCTION

In the context of 21st-century education, the development of literacy competencies has become a central objective of science learning. Recent studies emphasize that energy

literacy is not merely the understanding of energy concepts but also encompasses awareness, attitudes, and responsible decision-making related to energy use and sustainability (Aida et al., 2025; Santillán & Cedano, 2023). As global societies accelerate the transition toward renewable energy systems, education plays a strategic role in preparing students to understand the scientific, technological, environmental, and social dimensions of energy transformation. Within this framework, physics education is particularly significant because it provides the conceptual foundation for understanding energy conservation, energy conversion, efficiency, and energy systems as interconnected scientific principles.

Furthermore, the integration of renewable energy topics in physics classrooms aligns with the broader agenda of sustainable development and 21st-century competencies. A systematic review by Sriatun et al. (2025) highlights that strengthening energy literacy in physics education requires pedagogical strategies that connect conceptual understanding with real-world sustainability issues. Similarly, technology-enhanced science teaching approaches have been shown to support critical thinking, problem solving, and sustainability awareness while aligning learning practices with Sustainable Development Goal 4 on quality education (Sayadi & Pangandaman, 2025). These findings indicate that renewable energy learning in physics is not solely conceptual instruction but a transformative educational approach that supports students' readiness to participate in the global energy transition.

A number of studies in physics education have developed various innovations in renewable energy learning, such as the study by Shahbazloo & Mirzaie (2023) which examined the 5E-STEM approach in the context of solar energy; the study by Rizki et al. (2024) discussing renewable energy learning projects to support Education for Sustainable Development; and (Satriawan et al., 2021) researching project-based learning (PBL) in the topic of ocean wave energy. In addition, the development of technology-based media and modules such as augmented reality in the study by Karlina et al., 2024), STEM-based e-worksheets in the research by Rachmawati & Wiyatmo (2025) and PBL-based e-magazines in the research by Wulandari et al. (2025) shows that pedagogical innovations in this topic are developing significantly.

In addition, Sriatun et al., (2025) research also highlights the importance of strengthening energy literacy in physics education, while Laila et al. (2025) research highlights the development of STEM-based interactive digital modules. These studies show that renewable energy has been positioned not only as conceptual content but also as an authentic context for building higher-order thinking skills and 21st-century competencies. Although many empirical studies on renewable energy learning in the context of physics education show significant improvements, systematic synthesis studies that map patterns of pedagogical approaches, learning media characteristics, intervention designs, and learning outcomes are still relatively limited. Most of the available research tends to focus on testing the effectiveness of one specific type of intervention, without accompanying comparative analysis across studies that would enable the identification of dominant trends, methodological gaps, and the consistency and variation of empirical findings in a more comprehensive manner.

Theoretically, this gap is important because the integration of renewable energy in physics education lies at the intersection of three main conceptual frameworks: (1) constructivism in science learning, (2) STEM integration as an interdisciplinary approach, and (3) Education for Sustainable Development (ESD). Without systematic synthesis, it is not yet certain how these three frameworks are actually implemented in learning design, whether they are more dominant in project-based, immersive technology-based, or energy literacy-based approaches. In other words, the research gap is not merely a "lack of research," but rather the absence of comprehensive theoretical and empirical mapping of the direction of renewable energy learning in physics education.

In addition, variations in research methods, measurement instruments, and sample characteristics in previous studies necessitate descriptive quantitative analysis. in order to obtain a more objective picture of research trends. A methodologically robust systematic review using transparent selection procedures such as PRISMA and clear inclusion and exclusion criteria is essential to improve the validity of the synthesis of findings.

Based on this urgency, this study aims to conduct a Systematic Literature Review (SLR) of studies on renewable energy learning in the context of physics education. Specifically, this study seeks to:

- identify trends in learning approaches used
- analyze the types of media or interventions developed
- map the learning outcome variables measured, and
- identify theoretical and methodological gaps for further research

Thus, this study is expected to contribute not only in the form of a descriptive summary but also an analytical synthesis that can clarify the direction of renewable energy learning development in physics education conceptually and empirically.

METHODS

This study uses the Systematic Literature Review (SLR) method to systematically identify, evaluate, and synthesize empirical research on renewable energy learning in the context of high school physics education. This method was chosen to ensure that the literature search and selection process was conducted transparently, systematically, and replicably. The SLR implementation procedure in this study refers to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines and the methodological principles described in Systematic Reviews in Educational Research (Zawacki-Richter et al., 2019).

Research Question

The research questions guiding this review are presented in Table 1.

Table 1 Research question

#	Research Question
RQ1	How are essential physics concepts applied in the discussion of renewable energy topics in the context of high school physics education?
RQ2	What learning approaches, models, and media are used in teaching renewable energy in high school physics?
RQ3	How is the importance of renewable energy education emphasized and integrated into high school physics curricula?

Selection Criteria

The next stage is the screening stage, which ensures the suitability of the scientific literature by categorizing it according to inclusion and exclusion criteria. The selection criteria in this study are shown in Table 2.

Table 2 Selection criteria

Aspect	Criteria
Inclusion	• Focuses on renewable energy in the field of physics or physics education. • Researches the population of high school/upper secondary school students. • Available in full text format. • Publication range 2021–2025. • Publications in Google Scholar. Contains empirical data, learning models, or studies of physics concepts.
Exclusion	• The research subjects are not high school students. • Does not explicitly mention physics concepts. • Only discusses renewable energy from an economic or environmental perspective without any physics aspects. • The article is an editorial, opinion piece, or abstract only.

Search Strategy

The literature search was conducted in four electronic databases:

- Scopus
- Web of Science
- Google Scholar

The search was limited to publications between 2021–2025 to capture recent developments in renewable energy education within physics. Boolean operators were used to refine the search. The main search strings, included:

- "renewable energy" AND "physics education" AND "high school"
- "renewable energy" AND "high school physics"
- "STEM" AND "renewable energy" AND "physics classroom"
- "solar energy learning" AND "physics students"

Study Selection Procedure (PRISMA)

The study selection process follows the PRISMA steps, which include:

1. Identification (Identification of all articles from the database)
2. Screening (Screening based on titles and abstracts)
3. Eligibility (Assessment of eligibility based on full text)
4. Included (Articles that meet all criteria are included in the final analysis)

Duplicate articles are removed before the screening stage. The number of articles at each stage is reported in the PRISMA flow chart to ensure transparency of the selection process. You can see the prism procedure in Figure 1.

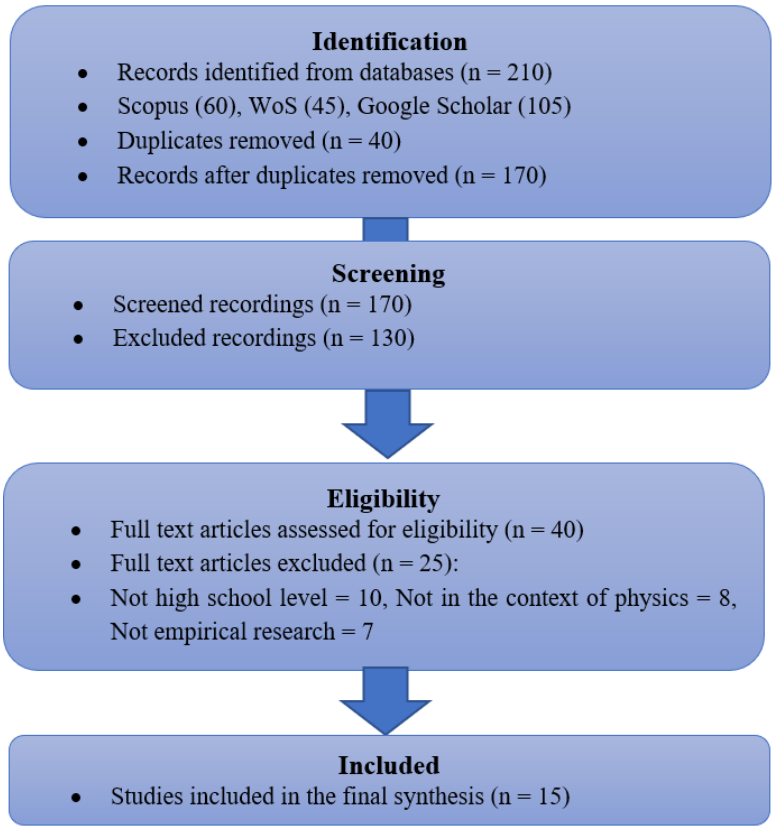

Figure 1 PRISMA flow diagram of study selection

Screening Reliability

To maintain the credibility of the selection process, articles are screened independently by two reviewers based on predetermined inclusion and exclusion criteria. Differences in selection results are discussed until consensus is reached.

The Quality of Studies

Assessment using assessment criteria (0-2). The assessment criteria for evaluating the quality of studies can be seen in Table 3.

Table 3 The quality of studies

Criterion	0 (Poor)	1 (Adequate)	2 (Comprehensive)
Research objectives clarity	Not stated	General	Clear & specific
Methodological transparency	Unclear	Partially explained	Fully detailed
Learning instruments described	Not described	Brief	Valid & reliable instruments
Physics concepts integration	Not explicit	Mentioned	Clearly integrated
Data analysis explanation	Not explained	Basic	Systematic & appropriate

RESULTS AND DISCUSSION

For research using the Systematic Literature Review (SLR) method, there are four stages that must be carried out to obtain appropriate literature according to the criteria, according to (Suciati, 2022, Nisa et al., 2025), namely:

- Identification of literature with relevant topics. This stage has been explained in the method section through the search keywords on Google Scholar.
- Screening: initial screening based on the title and abstract, using the literature identified. Articles that do not match the topic of this research will be eliminated.
- Eligibility and completeness of text in articles that have gone through the identification and screening stages.
- Included are articles that fulfill the eligibility criteria. This stage has been presented in the research method on inclusion and exclusion criteria.

Based on the four selection stages in the Systematic Literature Review (SLR) process, which refers to the PRISMA guidelines, researchers identified 210 articles from three databases, namely Scopus (60), Web of Science (45), and Google Scholar (105), for the period 2021–2025. After removing 40 duplicate articles, 170 articles remained for the title and abstract screening stage. At this stage, 130 articles were excluded because they were not relevant to the context of high school physics learning. Next, 40 articles were analyzed in full text at the eligibility stage. A total of 25 articles were eliminated because they did not meet the inclusion criteria, namely, not focusing on the high school level, not having a clear physics context, or not being empirical research. Thus, 15 articles were declared to meet the criteria and were used in the qualitative synthesis, which can be seen in Table 4.

Table 4 Article search result

Article Title	Learning Approach, Models, or Media	Essential Physics Concepts
STEAM-based learning on renewable energy topics in high school physics for grade X (Yusofaa & Lukma, 2025)	STEAM-based Learning	Solar panel energy, power, and efficiency
The Effectiveness of a Renewable Energy E-Worksheet in STEM-Project Based Learning to Improve Students' Critical Thinking and Collaboration Skills(Rachmawati & Wiyatmo, 2025)	E-Worksheet and STEM Project-Based Learning	Solar power conversion and power calculation

Article Title	Learning Approach, Models, or Media	Essential Physics Concepts
Development of Science Process Skills-Based Student Worksheets on Renewable Energy Materials to Enhance Mutual Cooperation and Creative Character (Maimunah et al., 2025)	E-Worksheet and Model *4-D* (Define, Design, Develop, Disseminate)	Renewable energy materials
Strategies for Promoting Energy Literacy in Physics Education: Insights from a Systematic Literature Review (Sriatun et al., 2025)	Context-based learning, sustainability-oriented modules, digital learning media	Energy conversion, efficiency, sustainable energy use
A Contextual Semi-Assisted Project-Based Learning on Ocean Wave Energy: Pre-service Physics Teachers' Perceptions (Satriawan et al., 2021)	Semi-Assisted Project-Based Learning	Wave energy
The Application of Problem-Based Learning with STEM Approach to Practice Students' Self-Regulated Learning on Renewable Energy Topic(Savana et al., 2023)	Problem-Based Learning (PBL) + STEM	Renewable Energy Topic
Development of Renewable Energy Modules with Contextual Teaching Learning Helpful Augmented Reality (AR) Integrated Al-Qur'an Class X SMA/MA (Karlina et al., 2024)	Augmented Reality Module and Contextual Teaching Learning (CTL)	Solar panels, turbines, and energy flow
Strategies for Promoting Energy Literacy in Physics Education: Insights from a Systematic Literature Review(Sriatun et al., 2025)	Context-based learning, sustainability-oriented modules, digital learning media	Energy conversion, efficiency, sustainable energy use
Renewable energy education and awareness among Indonesian students: Exploring challenges and opportunities for a sustainable future (Agung et al., 2024)	Sustainable Development approach	Renewable energy education
Renewable Energy Learning Project in Physics Classroom: Achieving Education for Sustainable Development(Rizki et al., 2024)	Project-Based Learning (PBL)	Renewable energy education
Exploring Indonesian Students' Views on Solar Panels and Fossil Fuels: Education for Sustainable Development Perspective (Rusmana et al., 2025)	Sustainable Development Approach	Science education and renewable energy technology
Design and evaluation of solar power plant-based learning media for renewable energy education in high schools(Entang et al., 2024)	Learning Media (Solar Power Plantbased)	Contextual learning media for renewable energy in physics lessons in high school
Integration of Project Based Learning with STEM Approach to Alternative Energy Material as Effective Learning to Improve Problem Solving Skills (Roslina et al., 2024)	Project Based Learning (PBL) + STEM	Energy conversion and alternative energy system design
Implementation of Education for Sustainable Development-Based STEM Learning on the Topic of Renewable Energy to Improve Systems Thinking Skills(Kurniawan & Rosidin, 2024)	STEM + Education for Sustainable Development (ESD)	Energy literacy and sustainability
Characteristics of High School Physics Problem-Solving Skills and Integrating the PBL Model Assisted by E-Book (Dawana & Dwikoranto, 2024)	Problem-Based Learning (PBL) + (E-Book)	Power, energy, and problem solving analysis
Design of A Stem Project-Based Learning Digital Module on Renewable Energy(Putri et al., 2024)	Digital Module + STEM Project Based Learning	Energy efficiency and power generation systems

The final stage in the Systematic Literature Review (SLR) procedure is data synthesis, which is the process of integrating findings from 15 selected articles to comprehensively answer three research questions. Synthesis is carried out through thematic grouping based on: (1) essential physics concepts, (2) learning approaches and media, and (3) integration of renewable energy in high school physics curricula.

RQ1: How are essential physics concepts applied in the discussion of renewable energy topics in the context of high school physics education?

The synthesis results indicate that the essential physics concepts in renewable energy learning in high schools are centered on three main domains: (1) basic energy concepts and the law of conservation of energy, (2) energy conversion and energy transformation, and (3) power, efficiency, and quantitative analysis of energy systems (Dawana & Dwikoranto, 2024, Putri et al., 2024, Roslina et al., 2024, Rachmawati & Wiyatmo, 2025, Yusofaa & Lukma, 2025). The fifteen articles consistently show that renewable energy is used as an applied context to strengthen the understanding of these concepts, whether through solar panel systems, turbines, ocean waves, or alternative energy-based power generation systems (Entang et al., 2024, Karlina et al., 2024, Rizki et al., 2024; Savana et al., 2023; Satriawan et al., 2021). In summary, there are two main patterns in the application of physics concepts:

1. Contextualization of Abstract Concepts
   Concepts such as electrical power, efficiency, kinetic-potential energy, and energy conversion are represented through real systems such as solar panels and mini power generation systems (Entang et al., 2024, Karlina et al., 2024, Rachmawati & Wiyatmo, 2025, Yusofaa & Lukma, 2025). This approach narrows the gap between mathematical abstraction and real phenomena and strengthens students' energy literacy (Agung et al., 2024; Sriatun et al., 2025)
2. Integration of Concepts with Technology Design
   Several studies show that students not only calculate power or efficiency but also design prototypes, analyze energy systems, and evaluate the performance of alternative energy technologies (Putri et al., 2024; Rizki et al., 2024; Roslina et al., 2024; Savana et al., 2023). This indicates a shift from formula-based learning to energy system-based learning and authentic problems (Dawana & Dwikoranto, 2024; Satriawan et al., 2021)

However, cross-study analysis shows that the application of physics concepts is no longer representational but is moving towards a systemic approach. Renewable energy is used as a framework for understanding the relationship between input, process, and output in energy systems. This indicates a shift from formula-based learning to technology-based learning.

Nevertheless, there is a tendency for most studies to focus on electrical aspects and efficiency calculations, while more in-depth conceptual explorations, such as energy degradation, system limitations, or thermodynamic dimensions, do not appear much. This indicates that the integration of renewable energy is still dominant at the quantitative application level, not yet fully at the epistemological conceptual level. Thus, conceptually, it can be concluded that renewable energy learning in high schools has shifted its focus from “calculating energy” to “understanding energy systems,” but there is still room to expand the conceptual depth across branches of physics.

RQ2: What learning approaches, models, and media are used in teaching renewable energy in high school physics?

A synthesis of 15 articles shows the dominance of project-based approaches, STEM/STEAM integration, contextual approaches, and the use of interactive digital media.

1. Project-Based Learning (PBL)
   PBL emerged as the most consistently used model in the renewable energy learning (Dawana & Dwikoranto, 2024; Putri et al., 2024; Rizki et al., 2024; Roslina et al., 2024; Satriawan et al., 2021; Savana et al., 2023). Through this approach, students design simple energy systems, conduct energy conversion experiments, and analyze system efficiency. This model has been proven to not only improve conceptual understanding but also develop problem-solving, collaboration, and systemic thinking skills.
2. STEM/STEAM Integration
   The STEM/STEAM approach expands learning to be integrative between science, technology, engineering, and mathematics. This integration strengthens students' quantitative abilities, encourages innovative energy system design, and enhances creativity and self-regulated learning (Kurniawan & Rosidin, 2024)
3. Contextual Teaching and Learning (CTL)
   The contextual approach is used to connect energy material with environmental and community needs. CTL helps increase the relevance of learning and strengthens energy literacy in the context of sustainability (Agung et al., 2024; Rusmana et al., 2025)
4. Digital Media and Technology (E-worksheets, Digital Modules, AR)
   The use of e-worksheets, digital modules, e-books, and augmented reality has become a significant trend in renewable energy learning. Digital media serves as a tool for visualizing energy flows, simulating energy conversion, and providing interactive feedback that helps transform abstract concepts into concrete ones (Maimunah et al., 2025; Rachmawati & Wiyatmo, 2025)

The dominance of Project-Based Learning (PBL) demonstrates the compatibility between the characteristics of renewable energy materials and the design-based approach. Renewable energy is applicable and systemic, so project-based learning is relevant because it allows students to design, test, and evaluate energy systems directly. Thus, PBL is not just a popular method but is pedagogically aligned with the structure of the concept of energy itself.

STEM/STEAM integration expands learning from simply understanding physics concepts to the process of designing, optimizing, and analyzing energy systems. However, the depth of integration varies. In some implementations, STEM appears only as a combination of disciplinary labels, while in stronger practices, integration is evident in calculation-based engineering activities and authentic problem solving. This shows that the quality of integration is more important than simply using the term STEM.

Digital media such as e-worksheets, digital modules, AR, and e-books serve as a bridge between abstract concepts and concrete representations. This technology helps visualize energy flows and conversion processes that are difficult to observe directly. However, digital media essentially functions as a cognitive facilitation tool; its effectiveness is highly dependent on the underlying pedagogical design. Without strong instructional design, technology does not automatically enhance depth of understanding.

Overall, effective renewable energy learning occurs when there is coherence between the nature of the concept (energy systems), the learning model (PBL or STEM), and the representation media (digital or AR). Effectiveness does not lie in a single approach but rather in the harmonious integration of pedagogy, technology, and content.

RQ3: How is the importance of renewable energy education emphasized and integrated into high school physics curricula?

The synthesis shows that renewable energy is no longer positioned as an additional context but as a strategic instrument for building energy literacy and sustainability

awareness (Agung et al., 2024; Kurniawan & Rosidin, 2024). This integration is evident through clean energy design projects (Rizki et al., 2024; Roslina et al., 2024), sustainability-based modules (Sriatun et al., 2025), and the ESD STEM approach (Kurniawan & Rosidin, 2024). However, analysis shows that this integration is mostly instructional and contextual, not yet fully curricular or structural. Renewable energy is more often integrated as a learning context in energy and electricity topics, rather than as a cross-subject thematic domain or explicit curriculum policy.

Nevertheless, there are indications of a paradigm shift from physics as content to physics as socio-scientific literacy. In this paradigm, physics learning not only transmits the laws of energy but also shapes awareness of the global energy transition and ecological responsibility. Thus, the integration of renewable energy in high school physics can be understood as a first step toward a sustainability-oriented physics education model, although more systemic curricular transformation is still needed.

Based on the three research questions that have been analyzed, there is a consistent pattern that renewable energy learning in high school physics has undergone a paradigm shift from a concept-centered approach to a system-oriented and sustainability-oriented framework. RQ1 shows that concepts in physics are increasingly contextualized within energy systems, while RQ2 shows that pedagogical approaches such as PBL and STEM are structurally integrated with renewable energy topics in a systematic manner. Furthermore, RQ3 also confirms that renewable energy is no longer positioned as an instructional example but rather as a strategic medium for building energy literacy and sustainability awareness.

From all of the above findings, it can be said that the transformation in physics education that has taken place is not only methodological, such as teaching formulas, but also epistemological, such as developing an understanding of energy and technology as systematic scientific phenomena. However, the synthesis findings in this study also reveal structural limitations, particularly the dominance of electrical perspectives and efficiency calculations, as well as the limited exploration of more in-depth concepts such as thermodynamics and interdisciplinary approaches. This shows that although the integration of renewable energy has developed pedagogically, conceptual depth and curricular integration still need to be strengthened in further research and development.

CONCLUSION

This systematic literature review aimed to analyze how renewable energy is conceptualized, taught, and integrated within high school physics education. Based on the synthesis of 15 selected studies, several key conclusions can be drawn in direct relation to each research question.

Regarding RQ1, essential physics concepts in renewable energy learning are primarily centered on energy conservation, energy conversion, power, and efficiency. However, the findings indicate a conceptual shift from formula-oriented instruction toward system-based understanding. Renewable energy topics function not merely as application examples but as structured contexts for analyzing real energy systems. Despite this progress, the emphasis remains largely on electrical applications and quantitative calculations, suggesting that deeper conceptual integration, such as thermodynamic limitations and systemic energy analysis, remains underdeveloped.

In relation to RQ2, Project-Based Learning (PBL) and STEM/STEAM integration emerge as the most dominant instructional approaches. Their prevalence reflects structural alignment between the applied nature of renewable energy systems and design-oriented pedagogies. Effective learning occurs when students engage in designing, testing, and evaluating energy systems rather than only solving abstract problems. Digital media (e-worksheets, modules, and AR) support this process by bridging abstract concepts and concrete visualization. However, the review also reveals that pedagogical coherence rather

than the mere adoption of labels such as “STEM” or the use of technology determines instructional effectiveness.

Concerning RQ3, renewable energy education is increasingly positioned as a vehicle for promoting energy literacy and sustainability awareness in physics classrooms. The integration is predominantly contextual and instructional, embedded within energy and electricity topics, rather than structurally embedded at the curriculum policy level. Nevertheless, the findings suggest an emerging paradigm shift: physics education is moving from a content-centered orientation toward a sustainability-oriented framework where conceptual understanding, technological design, and socio-environmental responsibility intersect.

Overall, this review highlights that renewable energy serves as an epistemic bridge connecting core physics principles, engineering design thinking, and education for sustainable development. The effectiveness of its implementation depends on the coherence among conceptual depth, pedagogical design, and sustainability orientation. Future curriculum development should therefore move beyond contextual integration and aim for more systemic incorporation of renewable energy as a core organizing theme in physics education.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

AUTHOR CONTRIBUTIONS STATEMENT

Conceptualization, AAI, and K; methodology, AAI; formal analysis, AAI; investigation, AAI; data curation, AAI; writing—original draft preparation, AAI; writing—review and editing, AAI, K, and AT; supervision, K and AT.

AI DISCLOSURE STATEMENT

The authors declare that this research was prepared, researched, written, and edited without the aid of artificial intelligence (AI) techniques.

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