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Global Trend of Factors and Effective Learning in Renewable Energy Education: A Systematic Literature Review

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ABSTRACT

The current study is a systematic review of success factors in renewable energy learning and effective learning systems in teaching renewable energy topics and analyzing trends in renewable energy topics globally. Eighty-five articles from 2014 to 2024 have been analyzed to compile a comprehensive picture of the latest developments and challenges in renewable energy education. The results show that the use of technologies such as Virtual Reality (VR) and virtual laboratories, as well as the integration of hands-on projects such as solar panel manufacturing programs, positively impact students' understanding and skills. Collaboration between industry and academia, along with active learning approaches such as Problem-based learning (PBL), Project-based Learning (PjBL), and Science, Technology, Engineering, Arts, and Mathematics (STEAM), proved effective in improving student learning outcomes, motivation, and participation. The findings highlight the enhanced interest and focus on renewable energy at the global level. The implications of this research emphasize the importance of encouraging the development of innovative and relevant learning designs to support the transition to an energy-sustainable future. By understanding success factors and effective learning strategies, educational institutions could be better equipped to meet the demands of a skilled renewable energy workforce and help accelerate the adoption of green technologies and practices in a globalized society.

1. INTRODUCTION

Renewable energy studies have become increasingly important in facing global energy challenges and supporting sustainable development (Ambrosini and Cirillo 2024; Biancardi et al. 2023). Along with the increasing awareness of the negative impacts of conventional energy consumption patterns (Bordin et al. 2023; Collado et al. 2015), such as environmental degradation and dependence on finite resources (Caudo et al. 2023; Collado et al. 2015), learning about renewable energy is crucial. Renewable energy learning can equip students to understand the basic concepts of renewable energy (Abdurrahman et al. 2023; Abichandani et al. 2019), including using renewable natural resources such as solar, wind, and water, and related technologies. Moreover, renewable energy learning also prepares future generations to actively develop innovative solutions for environmentally friendly energy (Huihui et al. 2024). Integrating renewable energy learning into the curriculum (Abdurrahman et al., 2023; Özbay & Duyar, 2022; Wang & Guo, 2021), educational institutions can provide a strong foundation for students to become future leaders and innovators in creating positive changes in the energy sector (Akinwale 2022; Jafarinejad et al. 2021). It also enables the global community to move towards a more sustainable energy transition, which takes into account environmental, social and economic aspects. Therefore, integrating renewable energy education into the curriculum is necessary and a strategic step in building a sustainable future for future generations.

The increasing demand for skilled labor in the renewable energy field has become a global trend in recent years (Jafarinejad et al. 2021; Rezende et al. 2021; Wang and Guo 2021). Along with the shift towards more sustainable energy sources, the renewable energy industry has become one of the fastest-growing sectors in the world (Khalid Malik et al. 2023; Malamatenios 2016). It creates an urgent need for a workforce with relevant knowledge, skills, and understanding of renewable energy. Due to the challenges of climate change and the need for energy diversification, professionals in the renewable energy sector must be able to develop and implement innovative solutions to meet global energy needs sustainably (Maniatis 2024). Educational institutions must be able to provide programs that not only teach basic theories about renewable energy (Maniatis 2024; Meiboudi et al. 2016) but also provide practical training and field experiences that prepare students to face real-world challenges in the industry (Otto et al. 2019). Therefore, renewable energy-focused education creates opportunities for students to develop meaningful and sustainable careers and supports the transformation towards a more sustainable energy system globally.

An analysis of global trends in renewable energy education highlights the increasing demand for sustainable education and the shift to green energy sources. Nonetheless, challenges such as the lack of an integrated curriculum, shortage of skilled teaching personnel, and limited funding for investment in educational facilities remain major concerns. Key factors influencing learning success include effective learning methods, availability of resources, and support from various stakeholders. The implication of this research finding for policymakers is that it is important to formulate renewable energy education policies that are more effective and relevant to today's challenges and needs. With a good understanding of these key factors, policymakers can allocate their resources and efforts more efficiently and promote the inclusion of renewable energy education in the national education policy agenda. By doing so, policymakers can ensure that renewable energy education adequately equips future generations to face the increasingly complex energy challenges ahead.

The research questions (RQs) to be answered through this study are: RQ1: What are the current global trends in renewable energy education research?; RQ2: What are the key success factors identified in the literature that contribute to effective renewable energy education?; and RQ3: What kind of learning systems have been proven to be most effective in teaching renewable energy topics?.

2. MATERIALS AND METHODS

This article is a systematic review, as the research objectives center on identifying and categorizing global trends, success factors in renewable energy learning, and effective learning systems in teaching renewable energy from the literature over the past ten years. The systematic review approach allows researchers to systematically investigate and collect evidence from various relevant literature sources to answer the research questions that have been set.

The Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA) by (Page et al. 2021) was followed in this study to conduct a systematic literature review. A comprehensive literature database has been the subject of this review. The document review process was carried out through six steps: (i) Identifying the research problem; (ii) Screening; (iii) Eligibility; and (iv) Included; (v) Summarizing data from the literature; and (vi) Interpreting the findings. This systematic approach ensures transparency, replicability, and rigor in the review process, allowing for a thorough examination of the global trends and factors influencing effective learning systems in renewable energy education.

The reviewed articles were identified through searches conducted in eight major online databases of research and academic literature, namely: IEEE Xplore, Scopus, Science Direct, Taylor and Francis, ERIC (Education Resources Information Center), ProQuest, JSTOR, and MDPI (Multidisciplinary Digital Publishing Institute). These databases were selected for their large repositories of research materials, including peer-reviewed journal articles. In conducting the search, two key phrases were used: "renewable energy education" and "renewable energy

instruction." Searching the databases for articles published between 2014 and 2024 with citations yielded 27,820 results, including publications in proceedings. This broad search strategy ensured comprehensive coverage of relevant literature on the topic, allowing for a thorough analysis of trends and factors in renewable energy education over the specified timeframe.

Examination of all identified articles from the searches revealed that some articles in IEEE Xplore were also found in Taylor and Francis. It was also noted that articles containing the phrase "green energy learning" were included in the search results. Most of the identified articles focused on renewable energy learning; therefore, filtering was necessary to identify articles relevant to renewable energy education. In the selection of articles for review, inclusion and exclusion criteria were established. This ensured that only articles directly related to the focus of the study, namely trends and factors in renewable energy education, were included in the analysis.

The inclusion criteria used focused solely on materials related to renewable energy education. These articles were identified by reading their abstracts. Subsequently, a final selection was made by identifying articles that directly addressed renewable energy education. The recency of the articles was also taken into consideration. Ultimately, 85 articles published between 2014 and 2024, which were found to be directly relevant to the scope of the study, were selected and reviewed. Thematic textual analysis was employed to analyze and synthesize the data. The data were initially coded, after which relevant themes aligned with the study's aims and objectives were identified and reviewed. Findings were presented descriptively using text, tables, and figures to facilitate understanding and clarity in the subsequent sections.

3. RESULTS AND DISCUSSION

3.1.Characteristics included study

This systematic literature review study analyzes 85 articles considering the global trend of factors and effective learning in renewable energy education. Through this study, we identified the distribution of research on renewable energy learning over the past ten years, presenting how research patterns in renewable energy learning have changed. Table 1 displays the SJR (Scimago Journal Rank) value in 2022 and the Q category (Q1-Q4) of the journals we collected in the top 10. The journal publications are organized by their frequency value, giving an idea of their contribution and relevance in renewable energy education research.

The decision not to include search results on proceedings, such as conferences or seminars, in Table 1 is a step we took to focus our analysis on journals that significantly impact disseminating research related to renewable energy learning. While proceedings are often an important platform for sharing the latest research, we chose to emphasize more established journals with a strong reputation in renewable energy learning.

Table 1. Scimago Journal Rank of Included Study

Journal	*f**	Q	SJR (2022)
Renewable and Sustainable Energy Reviews	13	Q1	3.23
Sustainability	9	Q1	.66
Solar Energy	5	Q1	1.37
Renewable Energy	3	Q1	1.28
Energy Research & Social Science	2	Q1	2.17
IEEE Access	2	Q1	.93
Interdisciplinary Journal of Environmental and Science Education	2	-	-
Journal of Cleaner Production	2	Q1	1.98
Resources Policy	2	Q1	1.87
Acta Innovations	1	Q3	.3

Note(s): **f* = Frequency

The results of the literature search in Table 1 reveal that Renewable and Sustainable Energy Reviews is the journal that presents the most research articles on renewable energy education, with a total of 13 articles. The journal has a Q1 and SJR category in 2022 of 3.23, indicating a significant level of influence and quality in disseminating research in the field. However, the Interdisciplinary Journal of Environmental and Science Education articles must still be included in the Scopus database. Therefore, they do not currently have an SJR score and Q category; indicators typically used to measure a journal's influence and impact in the scientific community.

3.2. Global Trend Renewable Energy Education

Figure 1 illustrates the global trend of renewable energy learning from 2014 to 2024. The analysis shows the evolution in research related to renewable energy learning over the ten years. Changes in research patterns can be observed in the number of publications that occur yearly. This graph visually represents how the interest and focus of research into renewable energy learning has evolved over time.

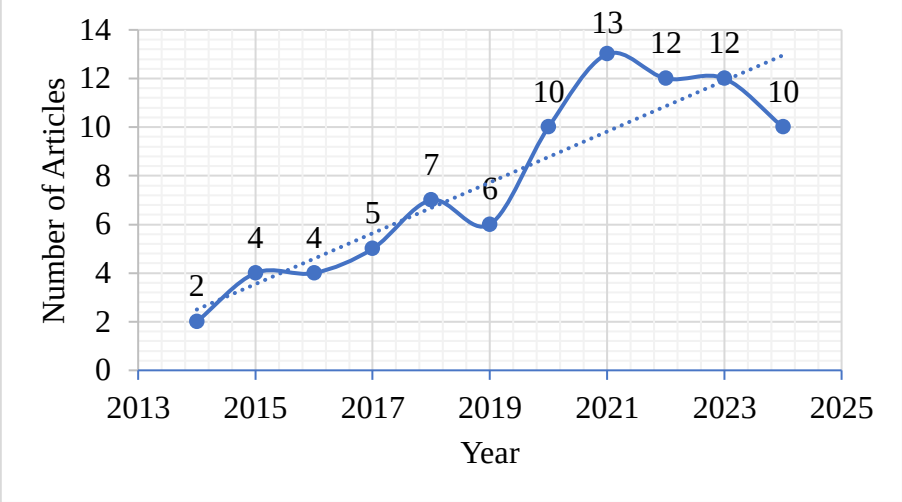

Figure 1. Global Trend of Renewable Energy Learning

Figure 1 reveals a significant increase in global research trends focusing on renewable energy. This phenomenon can be reflected in the growing number of articles, publications, and literature resources focused on teaching strategies, renewable energy development, and other efforts to reinforce renewable energy in students. A consistent increase in academic interest in renewable energy learning from 2014 to 2024 indicates a growing awareness of the importance of renewable energy education in preparing future generations. It indicates that the scientific community and educators are increasingly focused on meeting global energy challenges and driving the transition to renewable energy through focused and sustainable education.

Global trends in renewable energy learning provide important insights into how awareness of the importance of renewable energy has increased from 2014 to 2024. The emphasis on renewable energy in an educational context shows that many academics, educators, and practitioners are increasingly paying attention to and investing in developing renewable energy as a response to the world's complex challenges. The increased number of articles, publications, and literature resources focused on renewable energy learning reflects the growing interest in preparing future generations with a strong understanding of renewable energy and its impact on sustainable development.

3.3. The Factors for Success in Renewable Energy Education

Various studies have identified key factors contributing to success in renewable energy learning. The use of STEM-PBL (Science, Technology, Engineering, Mathematics - Problem-Based Learning) and STEAM-PjBL (Science, Technology, Engineering, Arts, Mathematics - Project-Based Learning) based approaches have been proven effective in teaching renewable energy concepts (Abdurrahman et al. 2023; Adriyawati et al. 2020). Integrating teaching aids and hands-on experience with renewable energy-related technologies also plays an important role in enriching learning (Chou et al. 2015). Research also highlights the importance of student-centered education and actively engaging students in the renewable energy learning process (Handayani et al. 2023; Keat and Sie 2022). In addition, the importance of education in increasing awareness and understanding of renewable energy is emphasized by several studies (Akinwale 2022; Ntanos et al. 2018; Pambudi et al. 2024), with findings that higher education levels correlate with increased awareness and understanding of renewable energy (Özbay and Duyar 2022; Pambudi et al. 2024). Integrating renewable energy into the formal curriculum at all levels of education was also identified as an important step in addressing the skills and workforce gap (Lucas et al. 2018). Implementing practical projects and using renewable energy research tools in the curriculum are also highlighted as effective strategies (Rego et al. 2021; Rezende et al. 2021). Furthermore, using technologies such as virtual reality and computer programs has been shown to enhance students' learning experience in the context of renewable energy (Alqallaf and Ghannam 2024; Zuvur et al. 2020). Increasing people's critical energy literacy, especially in more equitable energy planning focusing on renewable energy sources, is also important to consider in renewable energy learning (Lowan-Trudeau and Fowler 2022). Finally, integrating Nature of Science (NOS) aspects in renewable energy learning can strengthen science teachers' understanding and improve teaching quality (Utami et al. 2022). Thus, these factors collectively highlight the diversity of approaches and strategies that can be applied in renewable energy learning and the importance of education in shaping a comprehensive understanding of renewable energy concepts.

3.4. Effective Learning Design in Teaching Renewable Energy Topics

Research results on effective learning designs in teaching renewable energy topics show that the use of advanced technologies such as Virtual Reality (VR) and virtual laboratories has great potential to increase student engagement and understanding of renewable energy materials (Abichandani et al. 2019; Alqallaf and Ghannam 2024). Integrating practical projects and specialized training programs such as Solar Master has also proven effective in providing renewable energy professionals with the necessary knowledge and skills (Ciriminna et al. 2016; Gerhátová et al. 2020). Collaboration between industry and academia, as well as between students on renewable energy projects, as well as university-industry interaction with the use of co-working spaces, provide valuable learning experiences that can enhance student motivation and skills (Ariza and Olatunde-Aiyedun 2023; Enrique et al. 2022; Jafarinejad et al. 2021; Rivas 2017). Active learning approaches through Project-based Learning (PjBL) and outdoor learning have also proven their effectiveness in improving students' understanding of renewable energy concepts (Buldur et al. 2020; Cole et al. 2023). Using technologies such as simulations and computer programs for alternative energy process demonstrations can also enrich the learning experience by providing a better visual experience (Zuvur et al. 2020). The integration of environmental education in school curricula increases students' awareness and understanding of renewable energy, while discussion and education on renewable energy and critical energy literacy are necessary for effective dissemination in society (Lowan-Trudeau and Fowler 2022; Ntanos et al. 2018; Ntona et al. 2015). Finally, the development of new curriculum models that focus on student skills and awareness of renewable energy can improve the overall effectiveness of learning (Walz and Shoemaker 2017; Wang and Guo 2021). By integrating various approaches and technologies,

renewable energy learning can become more interactive, relevant, and impactful in preparing future generations to face global energy challenges.

3.5. Limitation and Future Studies

Although this research successfully identified success factors in renewable energy learning and effective learning systems, several limitations must be noted. First, this research is limited to articles published from 2014 to 2024, so some recent developments may not be included in this analysis. In addition, there is a possibility of bias in the selected articles analyzed, although efforts were made to select the most relevant and high-quality articles. Furthermore, regional and contextual aspects may affect the implementation of renewable energy learning systems, but this study must thoroughly consider these. For future research, conducting a more in-depth study of contextual and regional factors that influence renewable energy learning is recommended. In addition, future studies could delve deeper into the influence of new technologies, such as artificial intelligence and data analytics, in improving the effectiveness of renewable energy learning. Furthermore, longitudinal studies can also be conducted to monitor changes in trends and impacts of renewable energy education policy implementation over a longer period.

4. CONCLUSIONS

A systematic literature review has revealed that success factors in renewable energy learning and effective learning systems significantly impact the development of renewable energy education globally. Through the analysis of various studies conducted, we found that the use of advanced technologies such as Virtual Reality (VR), project-practical integration, collaboration between industry and academia, and active learning approaches such as Problem-based Learning (PBL), Project-based Learning (PjBL), and Science, Technology, Engineering, Arts, Mathematics (STEAM) are key in improving students' understanding of renewable energy. In addition, the results also highlighted a trend of increasing interest in renewable energy topics around the world. The main conclusion of this study is that implementing success factors and effective learning systems is crucial in providing relevant and quality education in renewable energy. It also points to the need to continue encouraging the holistic development of renewable energy education and increasing its accessibility worldwide to support the transition to an energy-sustainable future.

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