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Research Article

Sustainable Engineering Innovations for Renewable Energy Systems: A Systematic Literature Review of Technologies, Performance, and Environmental Impacts

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Abstract:

Background of study: The transition to sustainable energy is essential to mitigate climate change. While renewable sources like solar and wind are key to decarbonization, their adoption is hindered by performance intermittency. Current research is often fragmented by technology type, lacking an integrated framework that simultaneously addresses engineering innovations, technical performance, and environmental sustainability.

Aims paper: This study aims to synthesize sustainable engineering innovations by integrating technological development with operational performance and environmental impact assessments. The scope is limited to 20 peer-reviewed articles from the Scopus database published between 2019 and 2025.

Methods: The research follows a Systematic Literature Review (SLR) design and PRISMA 2020 guidelines. Data were analyzed using Biblioshiny for descriptive statistics and VOSviewer for thematic and network visualization

Result: Findings show an annual scientific growth rate of 44.22%. Key innovations focus on hybrid energy systems, smart grids, and energy storage. Recent trends indicate a shift toward digitalization, IoT-based management, and environmentally optimized materials.

Conclusion: Sustainable engineering innovations significantly enhance system efficiency and reliability. Although they reduce greenhouse gas emissions, environmental performance varies by technology. The study concludes that interdisciplinary, system-level approaches are vital for achieving global sustainability goals.

Keywords: Environmental impact; Renewable energy systems; Sustainable engineering; Systematic literature review; Technical performance

1. INTRODUCTION

The transition toward sustainable energy has become a critical global priority driven by the urgent need to mitigate climate change, reduce environmental degradation, and decrease dependence on fossil fuels. Renewable energy sources, including solar, wind, biomass, hydro, and geothermal systems, are widely recognized as key contributors to decarbonization and long-term energy security (Woldegiyorgis et al., 2024; Wang et al., 2023).

International initiatives and policy frameworks, such as those promoted by the Intergovernmental Panel on Climate Change (IPCC), further emphasize the necessity of accelerating renewable energy adoption to achieve global emission reduction targets (Warsame et al., 2024). Engineering innovations play a crucial role in enhancing the efficiency, reliability, and sustainability of renewable energy systems. Advances in hybrid energy systems, smart grids, power electronics, and energy storage technologies have significantly improved system performance and operational stability under variable generation conditions (Mansouri et al., 2023; Alam & Arefifar, 2022).

The integration of multiple renewable sources, supported by advanced control strategies and storage solutions, has been shown to mitigate intermittency challenges and improve overall energy management (Amusat et al., 2018; Raza et al., 2019). These innovations contribute to the development of more resilient and flexible energy systems capable of supporting sustainable economic growth. Despite the growing body of research on renewable energy technologies, existing studies are often fragmented by technology type, geographic region, or evaluation perspective. Many investigations focus exclusively on specific systems such as solar, wind, or biomass, while others examine technical performance or environmental impacts in isolation (Adepoju et al., 2022; Al-Hinai, 2024).

This fragmentation limits comprehensive understanding of how engineering innovations simultaneously influence system performance and environmental sustainability, particularly in hybrid and integrated renewable energy systems. Although systematic literature reviews (SLRs) have been conducted in the renewable energy domain, most tend to emphasize either technological development, performance optimization, or environmental assessment independently. Integrated analyses that jointly examine engineering innovations, technical performance, and environmental impacts within a unified framework remain limited.

Consequently, the interrelationships and trade-offs between efficiency improvements, system reliability, and life-cycle environmental impacts are not yet fully understood, creating a clear research gap in sustainable energy engineering studies.Therefore, this systematic literature review aims to provide a comprehensive synthesis of sustainable engineering innovations in renewable energy systems by integrating technological development, technical and operational performance, and environmental impact assessment. By addressing this gap, the study seeks to support more informed decision-making for researchers, engineers, and policymakers in advancing efficient, reliable, and environmentally responsible renewable energy systems.

2. MATERIAL AND METHOD

This study employed a Systematic Literature Review (SLR) as the research design to systematically analyze sustainable engineering innovations in renewable energy systems. The object of the research consisted of peer-reviewed journal articles related to renewable energy engineering innovations. A purposive sampling method was applied, selecting articles indexed in the Scopus database, published in English between 2019 and 2025, and relevant to engineering innovations, system performance, and environmental impacts. The research period corresponded to the publication timeframe of the selected articles (2019–2025), with data collection conducted during the manuscript preparation stage using the Scopus database as the primary data source. The research procedure followed a structured SLR workflow, beginning with keyword identification and database searching, followed by screening, eligibility assessment, data cleaning, and analysis stages, as illustrated in Figure 1, which presents the workflow of the Systematic Literature Review process.

The study selection process was conducted in accordance with the PRISMA 2020 (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines, as shown in Figure 2, which summarizes the identification, screening, eligibility, and inclusion of relevant studies. Data collection techniques involved systematic retrieval of bibliographic records from Scopus, which were exported in CSV format. Research instruments included bibliometric analysis and visualization tools, namely OpenRefine for data cleaning, Biblioshiny for descriptive bibliometric analysis, and VOSviewer for network and thematic visualization. The analysis plan comprised descriptive statistical analysis to examine publication trends and citation characteristics, as well as network and thematic analyses to identify dominant research themes and relationships among engineering innovations, technical performance, and environmental impacts. The scope of this research was limited to peer-reviewed journal articles indexed in Scopus and published within the defined timeframe. Consequently, studies from other databases or non-English publications were not included, which may limit the generalizability of the findings.

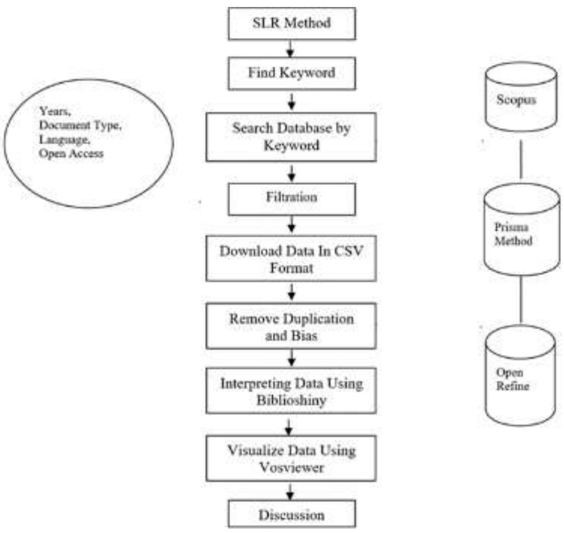

Figure 1. Workflow of the Systematic Literature Review (SLR) process

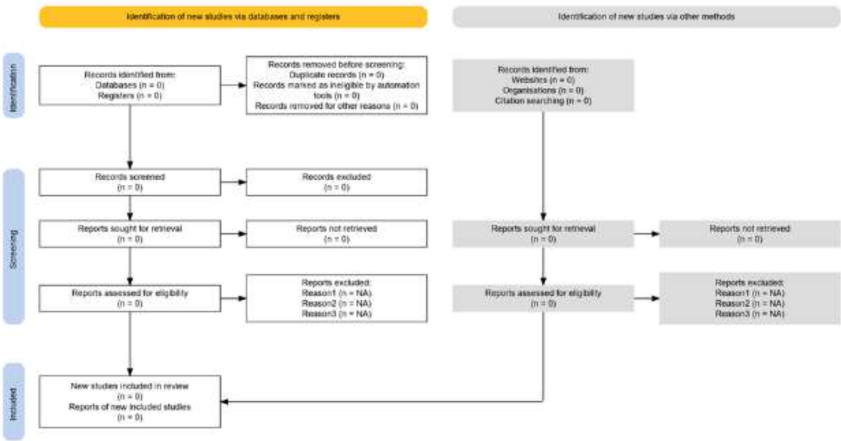

Figure 2. PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) Method

3. RESULT AND DISCUSSION

Result:

The results of this systematic literature review reveal a substantial growth in research on sustainable engineering innovations for renewable energy systems over the past decade. The descriptive bibliometric analysis indicates an increasing trend in annual scientific production, reflecting the rising global interest in renewable energy technologies and sustainability-driven engineering solutions. Keyword co-occurrence analysis highlights dominant research themes such as hybrid renewable energy systems, energy storage technologies, smart grids, life cycle assessment, and system optimization. Overlay visualization further demonstrates a temporal shift from conventional renewable system design toward advanced topics, including digitalization, IoT-based energy management, and environmentally optimized materials. These findings collectively indicate that renewable energy research has evolved from technology adoption toward integrated, performance-oriented, and sustainability-focused engineering innovation.

Discussion:

The observed growth in publication trends suggests that sustainable engineering innovations have become a central focus in addressing global energy transition challenges. The prominence of hybrid renewable energy systems indicates a strategic response to the intermittency issues associated with single-source renewable technologies. By integrating multiple energy sources with storage systems, researchers aim to enhance system reliability and operational efficiency. Furthermore, the strong presence of life cycle assessment-related keywords reflects increasing awareness of environmental performance beyond energy efficiency alone. This aligns with recent studies emphasizing that engineering innovation should balance technical performance improvements with environmental impact mitigation. The emergence of digital technologies, such as smart grids and IoT-based monitoring, demonstrates a shift toward intelligent energy systems capable of adaptive control and real-time optimization, reinforcing the role of engineering innovation in achieving sustainable and resilient energy infrastructures.

Completeness of metadata -- **20** docs from **Scopus**

Metadata	Description	Missing Counts	Missing %	Status
AB	Abstract	0	0.00	Excellent
C1	Affiliation	0	0.00	Excellent
AU	Author	0	0.00	Excellent
CR	Cited References	0	0.00	Excellent
DI	DOI	0	0.00	Excellent
DT	Document Type	0	0.00	Excellent
SO	Journal	0	0.00	Excellent
LA	Language	0	0.00	Excellent
PY	Publication Year	0	0.00	Excellent
TI	Title	0	0.00	Excellent
TC	Total Citation	0	0.00	Excellent
DE	Keywords	1	5.00	Good
RP	Corresponding Author	2	10.00	Good
ID	Keywords Plus	4	20.00	Acceptable
WC	Science Categories	20	100.00	Completely missing

Figure 3. Completeness of bibliographic metadata for the Scopus dataset (20 documents).

Table 1. Main Information

DESCRIPTION	RESULTS
MAIN INFORMATION ABOUT DATA	
Timespan	2019:2025
Sources (Journals, Books, etc)	18
Documents	20
Annual Growth Rate %	44.22
Document Average Age	2.5
Average citations per doc	5.6
References	194
DOCUMENT CONTENTS	
Keywords Plus (ID)	242
Author's Keywords (DE)	101
AUTHORS	
Authors	90
Authors of single-authored docs	1
AUTHORS COLLABORATION	
Single-authored docs	1
Co-Authors per Doc	4.8
International co-authorships %	20
DOCUMENT TYPES	
article	20

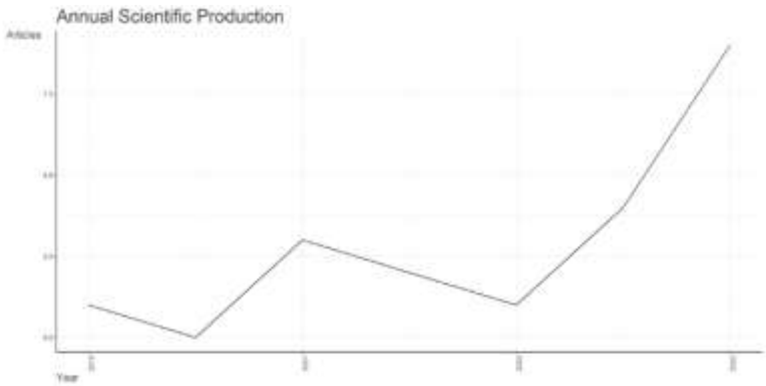

Figure 4. Annual scientific production of publications on sustainable engineering innovations (2019–2025).

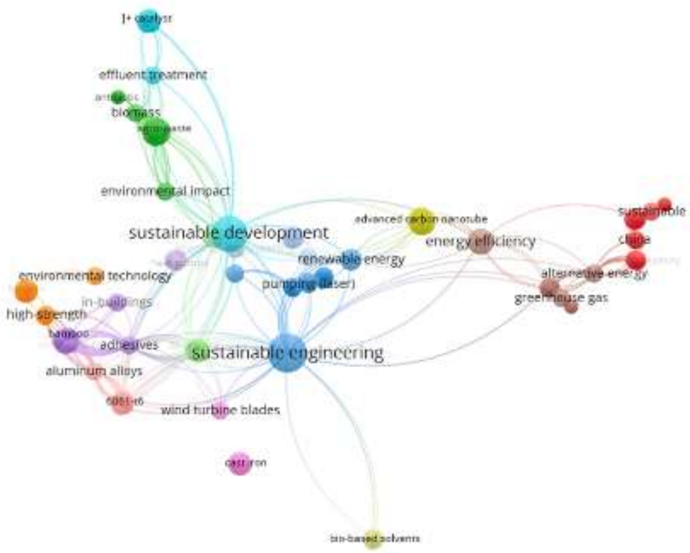

Figure 5. Keyword co-occurrence network illustrating the thematic structure of sustainable engineering innovations for renewable energy systems

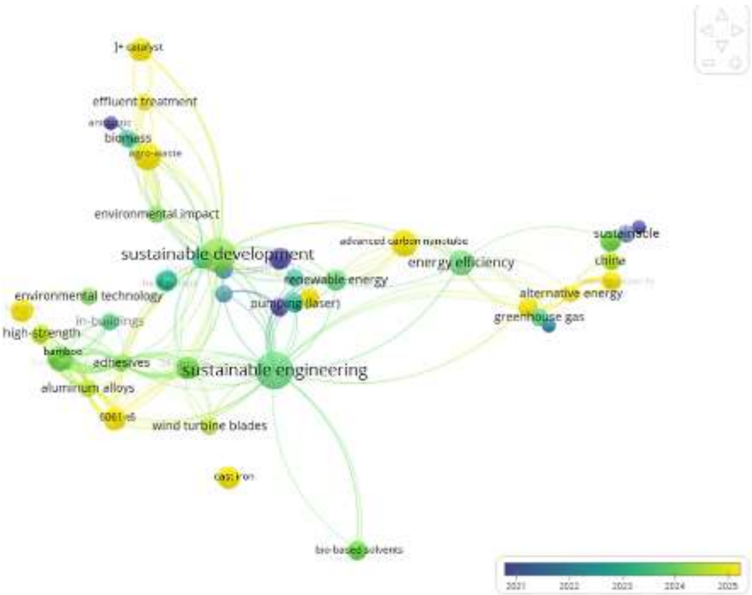

Figure 6. Overlay Visualization.

Implication:
The findings of this study have important implications for the development and deployment of renewable energy systems. From a technical perspective, the dominance of hybrid configurations and advanced control strategies suggests that future renewable systems should prioritize integration and flexibility. From an environmental perspective, the growing application of life cycle assessment implies that sustainability evaluation is becoming a critical design consideration rather than a post-implementation assessment. For policymakers, these results highlight the importance of supporting research and innovation frameworks that encourage integrated system development, environmental accountability, and technology transfer to accelerate sustainable energy transitions.

Research Contribution:
This study contributes to the existing body of knowledge by providing an integrated synthesis of sustainable engineering innovations in renewable energy systems through a systematic literature review approach. Unlike previous studies that focus on individual technologies or isolated performance indicators, this review simultaneously examines engineering innovation types, technical performance aspects, and environmental impacts. By mapping research trends and thematic evolution, the study offers a comprehensive overview of how renewable energy engineering has progressed toward more holistic and sustainability-driven solutions. This integrated perspective supports future research planning and informed decision-making in sustainable energy engineering.

Limitation:
Despite its contributions, this study has several limitations. First, the review is restricted to publications indexed in selected academic databases, which may exclude relevant studies published in non-indexed journals or regional outlets. Second, the bibliometric analysis relies on keyword-based mapping, which may not fully capture the depth of technical innovations described within individual studies. Third, the review focuses on peer-reviewed literature, potentially overlooking practical industrial developments and pilot-scale implementations that are not formally published.

Suggestion:
Future research is encouraged to expand the scope of systematic reviews by incorporating multiple databases and grey literature to capture a broader range of engineering innovations. Additionally, deeper qualitative analyses of selected case studies could complement bibliometric findings by providing insights into real-world system performance and implementation challenges. Further studies should also explore the integration of socio-economic and policy dimensions with technical and environmental assessments to support more comprehensive and inclusive sustainable energy system development.

4. CONCLUSION

This systematic literature review provides a comprehensive synthesis of sustainable engineering innovations in renewable energy systems by integrating technological, performance, and environmental perspectives. The findings address the formulated research questions and highlight several key conclusions. First, various sustainable engineering innovations have been identified across renewable energy technologies, with hybrid energy systems, advanced energy storage solutions, smart grid technologies, and digital monitoring systems emerging as the most prominent developments. These innovations reflect a shift toward integrated and intelligent system design in renewable energy engineering.

Second, the reviewed studies demonstrate that engineering innovations significantly enhance technical and operational performance, particularly in terms of efficiency, reliability, and system optimization. Hybrid configurations and advanced control strategies effectively mitigate the intermittency of renewable energy sources and improve overall system stability. Third, environmental impact assessments, especially those employing life cycle assessment approaches, indicate that sustainable engineering innovations contribute to reducing greenhouse gas emissions and improving resource efficiency. However, environmental performance varies depending on technology type, system configuration, and material selection, emphasizing the need for environmentally informed engineering design. Finally, the analysis reveals evolving research trends toward environmentally optimized, digitally enabled, and performance-oriented renewable energy systems, while also identifying research gaps related to integrated environmental–technical evaluation and real-world implementation challenges. Overall, this study underscores the importance of holistic engineering approaches that balance technological advancement, system performance, and environmental sustainability to support the global transition toward sustainable energy systems.

5. ACKNOWLEDGEMENT

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6. AUTHOR CONTRIBUTION STATEMENT

DS contributed to the research concept formulation, systematic literature review methodology design, literature search and selection, bibliometric analysis and data synthesis, and contributed to the validation of the methodology, interpretation of the results, and critical review of the scientific substance of the manuscript. All authors participated in the writing, revision, and final approval of the manuscript.

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