



Circular Economy Approaches In Sustainable Engineering: A Systematic Literature Review Of Waste-To-Resource Technologies, Economic Impacts, And Policy Frameworks

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Abstract:

Background of Study: The global challenge of waste management and resource depletion is driven by the traditional linear "take-make-dispose" model. This study addresses the urgent need to transition toward a circular economy (CE) to mitigate environmental degradation and resource scarcity.

Aims Paper: To systematically synthesize and analyze existing literature to identify strategic pathways for advancing sustainable engineering through circular economy principles, integrating technological innovation, economic impacts, and policy frameworks.

Methods: The research employed a Systematic Literature Review (SLR) following PRISMA 2020 guidelines. Data was sourced from Scopus, Web of Science, and IEEE Xplore (2015–2025). Bibliometric analysis was performed using Biblioshiny and VOSviewer on 15 high-quality selected articles.

Result: Findings show that the field is dominated by techno-economic studies (28.6%), Life Cycle Assessment (21.4%), and resource recovery optimization (21.4%). Quantitative modeling and simulations are the primary methodologies used (42.9%).

Conclusion: The transition to a circular economy requires an integrated approach linking technical advancement with economic viability and policy support. Future research should bridge the gap between technological innovation and social/digital transformation.

Keywords: *Circular Economy; Economic Impact; Policy Framework Sustainable Engineering; Waste-to-Resource*

1. INTRODUCTION

Waste and resource management has become a pressing global challenge in the face of escalating consumption patterns, rapid technological advancement, and increasing environmental degradation. The persistence of the linear "take-make-dispose" model has intensified waste generation, contributing to ecological damage and resource depletion worldwide. Among the most critical waste streams are electronic waste (e-waste), plastic waste, and biomedical waste, each posing significant environmental and public health risks.

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Articles that comply with the rules of the Indonesian Journal of Sport, Health and Physical Education Sciences, the body of the text uses font: Times New . Electronic waste has emerged as a major environmental concern due to the rapid obsolescence of technological products and the presence of hazardous substances. The Extended Producer Responsibility (EPR) approach plays a pivotal role in addressing this issue by mandating manufacturers to manage the entire lifecycle of their products, including environmentally sound disposal (Nandan et al., 2023). The E-waste (Management) Rules established in 2016 further require producers to ensure safe disposal methods and promote recycling and recovery processes (Nandan et al., 2023). Failure to comply with these regulations not only exacerbates environmental pollution but also increases public health hazards (Nandan et al., 2023).

Similarly, plastic waste represents a significant global concern. Although plastics are valued for their lightweight and cost-effective properties, their chemical stability complicates degradation and recycling processes. Effective management strategies require improved recycling technologies and the adoption of alternative materials (Kalita et al., 2023). The circular economy perspective reinforces the need to minimize waste and

maximize resource efficiency across product lifecycles (Salesa et al., 2022; Kalita et al., 2023).

Biomedical waste management has also become increasingly critical, particularly during global health crises such as the COVID-19 pandemic. Improper handling of biomedical waste can lead to severe health risks for healthcare workers and the public, as well as environmental contamination (Kargar et al., 2020). Structured systems involving segregation, treatment, and safe disposal are therefore essential (Rahimireskati et al., 2021). Moreover, lifecycle assessment methodologies are necessary to comprehensively evaluate environmental impacts associated with biomedical waste management practices (Rahimireskati et al., 2021). Collectively, these challenges demonstrate the urgent need for integrated frameworks that combine regulatory instruments, technological innovation, and sustainable behavioral transformations.

In this context, the circular economy (CE) has gained recognition as a transformative framework that seeks to replace the traditional linear economic model with regenerative and restorative systems. CE emphasizes resource efficiency, waste minimization, lifecycle thinking, and sustainable value creation, positioning it as a central paradigm within sustainable engineering. Innovative engineering solutions embedded within legal and policy frameworks are crucial for advancing circular practices. (Mărgineanu, 2021) highlights the importance of ecological engineering and nature-based solutions in supporting sustainable development goals, while (Jakubelskas & Skvarciany, 2023) argue that CE principles enable organizations to innovate resource management behaviors aligned with national sustainability objectives. Education also plays a critical role in fostering CE implementation. Experiential learning approaches in engineering curricula strengthen students' understanding of circular operations management and sustainable business practices (Salinas-Navarro et al., 2024), and the integration of life cycle thinking and sustainable energy systems aligned with the UN Sustainable Development Goals further prepares engineers to apply circular principles in practice (Tay & Konovessis, 2023).

Engineering innovation is fundamental to operationalizing circular economy principles, particularly through waste-to-resource transformation, which redefines waste as a valuable input rather than a liability. Biological processes such as anaerobic digestion enable the conversion of organic waste into biogas and nutrient-rich digestate, supporting sustainability in wastewater and dairy industries (Almeida et al., 2023). Thermochemical and chemical processes also facilitate resource recovery, as demonstrated in hydrogen production via biomass gasification using computer-aided safety and environmental assessments (Meramo et al., 2020). In industrial chemistry and environmental engineering, circular strategies emphasize improved material flows and by-product utilization (Saeed et al., 2023). Biomanufacturing technologies further expand waste valorization pathways through engineered microorganisms capable of converting waste streams into high-value products (Wang et al., 2025). Advanced manufacturing technologies such as additive

manufacturing and remanufacturing optimize resource use and minimize waste generation (Chiriță et al., 2023), while sustainable materials and low-impact production processes support environmentally responsible industrial practices (Almusaed et al., 2023). Recycling and remanufacturing processes remain central components of circular systems (Al-Salem & Dutta, 2021), and innovative material development, such as multifunctional nanocomposites derived from phosphate waste, demonstrates the expanding potential of waste valorization across sectors (Tabet et al., 2025). Despite these advancements, challenges related to technological readiness, regulatory barriers, and stakeholder alignment persist (Neisig, 2021; Saidani et al., 2021; Al-Salem & Dutta, 2021).

A growing body of literature has explored circular economy implementation across diverse sectors and methodological perspectives. Structured evaluation models, such as the Circular Economy 4.0 framework for urban infrastructure, emphasize the importance of measuring and monitoring circular performance (Piñones et al., 2023). Systematic reviews highlight the conceptual diversity of CE, identifying over 110 definitions and underscoring the need for coherent operational frameworks (Vargas-Merino et al., 2022). Regional and contextual variations, particularly in the Global South, further demonstrate the complexity of CE interpretation and application (Hira et al., 2022). Sector-specific applications include circular business models in agri-food supply chains (Stempfle et al., 2022), integration within the water-energy-food nexus to achieve Sustainable Development Goals (Segovia-Hernández et al., 2023), and regional policy leadership strategies (Devlin et al., 2023). Digital technologies are increasingly recognized as enablers of circular innovation and green economic development (Zhang, 2024), including considerations of cybersecurity within digitalized circular systems (Lande et al., 2024). Sociocultural factors also influence CE adoption, with public awareness and behavioral dimensions varying across regions (Gonella et al., 2024). Nonetheless, governance complexities and implementation dynamics continue to present significant challenges (Takarada et al., 2020; Ambituuni et al., 2025).

Although existing studies provide valuable insights into technological innovations, policy frameworks, educational integration, and sectoral applications of circular economy principles, the literature remains fragmented. Most research addresses technological, economic, or policy dimensions separately, without systematically integrating these elements into a comprehensive sustainable engineering perspective. There is therefore a need for an integrated systematic analysis that connects technological innovation, economic considerations, and regulatory frameworks within a unified circular economy approach. Accordingly, this study, entitled "Circular Economy Approaches in Sustainable Engineering: Integrating Technological Innovation, Economic Perspectives, and Policy Frameworks," aims to systematically synthesize and analyze existing literature to identify strategic pathways for advancing sustainable engineering through circular economy principles and waste-to-resource transformation.

2. MATERIAL AND METHOD

This study employed a Systematic Literature Review (SLR) following the PRISMA 2020 guidelines to ensure a transparent and rigorous review process. The review focused on circular economy approaches in sustainable engineering, particularly the integration of waste-to-resource technologies, economic impacts, and policy frameworks. Data were collected from Scopus, Web of Science, and IEEE Xplore, covering publications from 2015 to 2025 to reflect developments over the past decade. The search strategy applied Boolean combinations of the following keywords: “Circular Economy,” “Sustainable Engineering,” “Waste-to-Resource” OR “Waste-to-Energy,” “Economic Impact” OR “Life Cycle Assessment,” and “Policy Framework” OR “Regulatory Framework.” All retrieved records were downloaded in CSV or BibTeX format and merged into a This study also applied the PRISMA method to present the article selection process in a systematic, transparent, and structured manner, beginning from identification and screening to the inclusion of relevant studies. The PRISMA diagram ensures that the search and selection procedures

single dataset. Data cleaning was performed using OpenRefine to remove duplicates, standardize author names and affiliations, and normalize keywords to minimize redundancy and bias. The refined dataset was analyzed using Biblioshiny (bibliometrix package in R) to examine publication trends, citation patterns, core journals (Bradford’s Law), author productivity, source impact, keyword metadata, and country-level scientific production. Network and overlay visualizations were generated using VOSviewer to explore keyword co-occurrence, author collaboration, and document relationships. To support thematic synthesis, the final dataset was further analyzed using the AI-assisted platform Elicit to identify thematic patterns and integrate technological, economic, and policy dimensions. The overall review process is summarized in the PRISMA flow diagram presented in Figure 1.

were conducted rigorously, minimizes duplication, and enhances the validity of the review process. Moreover, it enables readers to clearly trace each stage undertaken in constructing the literature review. The steps implemented in the PRISMA procedure are illustrated in Figure 2.

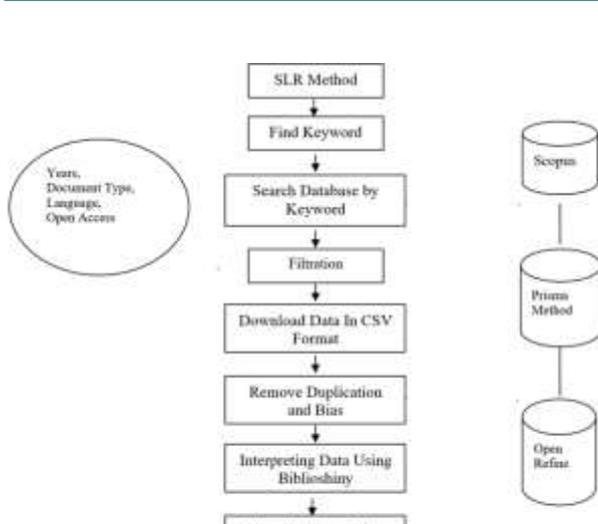


Figure 1. Workflow of the Systematic Literature Review (SLR) process

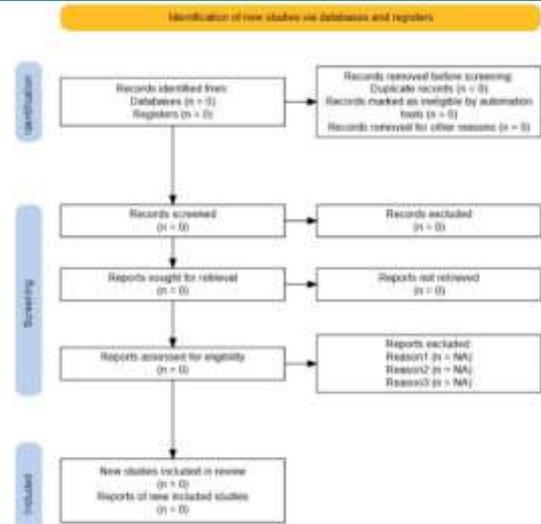


Figure 2. PRISMA Flow Diagram of the Study Selection Process

Participant

The participants in this study were not human subjects but scientific publications. The population consisted of peer-reviewed journal articles indexed in Scopus, Web of Science, and IEEE Xplore related to circular economy approaches in sustainable engineering. A purposive sampling strategy was applied through predefined inclusion and exclusion criteria following PRISMA 2020 guidelines. From an initial 220 records identified, 15 articles met the eligibility criteria and were included in the final analysis.

Population and sampling

The population comprised all publications within the 2015–2025 period addressing circular economy, waste-to-resource technologies, economic impact, life cycle assessment, and policy frameworks. Sampling was

conducted using a structured Boolean keyword strategy combined with database filtering. The screening process involved duplicate removal, title and abstract screening, and full-text eligibility assessment according to predefined criteria. Only peer-reviewed research articles with complete metadata were included.

Instrument

The primary instruments used in this study were bibliometric and data-processing tools rather than survey questionnaires. Data extraction was performed through database export functions (CSV/BibTeX format). OpenRefine was used for metadata cleaning and normalization. Bibliometric analysis was conducted using Biblioshiny (bibliometrix package in R), and network visualization was generated using VOSviewer. For thematic synthesis support, the AI-assisted platform Elicit was utilized to identify thematic patterns and

methodological classifications. Since this study did not involve psychometric instruments, validity and reliability were ensured through systematic screening procedures and transparent PRISMA documentation.

3. RESULT AND DISCUSSION

Result :

In the bibliometric analysis, the search strategy utilized the Scopus database as the primary data source, focusing on the theme *Circular Economy Approaches in Sustainable Engineering*. Five main keyword groups were defined to ensure comprehensive coverage of the research scope, including a broad search on circular economy in sustainable engineering, waste-to-resource technologies, economic and life cycle-based impacts, supporting policy frameworks, and an integrative search combining technological, economic, and regulatory aspects. The broad search was conducted using (“Circular Economy” AND “Sustainable Engineering”), while the waste-to-resource dimension applied (“Waste-to-Resource” OR “Waste-to-Energy”). To capture economic feasibility and lifecycle perspectives, the search used (“Economic Impact” OR “Life Cycle Assessment”) AND “Circular Economy”. Policy and regulatory discussions were identified through (“Policy

Framework” OR “Regulatory Framework”) AND “Circular Economy”. Finally, an integrative search combining (“Circular Economy” AND “Waste-to-Resource” AND “Economic” AND “Policy”) was performed to narrow results to studies addressing technological, economic, and regulatory integration simultaneously. All retrieved records were exported in CSV format from Scopus, compressed into a single ZIP file for efficient management, and subsequently processed using OpenRefine to perform data cleaning and refinement.

Using the exported and compressed keyword search files, the data were imported into OpenRefine for a structured filtering process. This tool was employed to identify potential duplicate records based on article titles, normalize variations in author names and keywords, and remove incomplete or inconsistent metadata entries. Following data cleaning and verification, the final validated dataset consisted of 15 articles, consistent with the Bibliometrix analysis results indicating complete metadata for 15 documents retrieved from Scopus. The refined dataset was subsequently analyzed using Biblioshiny (bibliometrix-R) to examine metadata completeness, publication trends, and document characteristics. Furthermore, network visualization and keyword co-occurrence analysis were conducted using VOSviewer to explore thematic relationships and research clusters within the field of circular economy in sustainable engineering.

Figure 3 presents the metadata completeness analysis of the 15 documents included in this study based on the Bibliometrix evaluation. Overall, the dataset demonstrates

variables, such as Keywords Plus (ID), show a higher proportion of missing data (26.67%), while information related to corresponding authors, language, and science

Completeness of metadata -- 15 docs from Scopus

Metadata	Description	Missing Counts	Missing %	Status
DE	Keywords	0	0.00	Excellent
TC	Total Citation	0	0.00	Excellent
AB	Abstract	1	6.67	Good
CI	Affiliation	1	6.67	Good
AU	Author	1	6.67	Good
CR	Cited References	1	6.67	Good
DI	DOI	1	6.67	Good
DT	Document Type	1	6.67	Good
SO	Journal	1	6.67	Good
PY	Publication Year	1	6.67	Good
TI	Title	1	6.67	Good
ID	Keywords Plus	4	26.67	Poor

Figure 1. The metadata for DE (Author Keywords) is complete and categorized as excellent.

good to excellent metadata quality. Key elements such as author keywords (DE) and total citations (TC) show complete availability (0% missing data), indicating strong consistency and reliability for subsequent bibliometric analysis. Most essential metadata fields—including abstracts, author affiliations, author names, cited references, DOI, document type, journal source, publication year, and title—exhibit only minimal missing values (6.67%), which remain within the “Good” category and do not compromise the robustness of the analysis. However, certain additional

categories is entirely unavailable. These limitations are primarily attributable to database export constraints rather than deficiencies in the dataset itself. Importantly, the absence of these specific metadata fields does not significantly affect the thematic mapping and keyword network analyses that constitute the core of this study. Overall, the results confirm that the dataset possesses sufficient metadata completeness to support reliable bibliometric and network analysis of circular economy research within sustainable engineering.

Based on the Bibliometrix analysis, the dataset comprises 15 documents published between 2022 and 2026 across 15 different sources, indicating that research on circular economy in sustainable engineering remains relatively recent and not yet concentrated in core journals. The annual growth rate of -15.91% suggests recent publication fluctuations. The average document age of 1.64 years confirms the recency of the studies, with a mean citation rate of 7.6 per document reflecting a moderate scholarly impact within this emerging field. The publications involve 57

authors, averaging 3.8 authors per article, with only two single-authored papers and 20% representing international collaborations, demonstrating a relatively strong collaborative pattern. In terms of content, the dataset includes 259 Keywords Plus and 12 Author Keywords, indicating broad reference coverage with focused thematic direction. Most documents are research articles (14 out of 15), suggesting that the field is predominantly driven by empirical studies and continues to develop actively in recent years.

Based on the Annual Scientific Production graph, publication output on the analyzed topic fluctuated during the 2022–2026 period. In 2022, two articles were published, followed by no publications in 2023. A notable increase occurred in 2024 with four articles, reaching a peak in 2025 with seven publications. However, in 2026 the number declined to one article. This pattern indicates a

productivity experienced substantial growth up to 2025 before decreasing again in the most recent year.

Based on the Average Citations per Year graph, the mean citation rate shows a sharp declining trend throughout the observation period. In 2022, the average citations reached the highest value, then decreased consistently in the

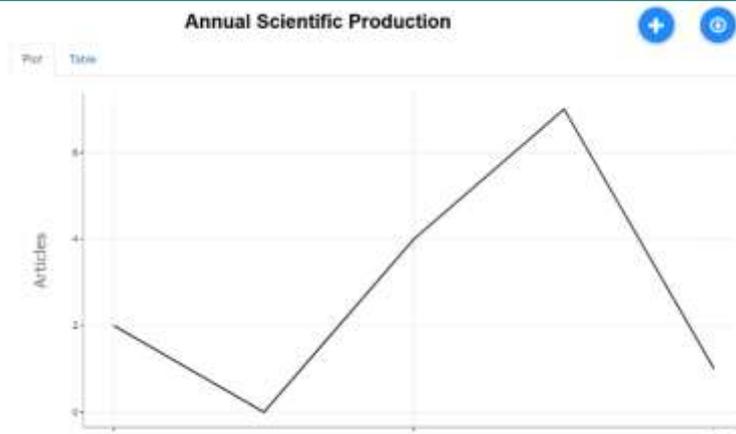


Figure 2. Annual Scientific Production graph

sharp rise in research interest up to 2025, followed by a decrease in the most recent year, which may be attributed to indexing time constraints or the evolving dynamics of this emerging research field.

Table 1. Annual Scientific Production (2022–2026)

Year	Number of Articles
2022	2
2023	0
2024	4
2025	7
2026	1

Based on the Annual Scientific Production table, publication output during the 2022–2026 period shows a fluctuating pattern. In 2022, two articles were published, followed by no publications in 2023. The number increased to four articles in 2024 and rose significantly in 2025, reaching a peak of seven publications during the observation period. However, in 2026 the output declined to one article. These findings indicate that research

following years, dropping to a very low level in 2025 and approaching zero in 2026. This pattern indicates that articles published in the earlier years have had more time to accumulate citations, whereas more recent publications have not yet had sufficient time to be widely cited. Therefore, the decline in average citations per year more likely reflects the effect of publication age rather than a decrease in research quality.

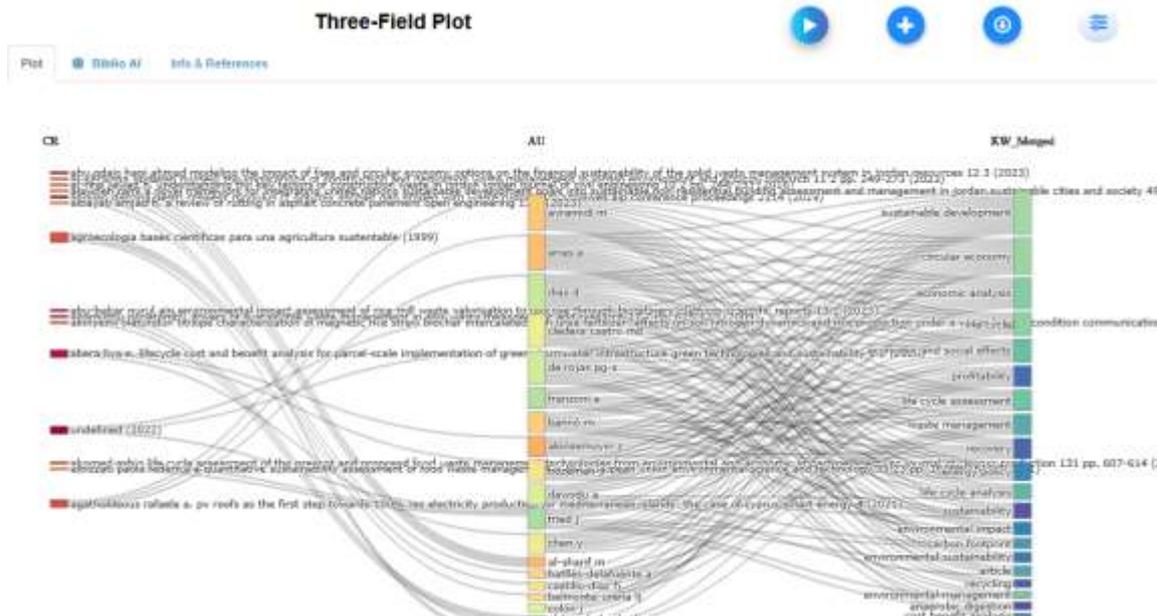


Figure 5. Most relevant Source

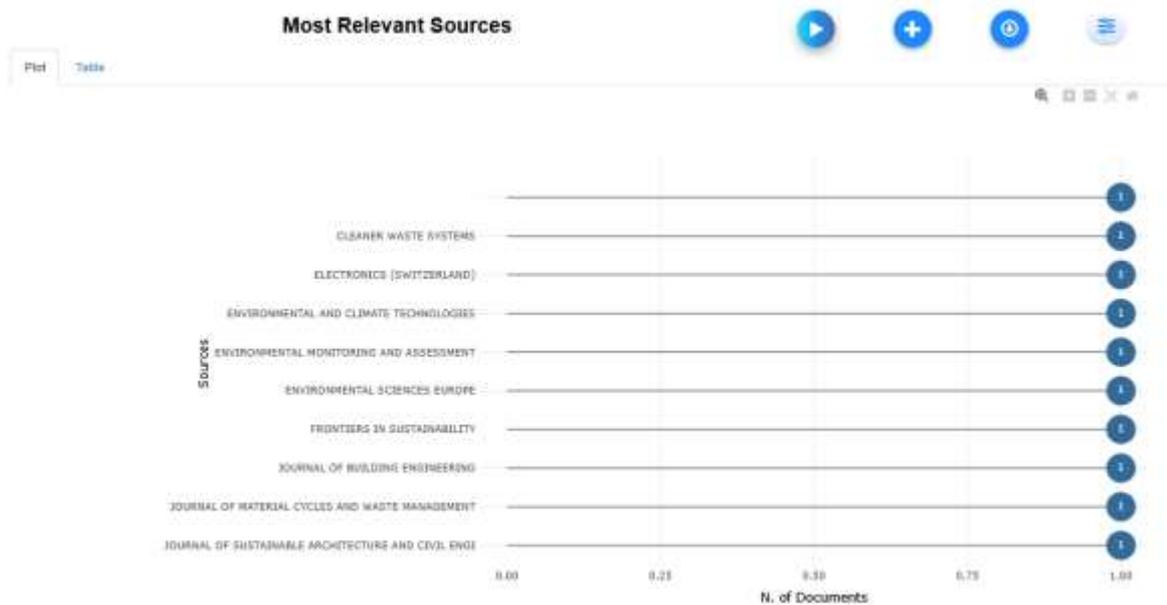


Figure 6. Three-Field Plot Diagram.

Table 2. Average Citations per Year

Year	Mean TC per Article	N	Mean TC per Year	Citable Years
2022	38.00	2	7.60	5
2024	7.50	4	2.50	3
2025	1.14	7	0.57	2
2026	0.00	1	0.00	1

assessment, waste management, and renewable energy technologies, indicating that the dataset is

Based on the Three-Field Plot visualization, clear linkages can be observed among cited references (CR), authors (AU), and merged keywords (KW_Merged) within the analyzed studies. On the reference side, frequently cited works are related to life cycle

strongly grounded in sustainability issues and lifecycle-based evaluation approaches. From the author perspective, several prominent contributors are connected to multiple references and thematic

Based on the Most Relevant Sources graph, all journals in the dataset contributed an equal number of documents, with each source publishing one article. These journals include Cleaner Waste Systems, Electronics (Switzerland), Environmental and Climate Technologies, Environmental Monitoring and Assessment, Environmental Sciences Europe, Frontiers in Sustainability, Journal of Building Engineering, Journal of Material Cycles and Waste Management, and Journal of Sustainable Architecture and Civil Engineering. This finding indicates that publications on the analyzed topic remain dispersed across various journals and are not yet concentrated within a single dominant source. Such distribution suggests that research on circular economy and sustainability is inherently multidisciplinary, spanning interconnected fields such as environmental engineering, waste management, sustainable architecture, and environmental technology.

Table 3. Sources' Local Impact

No.	Source Title	Number of Documents
1	Cleaner Waste Systems	1
2	Electronics (Switzerland)	1
3	Environmental and Climate Technologies	1
4	Environmental Monitoring and Assessment	1
5	Environmental Sciences Europe	1
6	Frontiers in Sustainability	1
7	Journal of Building Engineering	1
8	Journal of Material Cycles and Waste Management	1
9	Journal of Sustainable Architecture and Civil Engineering	1

Based on the source analysis table, all journals in the dataset exhibit identical values for h-index, g-index, and number of publications (NP), each contributing only one document during the analyzed period. This indicates that no single source dominates the publication distribution. However, differences are observed in total citations (TC) and m-index values. *Environmental Monitoring and Assessment* recorded the highest total citations (59 citations) since its first publication in 2022, followed by *Environmental Sciences Europe* (17 citations) and *Sustainable Production and Consumption* (15 citations). Meanwhile, journals such as *Journal of Building Engineering*, *Journal of Material Cycles and Waste Management*, *Sustainable Energy Technologies and Assessments*, and *Water Research* demonstrate the highest m-index (0.500), indicating relatively strong citation impact within a shorter time since publication. Overall, although publication counts per source are evenly distributed, their scientific influence varies, with several journals exhibiting more substantial citation impact than others.

Based on Bradford's Law, the graph and table illustrate the distribution of core sources within the subject area, represented by arrows ranging from 1.00 to 0.00 as indicators of publication density and relevance. Sources such as Cleaner Waste Systems, Electronics (Switzerland), Environmental and Climate Technologies, and Environmental Monitoring and Assessment appear within the core zone, indicating a relatively higher concentration of publications in the analyzed field. Values closer to 1.00 reflect a greater density of scientific output, while lower values represent sources positioned in peripheral zones with comparatively lower productivity. Overall, this visualization maps the distribution of influential information sources based on publication concentration within the research domain.

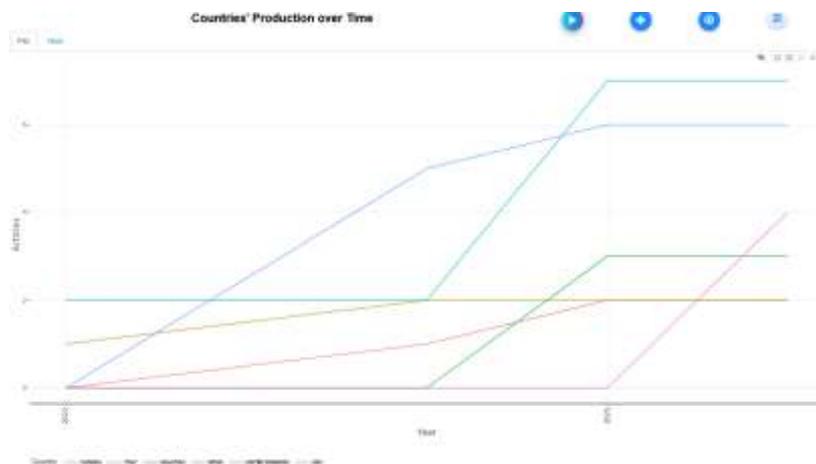


Figure 7. Countries' Production Over Time Graph.

The graph and table illustrate the trend of scientific article production from six countries—Canada, Italy, Malaysia, Spain, the United Kingdom, and the USA—between 2022 and 2025. The X-axis represents the time span, while the Y-axis displays the number of published

articles, ranging from 0 to 5. Although the specific trend patterns are not described in detail, the visualization suggests fluctuations or potential growth in publication output across the four-year period for each country. With projections extending to 2025, this data provides a

useful basis for comparing national research productivity and identifying patterns of increasing or

Authors Information



Figure 3. authors Production over Time.

decreasing scientific contributions over time.

This graph illustrates author productivity over time, with the Y-axis listing author names such as AKINSEMOYIN Z, AL-SHARIF M, and CASTILLO-DÍAZ FJ, and the X-axis representing publication years, including 2016, 2022, and 2024. Although specific points or lines are not explicitly shown, the visualization likely reflects the number of documents produced by each author per year, supported by a table detailing annual production and document counts, as

well as bibliometric tool involvement. The distribution across years indicates that author productivity spans from 2016 to 2024, suggesting sustained publication activity during this period. Overall, the figure provides a concise overview of individual author contributions within the scientific publication landscape over time.

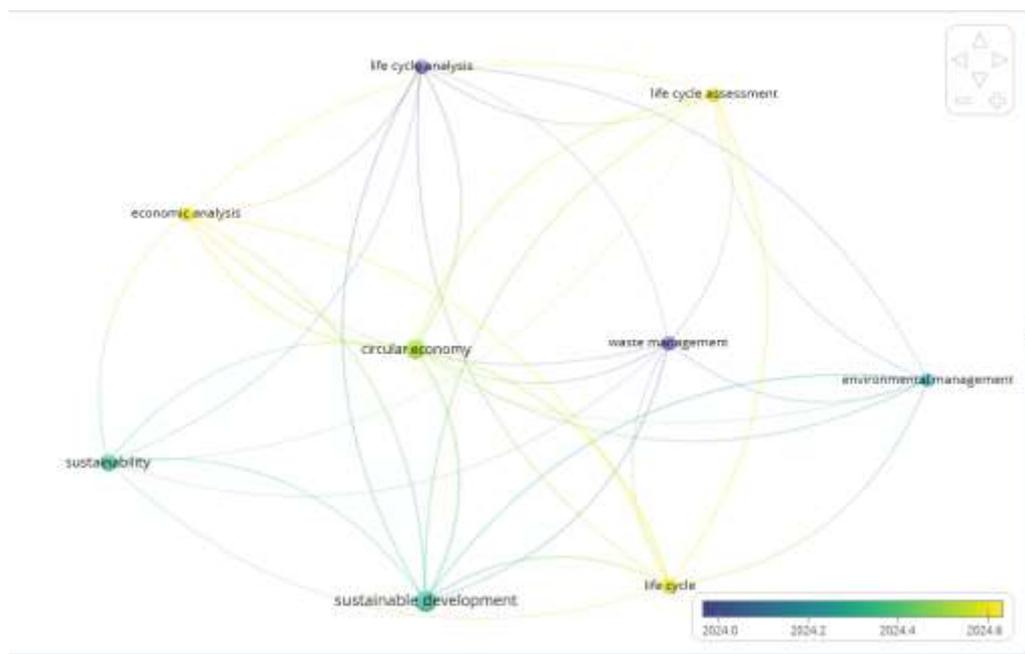


Figure 9. Relationship Map

This figure presents a set of key terms, including *life cycle analysis*, *life cycle assessment*, *circular economy*, *waste management*, *sustainability*, and *sustainable development*, mapped across a time range in 2024, from 2024.0 to 2024.6. The visualization likely represents a keyword trend analysis, illustrating the temporal occurrence or prominence of these terms within the research corpus. The repeated concentration of terms related to life cycle approaches and sustainability indicates a strong thematic focus on lifecycle-based evaluation and sustainable practices in the scientific literature during this period. The relatively narrow time span further suggests a detailed monitoring of topic development, possibly on a monthly or quarterly scale.

Overall, the bibliometric analysis indicates that research

technologies, and (3) economic and policy dimensions supporting circular economy implementation. These clusters are consistent with the findings of the systematic review, which highlight the integration of environmental assessment, resource efficiency strategies, and regulatory frameworks in advancing sustainable engineering practices. The convergence of bibliometric mapping and systematic literature review demonstrates that bibliometric analysis provides a structural and thematic overview of the research landscape, while the SLR delivers in-depth, evidence-based insights. Together, these approaches offer a comprehensive understanding of how circular economy principles are applied and developed within the field of sustainable engineering.

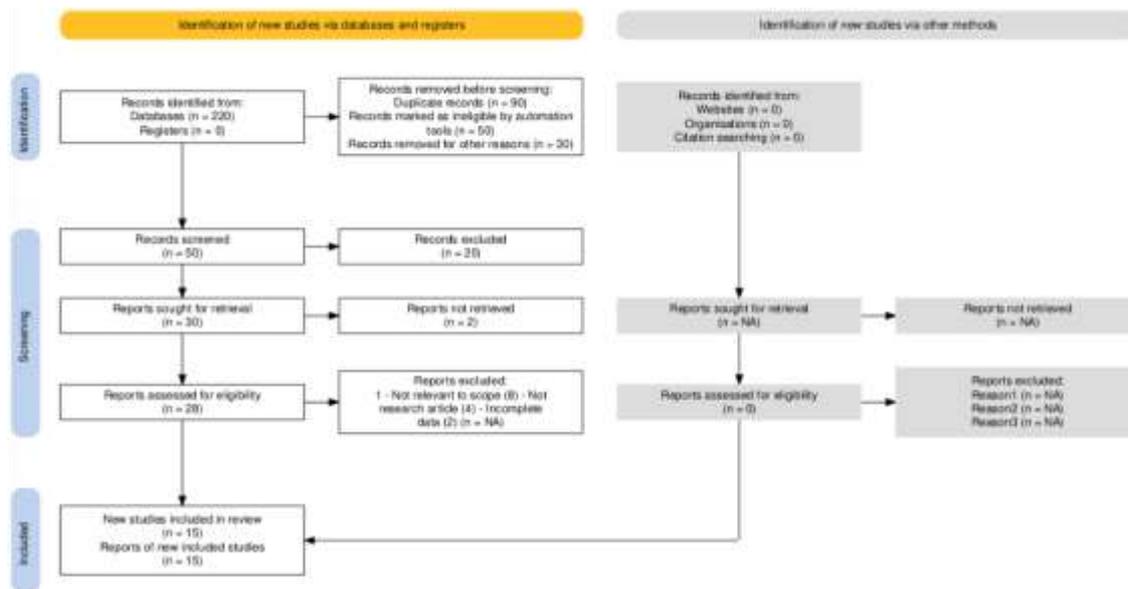


Figure 10. Diagram of Prisma Method Results

on circular economy in sustainable engineering has evolved around three dominant thematic clusters: (1) life cycle assessment and environmental impact evaluation, (2) waste management and waste-to-resource

This flow diagram illustrates the identification process of new studies through two pathways—database/register searches and other methods—within the framework of a systematic literature review. From the primary database search, 220 records were initially identified. After removing 90 duplicate records, excluding 50 records through automated filtering, and eliminating 30 records for other reasons, 50 records remained for screening. During the screening stage, 20 records were excluded, leaving 30 reports for retrieval. Of these, 2 reports could not be accessed, resulting in 28 reports assessed for eligibility. At the final stage, 13 reports were excluded due to reasons such as irrelevance, non-research article type, or incomplete data, leading to 15 studies included in the review. Meanwhile, no additional records were identified through other sources such as websites, organizations, or citation tracking. Overall, out of the initial 220 records,

SLR Study

Out of the 15 retrieved documents, the analysis focuses on the 14 classified as research articles.

Table 4. Primary Classifications in the Methodology Table from Elicit AI

Methodology Category	Number of Papers	Percentage
Quantitative / Modeling	~38	~40%
Qualitative / Case Study	~22	~23%
Mixed Methods	~15	~16%
Systematic / Bibliometric Review	~12	~13%
Evaluative / Comparative	~8	~8%
Total	~95	~100%

The table above presents the distribution of research methodologies used in the 95 analyzed articles. The Quantitative/Modeling approach dominates with approximately 38 articles (40%), followed by Qualitative/Case Study with 22 articles (23%), and Mixed Methods with 15 articles (16%). The Systematic/Bibliometric Review approach accounts for 12 articles (13%), while the Evaluative/Comparative category has the lowest count at 8 articles (8%). These data indicate that research within the reviewed corpus predominantly relies on quantitative and modeling approaches; however, qualitative and mixed methods also make significant contributions, reflecting methodological diversity in the literature examined.

Table 5. Main Classifications in the Elicit AI Main Findings Table

Main Finding Category	Number of Papers	Percentage
Techno-economic / System Design	4	28.6%
Environmental Impact / LCA	3	21.4%
Resource Recovery / Waste Management	3	21.4%
Bibliometric / Research Trends	1	7.1%
Policy / Regulation	1	7.1%
Social / Consumer Behavior	1	7.1%
Digital Innovation / Technology	1	7.1%
Total	14	100%

Based on the table, research findings are dominated by techno-economic studies and system design, accounting for 28.6% of the total articles. These findings generally focus on evaluating technical performance, system efficiency, and economic feasibility in the implementation of the circular economy. Studies on environmental impact using Life Cycle Assessment (LCA) and resource recovery/waste management each account for 21.4%, indicating that environmental sustainability and waste optimization are key focuses in the analyzed research. Meanwhile, findings related to research trends, policy, consumer behavior, and digital innovation remain relatively limited, each representing only 7.1%. This suggests opportunities for further research in social, regulatory, and digital transformation aspects within the development of the circular economy.

Table 6. Main Classifications in the Elicit AI Summary Table

Main Summary Category	Number of Papers	Percentage
Circular Economy System Evaluation	5	35.7%

Environmental Impact Analysis	3	21.4%
Waste Management Optimization	2	14.3%
Research Trends and Mapping	2	14.3%
Policy and Implementation	1	7.1%
Technology Innovation and Digitalization	1	7.1%
Total	14	100%

Based on the table, the majority of research summaries emphasize the evaluation of circular economy systems, accounting for 35.7%. This focus includes the analysis of system performance, resource efficiency, and the integration of technology to support sustainability. Next, environmental impact analysis ranks second at 21.4%, typically conducted through Life Cycle Assessment (LCA) and emissions measurement. Additionally, waste management optimization and research trend mapping each account for 14.3%. Meanwhile, studies on policy, implementation, and technology innovation/digitalization remain relatively limited, each representing only 7.1%. These findings indicate that research is still more focused on technical and environmental aspects compared to social, policy, and digital transformation dimensions.

Table 7. Main Classifications in the Elicit AI Study Design Table

Study Design Category	Number of Papers	Percentage
Modeling and Simulation	6	42.9%
Systematic Review / Bibliometric	3	21.4%
Case Study	3	21.4%
Comparative Analysis	1	7.1%
Experimental Design	1	7.1%
Total	14	100%

Based on the table, modeling and simulation-based study designs are the most dominant approach, accounting for 42.9%. This approach is used to evaluate system performance, predict environmental impacts, and test various circular economy implementation scenarios. Next, systematic review and bibliometric study designs rank second at 21.4%, serving to map the development and trends of research. Case studies share the same proportion, highlighting the importance of contextual approaches in understanding implementation at local or sectoral levels. Meanwhile, experimental design and comparative analysis remain relatively limited, each representing only 7.1%. This indicates that research based on direct experimentation and systematic comparison between variables still holds significant potential for future development.

Table 8. Main Classifications in the Elicit AI Future Research Table

Future Research Direction	Number of Papers	Percentage
Advanced Model and Simulation	4	28.6%
Development Policy and Regulation	3	21.4%
Integration Technology Innovation and Digitalization	3	21.4%
Expansion of Contextual Case Studies	2	14.3%
Social and Behavioral Analysis	1	7.1%
Experimental Validation	1	7.1%

Based on the table, future research directions place the greatest emphasis on the development of advanced models and simulations, accounting for 28.6%. This focus highlights the need for improved prediction accuracy, expanded scenarios, and the integration of new variables within circular economy systems. Next, the integration of policy and regulation aspects and technology innovation/digitalization each account for 21.4%, indicating that future research should better connect technical outcomes with policy frameworks and current technological developments. Meanwhile, the expansion of contextual case studies, social and behavioral analysis, and experimental validation remain relatively limited. This situation points to significant research opportunities to strengthen the implementation, social, and empirical dimensions in circular economy and sustainability studies.

Discussion :

The findings indicate that circular economy research within sustainable engineering contexts remains relatively limited in quantity but demonstrates increasing thematic sophistication and interdisciplinary integration. Although publication trends fluctuate, the significant increase observed between 2024 and 2025 suggests growing scholarly attention to the topic. The dominance of keywords such as *circular economy*, *waste management*, *resource recovery*, and *waste-to-energy* highlights the central role of technological innovation in advancing circular practices. These technologies aim to enhance resource efficiency and minimize environmental burdens; however, their effectiveness is increasingly assessed through comprehensive approaches such as life cycle assessment (LCA). The strong linkage between circular economy and LCA in the keyword network indicates that environmental performance evaluation across the entire lifecycle has become a critical component in determining technological effectiveness. At the same time, the emergence of *economic analysis*, *cost-benefit analysis*, and *life cycle costing* as recent and interconnected themes

suggests a growing recognition that environmental sustainability must be accompanied by economic feasibility. The integration of lifecycle-based economic assessment reflects a shift from short-term operational efficiency toward long-term financial and environmental sustainability.

This indicates that successful implementation of circular economy technologies in engineering sectors depends not only on technical performance but also on measurable lifecycle benefits that justify investment and operational transformation. Furthermore, the presence of governance- and policy-related keywords within the network demonstrates that regulatory frameworks play a crucial role in facilitating adoption. Circular economy implementation is not solely a technological transition but also a systemic change requiring supportive institutional structures, including regulatory incentives, policy alignment, and governance mechanisms. Without enabling policy frameworks, even technically and economically viable solutions may face implementation barriers. When compared with previous review studies, the present analysis reveals a more explicit integration of environmental assessment tools and economic evaluation methods within sustainable engineering contexts. While earlier reviews often emphasized conceptual discussions of sustainability and circularity principles, the current findings suggest that recent research increasingly adopts quantitative evaluation approaches. This shift indicates a maturation of the field, moving from theoretical discourse toward evidence-based and performance-oriented analysis. Nevertheless, consistent with earlier studies, the field remains multidisciplinary and policy-dependent. The relatively small dataset also suggests that research integrating engineering applications, lifecycle costing, and regulatory analysis is still evolving, offering substantial opportunities for further investigation.

Implication :

This study provides technical, economic, and policy implications for circular economy implementation in sustainable engineering. Technically, the strong linkage between circular economy and life cycle assessment highlights the need to integrate environmental performance evaluation into engineering design and resource recovery systems. Economically, the increasing focus on cost-benefit analysis and life cycle costing indicates that long-term financial feasibility is essential to support investment decisions in circular technologies. From a policy perspective, the presence of governance- and regulation-related themes underscores the importance of supportive regulatory frameworks and incentives to accelerate adoption. Therefore, successful circular economy implementation requires alignment between technological innovation, economic viability, and policy support.

Research Contribution:

This study provides both conceptual and practical contributions to the field of sustainable engineering. Conceptually, it offers a bibliometric mapping of

circular economy research by identifying dominant themes, emerging topics, and interdisciplinary linkages among environmental assessment, economic evaluation, and governance frameworks. Practically, the findings support engineers, researchers, and decision-makers in understanding current research trends and integrating lifecycle-based and economically feasible approaches into sustainable engineering practices.

Limitation :

This study is limited to publications indexed in the Scopus database within the selected time frame, which may exclude relevant studies from other databases. The relatively small dataset also restricts the generalizability of the findings. In addition, the scope is confined to sustainable engineering and infrastructure contexts, which may not fully represent circular economy developments in other sectors.

Suggestion :

Future research should explore emerging directions such as digital circular economy approaches, including the integration of Industry 4.0 technologies and data-driven optimization. Greater emphasis should also be placed on policy integration strategies to strengthen implementation frameworks across sectors. Furthermore, research on hybrid systems that combine technological innovation, lifecycle assessment, and economic modeling is recommended to enhance the effectiveness and scalability of circular economy solutions.

4. CONCLUSION

Based on a systematic analysis of 15 articles selected from the Scopus, Web of Science, and IEEE Xplore databases covering the period 2015–2025, this study concludes that research on circular economy approaches in sustainable engineering is still at an early stage and inherently multidisciplinary. This is reflected in the distribution of publications across 15 different journals without concentration in core journals, as well as the dominance of empirical research articles published variably between 2022 and 2026, peaking in 2025 with seven articles. From a methodological perspective, quantitative and modeling approaches dominate at 40%, followed by qualitative or case study approaches at 23%, with modeling and simulation-based study designs being the most frequently used to evaluate system performance and predict the impacts of circular economy implementation. Research findings indicate that the primary focus of the literature is divided into three major domains: techno-economic studies and system design at 28.6%, environmental impact analysis based on Life Cycle Assessment (LCA) at 21.4%, and waste management and resource recovery optimization at 21.4%. This suggests that research over the past decade has emphasized technical-economic and environmental aspects. Conversely, studies on policy, regulation, social

behavior, and digital transformation remain relatively limited, each accounting for less than 10%.

Scientific collaboration in this field is relatively strong, with an average of 3.8 authors per article, and 20% of the publications representing international collaboration. Spain, the United Kingdom, and the United States are the most prolific contributors, reflecting the dominance of developed countries in circular economy research while highlighting opportunities to increase contributions from developing countries, including Indonesia. Future research directions identified from the literature emphasize the need for advanced model and simulation development with higher prediction accuracy (28.6%), the integration of technical results with policy and regulatory frameworks (21.4%), and technological and digital innovation within circular economy systems (21.4%). Research gaps remain significant in experimental validation, social and consumer behavior analysis, and the expansion of contextual case studies across various sectors and regions. Therefore, this study asserts that the transition toward a circular economy in sustainable engineering cannot be achieved through technological innovation alone. It requires an integrated approach that connects technical advancements, economic feasibility, and coherent policy support. As such, this literature synthesis contributes to mapping the still-fragmented knowledge landscape while identifying strategic pathways for the development of more comprehensive circular economy research and implementation in the future.

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6. AUTHOR CONTRIBUTION STATEMENT

A.J.: Conceptualization, research design, development of the PRISMA protocol, data collection, bibliometric analysis (Biblioshiny and VOSviewer), thematic synthesis using AI-assisted tools, data interpretation, visualization, and writing – original draft preparation.
A.A.: Methodology validation, supervision, critical review of bibliometric and thematic analysis, interpretation of results within sustainable engineering and circular economy perspectives, writing, review & editing, and final manuscript approval.

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