

REVIEW

Mapping Research Trends in Green Packaging: A Bibliometric Review (2000–2023)

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ABSTRACT

With over 141 million tons of packaging waste generated globally each year and limited recycling efficiency, packaging pollution has become a pressing environmental issue, driving increased scholarly interest in green packaging. However, existing studies have primarily focused on individual domains, lacking a systematic and comprehensive review, which restricts interdisciplinary integration and obscures overarching trends and gaps. To address this, we conducted a bibliometric analysis of green packaging research using CiteSpace and VOSviewer, drawing on peer-reviewed English-language articles published between 2000 and 2023 in the Web of Science Core Collection. The analysis examined collaboration networks, co-citation patterns, and keyword co-occurrence trends. Results reveal significant growth in publications since 2018, with research spanning environmental science, food technology, and business, alongside increasing interdisciplinary integration. Collaboration networks are particularly strong within China and Malaysia, though international collaboration remains limited, while co-citation analysis highlights high-impact work on material performance, consumer behavior, and supply chain strategies, with life cycle assessment emerging as the most widely applied analytical tool. This study synthesizes the current knowledge framework, identifies key trends and challenges, and outlines future research directions—including consumer

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ARTICLE INFO

Received: 13 July 2025 | Revised: 29 July 2025 | Accepted: 31 July 2025 | Published Online: 18 August 2025

DOI: <https://doi.org/10.30564/jees.v7i8.11013>

CITATION

Jun, L., Hasan-Basri, B., Bakar, N., 2025. Mapping Research Trends in Green Packaging: A Bibliometric Review (2000–2023) Journal of Environmental & Earth Sciences. 7(8): 101–130. DOI: <https://doi.org/10.30564/jees.v7i8.11013>

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payment behavior, corporate sustainability strategies, and the development of innovative packaging materials—providing strategic guidance for advancing green packaging research.

Keywords: Green Packaging; Bibliometrics; CiteSpace; VOSviewer; Visualization

1. Introduction

The imperative for environmental protection and sustainable development has garnered significant attention across various industries, including packaging^[1]. The packaging industry is a major source of global solid waste, largely due to the non-biodegradability of materials^[2]. As market competition intensifies and consumer demands diversify, packaging has evolved beyond its traditional role of protection and transportation to become a critical component of the marketing mix^[3]. It now serves as a medium for conveying brand identity and corporate social responsibility. Packaging materials include paper, plastic, metal, and glass, among others^[4]. According to projections, the global protective packaging market will reach \$29.7 billion by 2024, with plastic packaging accounting for 52%^[5].

With shifting global consumption patterns, the demand for express packaging solutions has been steadily increasing. However, the recycling rates for packaging waste remain substantially below environmental standards, leading to considerable resource waste and environmental pollution^[6]. Approximately 1.7 million tons of plastic enter the oceans annually, posing significant threats to marine ecosystems^[7]. Moreover, not all waste packaging materials are subject to recycling. In Europe, 40% of packaging waste ends up in landfills^[8], while in China, a leading consumer of packaging materials, the volume of packaging waste could fill nearly 200,000 football fields, with 95% of plastic packaging being non-recyclable^[9].

In response to the escalating issues of packaging waste, numerous countries have introduced legislation to promote the adoption of “green” packaging solutions. Examples include the European Union’s Packaging and Packaging Waste Directive^[10], Japan’s Container and Packaging Recycling Law^[11], and Germany’s successive revisions to the Packaging Act, which established the world’s first system for recycling and reusing packaging waste^[12]. Green packaging—also known as “eco-packaging”—is considered the most effective solution to this waste crisis. It minimizes environ-

mental impact by using biodegradable or recyclable materials and reducing emissions throughout the packaging life-cycle^[13]. Scholars have addressed various facets of green packaging, ranging from the development and application of eco-friendly materials to innovations in green packaging across industries and consumer preferences for sustainable packaging solutions^[14–16]. However, existing research tends to be fragmented, often lacking an integrated perspective on the field’s evolution, dominant themes, and interdisciplinary connections. Thus, there is a critical need to consolidate dispersed findings, identify emerging trends, and map collaboration networks within the research community.

In light of these challenges, bibliometric analysis provides a structured, quantitative approach to uncovering a field’s knowledge base, research trends, and evolving frontiers^[17,18]. Through bibliometric analysis, we can identify high-frequency keywords, core authors, research hotspots, and emerging research trends, which not only help researchers stay informed of the field’s development but also provide valuable guidance for future studies^[19].

Among the available bibliometric tools, CiteSpace and VOSviewer are two of the most widely used and influential software packages^[20]. Both tools offer unique strengths in data processing, network visualization, and research trend analysis. CiteSpace is particularly adept at mapping temporal patterns and identifying emerging research trends, as demonstrated in studies analyzing fields such as artificial intelligence and sustainable development^[21,22]. VOSviewer, on the other hand, is renowned for its intuitive interface and powerful clustering techniques, widely applied in systematic reviews of medical literature and interdisciplinary science mapping^[23,24]. These tools have been extensively used across various disciplines, validating their robustness in large-scale bibliometric analysis^[25].

CiteSpace, a Java-based software, is designed for scientific drawing and visualization within the research domain. By utilizing methods such as keyword co-occurrence, burst term analysis, citation co-citation, and collaboration network analysis, CiteSpace enables researchers to visualize knowl-

edge maps and uncover the frontiers and development trends within disciplines^[26]. VOSviewer is a highly intuitive tool for network construction and analysis^[27], offering interactive and dynamic visualizations that provide a clear display of the knowledge structure within a given field.

Given the complementary strengths of both tools, this study integrates CiteSpace and VOSviewer to leverage their advantages for a comprehensive bibliometric analysis. CiteSpace excels at temporal and evolutionary analysis, identifying research frontiers through burst detection and time-sliced co-citation networks, while VOSviewer offers superior visualization and clustering of co-occurrence networks, revealing key research themes and collaboration patterns. By cross-validating results—such as CiteSpace’s burst terms with VOSviewer’s keyword clusters—this dual approach ensures a robust identification of knowledge structures and emerging trends in green express packaging research^[28].

The objectives of this paper are as follows:

- (1) To map the interdisciplinary collaboration patterns among key stakeholders in green express packaging research.
- (2) To reveal the knowledge structure and evolutionary trajectory of this field through co-citation and co-occurrence analysis.
- (3) To identify emerging research frontiers and hotspots to guide future scholarly and industrial efforts.

The conceptual framework of this paper is shown in **Figure 1**. First, the publication statistics should be discussed. Second, we map the interdisciplinary collaboration patterns among key stakeholders in green express packaging research, identifying the most productive institutions and international cooperation networks. Next, we reveal the knowledge structure and evolutionary trajectory of this field through co-citation and co-occurrence analysis, uncovering foundational works and paradigm shifts. Finally, we identify emerging research frontiers and hotspots through burst detection analysis, which points to promising directions for future scholarly and industrial efforts. The concluding section discusses the theoretical and practical implications of these findings for advancing sustainable packaging solutions.

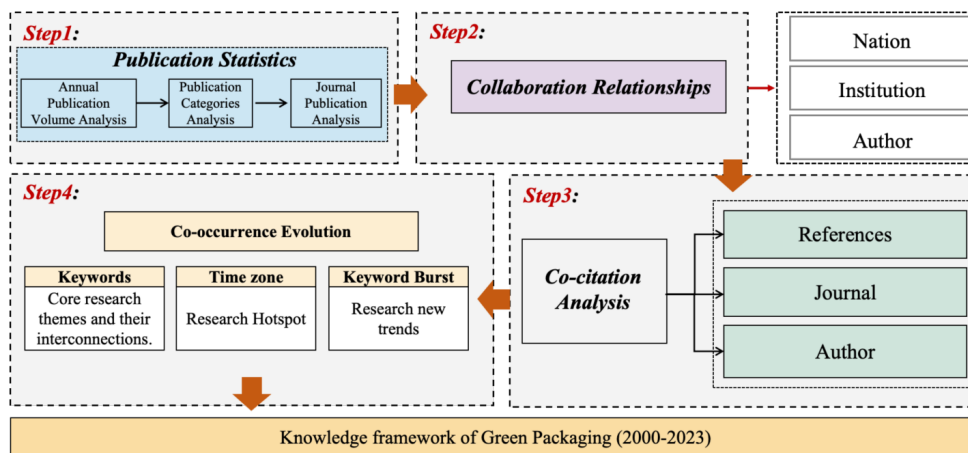


Figure 1. Conceptual framework.

2. Literature Review

From a macro perspective, many studies have explored the dynamic relationship between green express packaging and environmental sustainability. For example, research has examined the role of green packaging in reducing carbon emissions in the logistics and e-commerce sectors^[29], discussed how the Sustainable Development Goals (SDGs) promote the adoption of environmentally friendly packaging

practices in supply chains^[30], and analyzed the impact of national environmental policies in driving the use of sustainable packaging materials^[31]. These studies emphasize the importance of integrating sustainability into logistics and e-commerce, noting that green packaging not only addresses environmental issues but also contributes to the broader global sustainability goals.

From a meso perspective, studies have explored the interactive relationship between green express packaging

and other fields. For example, some studies indicate that green express packaging is intricately linked to social and economic factors, including consumer behavior, corporate social responsibility, policies and regulations, supply chain management, and market competitiveness^[31–35]. Other studies highlight the significance of environmental and technological factors in green packaging, including material innovation, waste management, carbon footprint reduction, and eco-friendly logistics practices^[36–38]. These studies suggest that the adoption of green packaging is not only influenced by internal business strategies but is also driven by external pressures such as environmental policies and technological advancements.

From a micro perspective, studies have examined the dynamic relationship between individual companies and the adoption of green express packaging. For example, some research discusses corporate attitudes and willingness toward green packaging, addressing the relationship between corporate social responsibility and environmentally friendly packaging solutions^[39,40]. Additionally, the driving factors and barriers to packaging sustainability depend on the company size^[33]. Meanwhile, the adoption of green packaging also improves business performance, enhancing corporate reputation, customer satisfaction, and compliance with environmental regulations^[41–43]. Further research points out that companies involved in green packaging projects gain competitive advantages through innovation and market differentiation, establishing their leadership in sustainable practices^[44–47].

From the perspective of literature reviews, various methods have been used to review subtopics related to green packaging. Methods such as bibliometric analysis, content analysis, meta-analysis, and case studies have been employed to explore different dimensions of green packaging research^[48–51]. These studies focus on themes such as the environmental impact of packaging materials, the role of green packaging in supply chain sustainability, consumer willingness to pay for eco-friendly packaging, and the role of corporate social responsibility in the adoption of green packaging^[17,52,53]. Through these diverse research methods, the literature on green express packaging has been expanded, providing a more comprehensive understanding of the field and highlighting future research directions.

In summary, review articles in the field of green packaging

tend to focus on specific disciplines or aspects of research. For example, some scholars concentrate on the study of green packaging materials, discussing the performance, application, and development trends of biodegradable plastics, plant fiber materials, and other eco-friendly alternatives to traditional plastics^[19]. Additionally, some scholars explore the application and research progress of recycling technologies for green packaging^[26]. While review articles in single disciplines have achieved certain results, the systematic analysis of interdisciplinary cooperation in the green packaging field remains relatively scarce. Green packaging involves a wide range of disciplines, including materials science, environmental science, engineering technology, economics, sociology, and management. As a result, a single-disciplinary perspective often cannot comprehensively reveal the full scope of the field. The lack of in-depth exploration of the integration and collaborative innovation across disciplines limits scholars' understanding of the overall development of the field and poses challenges for researchers seeking emerging research directions.

However, existing studies, while advantageous in certain aspects, also have some shortcomings. For instance, current research tends to focus on specific areas of green packaging, such as innovative technologies for green packaging materials, consumer preferences, or recycling practices. Although these studies provide valuable insights, there remains a gap in the systematic analysis of the overall knowledge structure and interdisciplinary integration of green packaging. Green packaging spans various disciplines, including materials science, environmental science, engineering technology, economics, sociology, and management. A single-disciplinary perspective often cannot fully unveil the entire field, and the lack of detailed discussion on the integration and collaborative innovation between disciplines limits the overall understanding of the field's development, making it challenging for researchers to identify emerging research directions. Additionally, although some studies have used bibliometric analysis tools such as CiteSpace, there has been limited research combining the strengths of different tools to analyze the knowledge structure of this field. Therefore, we aim to address these gaps by conducting a comprehensive bibliometric analysis of the knowledge structure and research evolution in the green packaging field.

We employed the advantages of both CiteSpace and

VOSviewer to conduct a bibliometric analysis of the knowledge structure and research development in green packaging. (1) We analyzed the core volume of publications in the field to understand the overall publication trends; (2) We examined global interdisciplinary cooperation and interaction trends through country, institution, and author network relationships; (3) We identified key literature and scholars in the field through citation and co-citation analysis of documents and authors; (4) We explored current research hotspots and revealed the disciplinary structure of the field through co-occurrence and clustering of keywords; (5) Furthermore, we revealed the development trends of the discipline, identified emerging research hotspots, and predicted future research directions through burst terms and time-zone graph analysis.

Based on these analyses, we have constructed a theoretical knowledge framework that provides an intuitive and comprehensive research panorama, discussing existing challenges and future research directions.

3. Data Sources and Analysis Methods

3.1. Data Sources

The subject of this study is “green packaging”. To obtain relevant literature, the Web of Science (WoS) Core Collection was chosen as the primary database because of its comprehensive coverage and reliability across various scientific fields^[19]. WoS provides a broad range of high-quality publications, ensuring that the data collected for this analysis is authoritative and represents the current research landscape on green express packaging.

To ensure a comprehensive search for research relevant to the topic, a broad set of keywords was used for literature retrieval. The search formula is as follows:

(“green package* degradable*” or “green* package*” or “green* packaging” or “green* packing*” or “ecologic* package*” or “ecologic* packaging” or “ecologic* packing” or “environment* friendly package*” or “environment* friendly packaging” or “environment* friendly packing” or “environmentally friendly packaging” or “environmental* protection package*” or “green* express packaging” or “eco-packaging” or “sustainable packaging” or “recyclable packaging”).

The search method used was “Topic”, and the data col-

lection was limited to “Core Journals” as the primary source of literature. The search was conducted on May 24, 2024, and only “article” types were retained. After data cleaning and deduplication, a total of 1,020 papers directly related to green express packaging were obtained. The search strategy is clarified as follows:

The reason for choosing “Topic” instead of “Title” as the search criterion was to maximize the relevance of the retrieved literature, as “Topic” allows for a broader and more comprehensive capture of research discussing green express packaging in different contexts.

An asterisk * was used in the search string to account for variations in word forms, thus improving the comprehensiveness of the search. For example, “green package” can include terms such as “green packaging”, “green package”, and “greenly packaged”. This increases the flexibility of the search and enhances the chances of retrieving highly relevant publications.

The data collection was limited to “Core Journals” to ensure the quality and academic rigor of the results. Core journals in the Web of Science are known for their high impact and strict peer-review processes, ensuring that the literature covered in this study is authoritative and reliable.

To focus on original research contributions, only “article” types were selected for this analysis. Articles provide in-depth empirical data and theoretical analysis, which is crucial for building a detailed and thorough understanding of the knowledge structure of green express packaging. Other document types, such as reviews, editorials, or conference papers, were excluded to maintain the consistency and rigor of the analysis.

No time span limitation was applied to capture the full scope of research development in the field. This unrestricted time frame allows for an analysis of the evolution of green express packaging research, providing insights into historical trends and identifying shifts in research focus. This helps to provide a comprehensive understanding of the development trajectory of the green express packaging field and offers direction for future research.

3.2. Analysis Methods

When conducting bibliometric analysis, various software tools can be chosen, each with its own characteristics^[17]. For example, HistCite excels in frequency analysis

but lacks in co-citation and co-occurrence relationship analysis^[54]. SATI can perform co-citation and co-occurrence analysis but cannot directly present clustering maps or temporal evolution processes of the research field^[55]. In contrast, CiteSpace and VOSviewer offer some clear advantages for the needs of this study. First, CiteSpace supports multi-dimensional analysis, including clustering analysis and keyword evolution, allowing researchers to explore the relationships between literature from multiple angles and uncover research trends and knowledge development^[19]. Second, CiteSpace can visually present analysis results through intuitive charts, clearly showing correlations, development trends, and structures in the research field, making complex literature data easier to understand^[54]. Additionally, CiteSpace performs well in handling large-scale literature databases, meeting the demands of complex bibliometric analysis, and ensuring the reliability and repeatability of the results^[36]. Therefore, we chose to use CiteSpace for analyzing co-citation networks, keyword co-occurrence, time-zone maps, and burst terms.

VOSviewer is popular for its free access and ease of use, with fast analysis and visualization processes that quickly display correlations between documents^[56]. It is highly suitable for analyzing collaboration networks. We selected VOSviewer to analyze the institutional and author collaboration networks, as the tool can generate highly visualized cooperation network graphs, helping us quickly identify key institutions and authors in the field of green packaging. Furthermore, VOSviewer's density map can show the association density of nodes through varying colors, which helps identify research hotspots, key authors, and institutions, revealing potential interdisciplinary collaboration opportunities within the field. However, we still chose CiteSpace for analyzing country collaboration networks, as it provides detailed information on interdisciplinary collaboration among scholars across regions.

3.3. Analysis Process

We used CiteSpace and VOSviewer to obtain results and conduct visualization analysis. The specific steps are as follows:

1. Data Import and Processing: Import the data file containing 1,020 articles exported from WoS and perform

deduplication. No duplicate content was found, and the final dataset confirmed 1,020 articles.

2. Time Slicing: Choose the time period from January 1978 (the year of the first relevant article published) to December 2024 (the year of the search). Set "one time slice per year".
3. Threshold Selection: In CiteSpace, the threshold parameters were set as 2, 2, 20; 4, 3, 20; and 4, 3, 20. The text processing terms were set to title, abstract, author keywords, and keywords plus. The Top 50 were selected as the standard for selection, with the top 50 cited or most frequent items from each time slice being chosen.
4. Collaboration Networks: Select author, institution, and country as node types to construct and visualize collaboration networks. This step displays the cooperation relationships between various nodes and helps identify the most influential stakeholders and research centers in the green express packaging research field.
5. Co-citation Analysis: Choose reference documents, cited authors, and cited journals as node types to obtain the co-citation status in the research field. Through the co-citation network, the knowledge base and research frontiers are revealed.
6. Keyword Co-occurrence Network: Choose keywords as node types to generate a keyword co-occurrence network, helping to understand the evolution of research, current research hotspots, and potential turning points.
7. Burst Detection: Use CiteSpace's burst detection function to identify emerging trends and significant shifts in research focus within the field, providing insights for the development of future research.

4. Results and Analysis

4.1. Publication Statistics

The aim of publication statistics analysis is to reveal research trends and development dynamics, helping us understand the research activity, popular topics, and future development directions in the field^[19].

4.1.1. Annual Publication Volume Analysis

The first core paper in the green express packaging research field was published in 1978. The overall trend of publication volume up to the date of literature retrieval is shown

in **Figure 2**. The closer the R^2 value is to 1, the more reliable the trend line is. The publication trend demonstrates a clear

transition from sporadic research activity to an established and rapidly growing field, especially in the last five years.

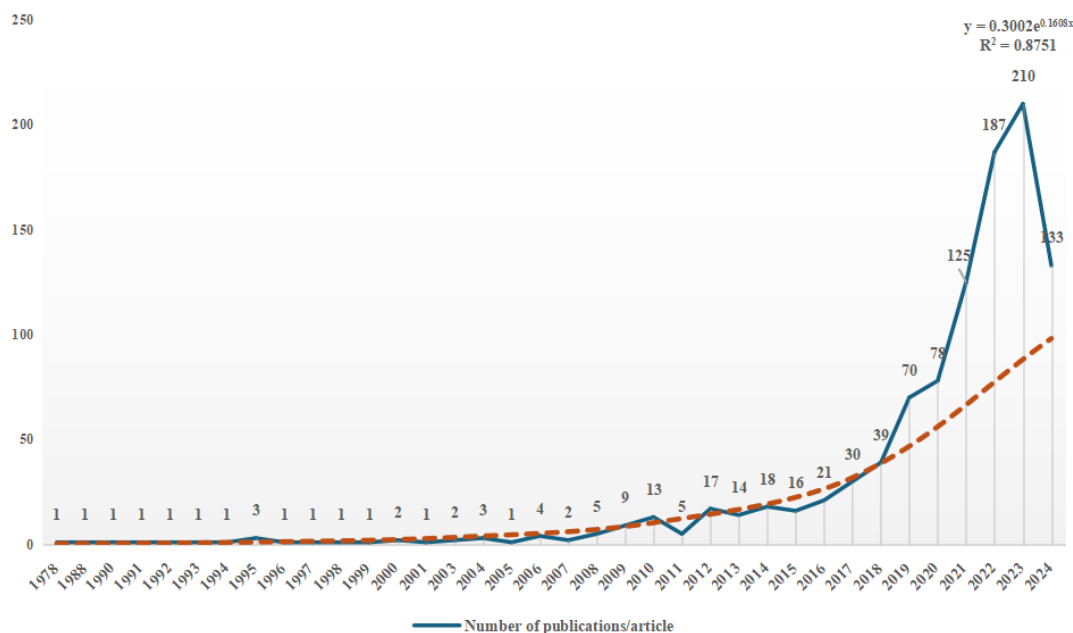


Figure 2. Annual publication statistics.

Specifically, there are three stages. The first stage is the initial phase (1978 to 2007), where the number of publications was minimal (usually only one or two papers published each year), indicating that green express packaging research was not highly prioritized during this period. This may be due to the nascent stage of environmental awareness and limited focus on the sustainability of the logistics sector. However, these publications laid the foundation for future growth. The second stage is the childhood phase (2008 to 2017), during which the publication volume began to increase following the enactment of the Kyoto Protocol in 2005. From around 2008, the number of published articles gradually grew. The establishment of the “Sustainable Development Goals” by the United Nations in 2015 and the Paris Agreement in 2016 were key historical developments that drove green express packaging research. By 2017, the number of articles had gradually increased from five in 2011 to 30. This marks the beginning of green express packaging research. The third stage is the adolescence phase (2018 onwards), where publication numbers surged exponentially, from 39 articles in 2018 to 210 articles in 2023, nearly a sevenfold increase. This surge in interest aligns with increasing pressure from regulatory bodies, growing consumer demand for environmentally

friendly solutions, and advances in green technologies. The sharp increase in publication volume indicates that green express packaging has become a key research focus, driven by the urgency of addressing the environmental impact of traditional packaging materials. Contemporary scholars should continue to invest in research in this field.

4.1.2. Publication Categories Analysis

From the distribution of disciplines in which the papers were published (**Figure 3**), the green packaging research field can be generally divided into two parts: The first part involves research conducted within single disciplines, primarily covering two disciplines: Chemistry and Science, including Polymer Science, Environmental Sciences, and Chemistry Applied. Among these, Polymer Science has the largest share (21%), focusing on the study of green packaging materials. The second part involves research conducted through interdisciplinary collaborations, involving nine different forms of collaboration, including Engineering Environmental, Materials Science Multidisciplinary, Food Science Technology, Green Sustainable Science Technology, Environmental Studies, Engineering Chemical, and Chemistry Multidisciplinary. Among these, Food Science

Technology ranks second (18%), focusing on the application of green packaging in the food industry, including the performance of green packaging, consumer preferences, and related aspects.



Figure 3. Publication category statistics.

4.1.3. Journal Publication Analysis

We have compiled the top ten journals with the highest publication volumes in the green packaging field in **Table 1**. From this, the following characteristics can be observed: (1) The journals with the highest publication volumes, such as International Journal of Biological Macromolecules, Sustainability, and Journal of Cleaner Production, focus on a range of interdisciplinary topics related to sustainability. These topics include sustainable materials, environmental science, packaging science, and applications in food and agriculture. (2) There is little difference in the publication volumes of different journals. Specifically, the top three journals account for approximately 4.2% of the total publications, while the other seven journals each account for around 2%. This relatively balanced distribution of publications indicates that

green packaging is an interdisciplinary field, with research outcomes being diverse. (3) Journals with more published papers tend to have higher impact factors. Among them, two journals have impact factors greater than 10, and four journals have impact factors greater than 5, indicating that the green packaging field is gradually gaining attention in the academic community. This information also provides a reference for researchers submitting papers and encourages them to improve the quality of their papers, positively contributing to the development of the field. (4) The field's publication distribution is concentrated, with MDPI and Elsevier playing dominant roles. Among the top ten journals, 48% are published by Elsevier, and 36% by MDPI. The former offers both open access and subscription models, while the latter is an open-access journal, thus increasing the dissemination of research outcomes in this field.

Table 1. Publication journal statistics.

Ranking	Journal	Count	5-Year IF	Publishers
1	INTERNATIONAL JOURNAL OF BIOLOGICAL MACROMOLECULES	43	7.7	Elsevier
2	SUSTAINABILITY	43	3.6	MDPI
3	JOURNAL OF CLEANER PRODUCTION	42	10.2	Elsevier
4	POLYMERS	30	4.9	MDPI
5	PACKAGING TECHNOLOGY AND SCIENCE	28	2.9	Wiley
6	FOODS	27	5.1	MDPI
7	FOOD PACKAGING AND SHELF LIFE	20	8.6	Elsevier
8	JOURNAL OF POLYMERS AND THE ENVIRONMENT	17	4.6	Springer
9	CARBOHYDRATE POLYMERS	15	10.3	Elsevier
10	INDUSTRIAL CROPS AND PRODUCTS	14	5.7	Elsevier

4.2. Collaboration Relationships

Collaboration networks examine the partnerships and collaborative efforts between different institutions, regions, or researchers involved in green packaging research. Analyzing these relationships helps understand the relevance of current research^[19], identify key contributors, and assess the impact of teamwork on advancing the field. At the same time, it encourages other scholars to participate in research in this area.

4.2.1. National Collaboration Network

Table 2 lists the top 15 countries actively engaged in collaborative green packaging research. Overall, Asia has the highest number of publications, with 389 articles, making it the most active region in green packaging research. Europe follows with 280 articles, demonstrating strong participation in the field. There are several noteworthy details in this analysis: (1) China is the country with the highest publication volume in this field (196 articles), thanks to the country's

investment in sustainable development. China's "dual carbon" goals and the "Green Packaging Management Plan for Express Delivery" are key drivers behind the promotion of green packaging research. However, China's centrality is relatively low (0.09), indicating that research in China is more concentrated domestically, with cooperation with global research networks needing improvement. (2) There are few countries with a centrality greater than 0.1. The United States, with the highest centrality (0.26), is also the second-largest contributor in terms of publications, and it was the birthplace of the first green packaging research paper in 1978. This is directly related to the United States' robust academic infrastructure and extensive international collaboration. (3) Malaysia is a "rising star" in the field. Research in this region started in 2012, and with a centrality of 0.14, Malaysia, although a latecomer to green packaging research, has rapidly established strong connections with research in other countries, making it a key bridge for international collaboration.

Table 2. Top 15 collaborative regions.

Ranking	Journal	Count	Centrality	Year
1	CHINA	196	0.09	2004
2	USA	104	0.26	1978
3	INDIA	91	0.1	1998
4	ITALY	75	0.05	2000
5	SPAIN	58	0.04	2006
6	BRAZIL	54	0.08	2009
7	GERMANY	44	0.06	2000
8	MALAYSIA	39	0.14	2012
9	ENGLAND	39	0.08	2011
10	CANADA	38	0.00	2011
11	PORTUGAL	37	0.09	2003
12	SOUTH KOREA	32	0.00	2007
13	IRAN	31	0.02	2013
14	AUSTRALIA	27	0.05	2003
15	SWEDEN	27	0.03	1999

Figure 4 displays the national collaboration network, consisting of 87 nodes and 535 links, with thicker lines indicating stronger cooperation. Clustering analysis shows that cross-regional collaboration has intensified in recent years. Distinct thematic focuses can be observed among country clusters: China and India concentrate on new material development and reducing supply chain environmental impacts (#0), including studies on biotechnological enhancements to packaging materials and consumer attitudes toward green packaging^[57–61]. Brazil and Portugal emphasize nanocomposite materials (#1)^[62–65], while Malaysia

and Australia focus on industrial applications of green packaging, especially in the food sector (#2)^[66–70]. Italy and Spain collaborate on sustainable food packaging technologies like modified atmosphere and vacuum packaging (#3)^[71–75]. The United States and Indonesia jointly explore packaging waste reduction and its influence on young consumers and supply chain practices (#4)^[76–81]. These patterns highlight the need for enhanced multinational cooperation in material innovation, consumer behavior research, green supply chain management, and packaging waste mitigation.

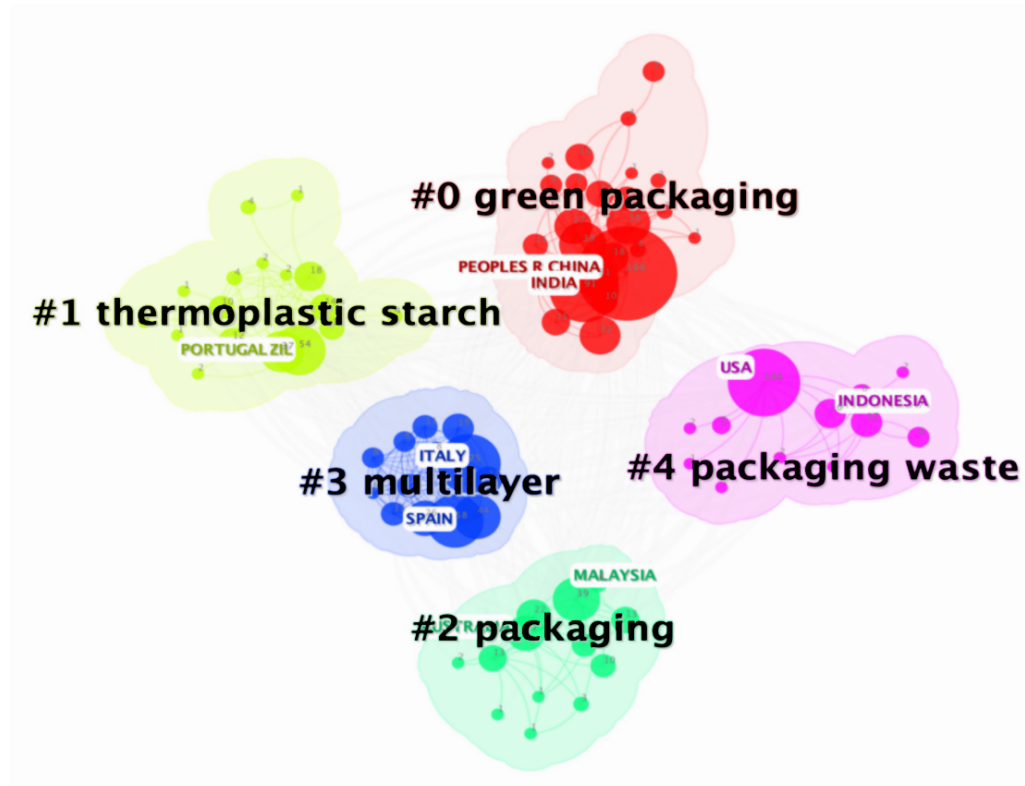


Figure 4. Regional collaboration network.

4.2.2. Institutional Collaboration Network

Table 3 presents the top 15 most collaborative institutions in the green packaging field. After specific analysis, two points are noteworthy: (1) Four of the top five institutions are based in Asia. Universiti Sains Malaysia, ranked first, published 16 collaborative papers, with the first collaboration taking place in 2012, indicating the institution's significant position in this field of research. The EGYPTIAN KNOWLEDGE BANK ranks second with 13 collaborative publications. Sichuan University and the Chinese Academy of Sciences, both from China, rank third and fourth, respectively, with 12 collaborative papers each. The first collaboration for these Chinese institutions occurred in 2014, highlighting the active role of Chinese academia in this field. In comparison to these Chinese institutions, the Indian Institute of Technology (IIT) system ranks fifth, with 11 collaborative papers published, and the first collaboration occurred in 2016, further demonstrating India's rapid involvement in this field. (2) In terms of the years of collaborative publications, most institutions began their first collaboration in 2016 or later, indicating that these institutions have only recently increased their investment in the field, particularly in cross-institutional

cooperation. For institutions and scholars wishing to enter this field, they can reference these institutions' collaboration models and actively seek collaboration opportunities.

Figure 5, generated using VOSviewer, illustrates the institutional collaboration network, with node size representing collaboration frequency or influence, and color indicating temporal evolution (from blue in 2018 to yellow in 2024). Notably, institutions such as Universiti Sains Malaysia, Sichuan University, the Chinese Academy of Sciences, and North Carolina State University have emerged as central hubs, showing sustained and growing collaboration in recent years. Clustering patterns reveal strong regional cooperation, particularly among Asian institutions, with Universiti Sains Malaysia forming close ties with Sichuan University and the Chinese Academy of Sciences. Meanwhile, North American institutions like North Carolina State University and Michigan State University also display distinct collaboration clusters. Smaller, newer nodes—such as Tabriz University and Anna University—reflect recent entrants into the network, whose increasing connectivity indicates rising collaborative potential. These trends underscore the importance of deepening institutional partnerships, promoting cross-regional and interdisciplinary research, and supporting

emerging institutions to enhance the diversity and resilience of the global green packaging research network.

Table 3. Top 15 most collaborative institutions.

Ranking	Institutions	Count	Year
1	UNIVERSITI SAINS MALAYSIA	16	2012
2	EGYPTIAN KNOWLEDGE BANK (EKB)	13	2017
3	SICHUAN UNIVERSITY	12	2014
4	CHINESE ACADEMY OF SCIENCES	12	2014
5	INDIAN INSTITUTE OF TECHNOLOGY SYSTEM IIT SYSTEM	11	2016
6	CONSIGLIO NAZIONALE DELLE RICERCHE (CNR)	11	2013
7	NORTH CAROLINA STATE UNIVERSITY	11	2018
8	SOUTH CHINA UNIVERSITY OF TECHNOLOGY	10	2016
9	UNIVERSITY OF CATANIA	10	2016
10	UNIVERSITY OF BOLOGNA	8	2018
11	UNIVERSIDADE DE AVEIRO	8	2003
12	Anna university	8	2017
13	Anna University Channel	8	2017
14	ISLAMIC AZAD UNIVERSITY	7	2013
15	Empresa Brasileira de Pesquisa Agropecuaria (EMBRAPA)	7	2018

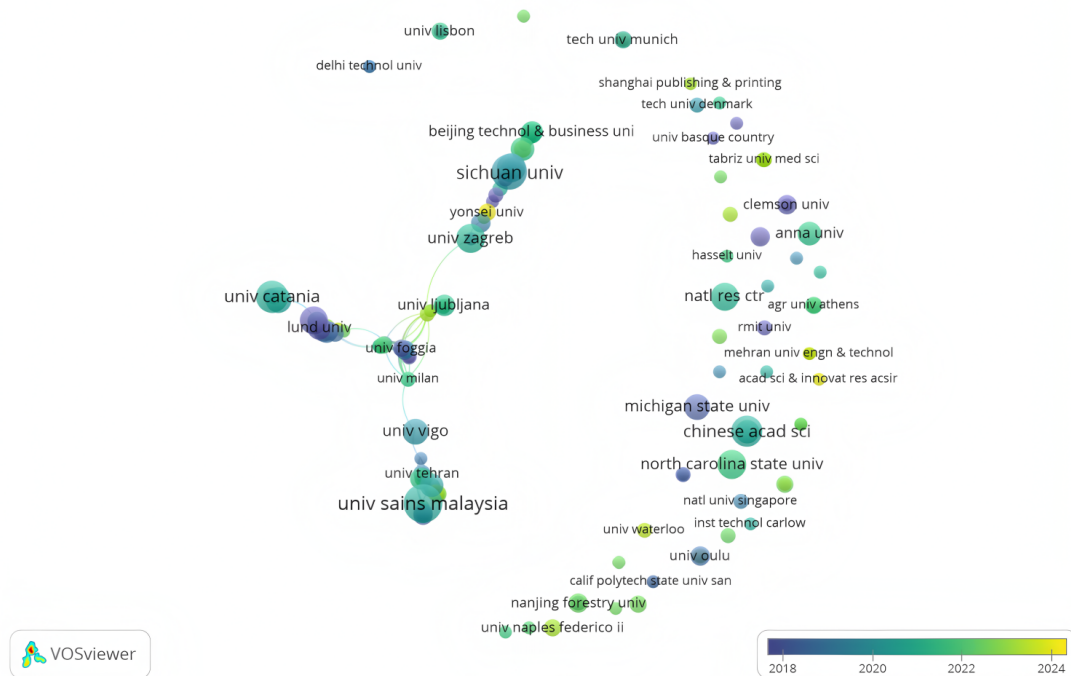


Figure 5. Institutional collaboration network.

4.2.3. Author Collaboration Analysis

We have listed the most collaborative authors along with the number of their collaborative publications and other relevant information, as shown in **Table 4**. After specific analysis, we found three noteworthy points: (1) The authors with the highest publication volume also have the highest Total Link Strength. In the rankings, Khalil HPSA, Siracusa V, Lotti N, and Soccio M are the top four authors, each with 7 collaborative publications, and all have a Total Link Strength

of over 20. Among them, Siracusa V, Lotti N, and Soccio M have a Total Link Strength of 34, indicating they have stronger linkages and are significant academic forces in the field. (2) The collaboration in this field generally began relatively late. The majority of authors' first collaborations occurred around 2018, which coincides with the "adolescence" phase of green packaging research, a stage characterized by a sharp increase in publication volume and rapid development of the field. Siracusa V, Lotti N, and Soccio M, among others,

began collaborating frequently in 2018, reflecting the rapid growth and internationalization of green packaging research during this period. This explosive growth further deepened collaborative research, with many scholars joining the collaboration network, bringing more academic achievements and influence. (3) The number of co-authored papers and Total Link Strength show differences. Some scholars with fewer co-authored papers, such as Marques, Clara Suprani, Guidotti G, and Gazzano M, published 6 and 5 papers, re-

spectively, but their Total Link Strengths are 21, 31, and 31, significantly higher than those of other authors with fewer co-authored papers. This suggests that despite having fewer co-authored papers, these authors' collaboration networks are more concentrated and of higher quality, which enhances their influence and link strength in academic collaboration. It also indicates that the depth and quality of academic collaboration sometimes have a more significant impact on link strength than the quantity of co-authored papers.

Table 4. Top 15 collaborative authors.

Ranking	Authors	Count	Total Link Strength	Year
1	Khalil HPSA	7	20	2019
2	Siracusa V	7	34	2018
3	Lotti N	7	34	2018
4	Soccio M	7	34	2018
5	Abdullah CK	6	6	2019
6	Marques, Clara Suprani	6	21	2021
7	Guidotti G	5	31	2018
8	Gazzano M	5	31	2018
9	Tavassoil, Milad	5	6	2022
10	Prado-prado JC	5	12	2022
11	Vargas, Maria	5	7	2014
12	Hernandez-garcia, Eva	5	7	2022
13	Hu, Han	4	13	2018
14	Rizal, Samsul	4	17	2019
15	Wang, Jinggang	4	13	2019

Figure 6 illustrates the density visualization of author collaboration, with color intensity reflecting collaboration strength across different groups. Central yellow areas indicate high-density clusters, where key authors like Khalil HPSA, Siracusa Valentina, and Lotti Nadia play a central role in the network due to their frequent collaborations. Authors such as Herbes Carsten, Gopakumar Deepu A., and Marques Clara Suprani also occupy high-density areas, suggesting their significant involvement in collaborative research. In contrast, the purple regions highlight authors like Cui Qingbin and Lignou Stella, whose collaboration networks appear weaker or more dispersed. These authors tend to engage in fewer cross-disciplinary or cross-regional collaborations. Additionally, the map reveals the evolution of collaboration networks: authors in central yellow areas, particularly those at the center, have experienced rapid growth in their collaborative relationships, while those on the periphery are newer entrants still establishing their networks. We recommend that researchers prioritize collaboration with both highly active authors and emerging scholars. The former, with well-established networks, can offer valuable insights, while engaging with the latter can foster new, innovative research

directions. Expanding interdisciplinary and cross-regional partnerships should be a focus to enhance global collaboration and drive innovation in green packaging research.

4.3. Current Situation of Co-Citation

Co-citation analysis is a method used to reveal the potential relationships between documents, mainly focusing on the interactions between authors, journals, and articles in the academic community. Specifically, when two or more documents are cited by the same source, it indicates that there is an academic link or a shared research theme between them. The higher the frequency of co-citation, the stronger the relationship between the documents, suggesting that these documents have a greater academic influence in the field and are key components of the research in that area. Through co-citation analysis, we can not only identify the core research achievements in the field of green packaging but also explore the mutual influence and academic inheritance between documents, leading to a more comprehensive understanding of the research background and progress in this field.

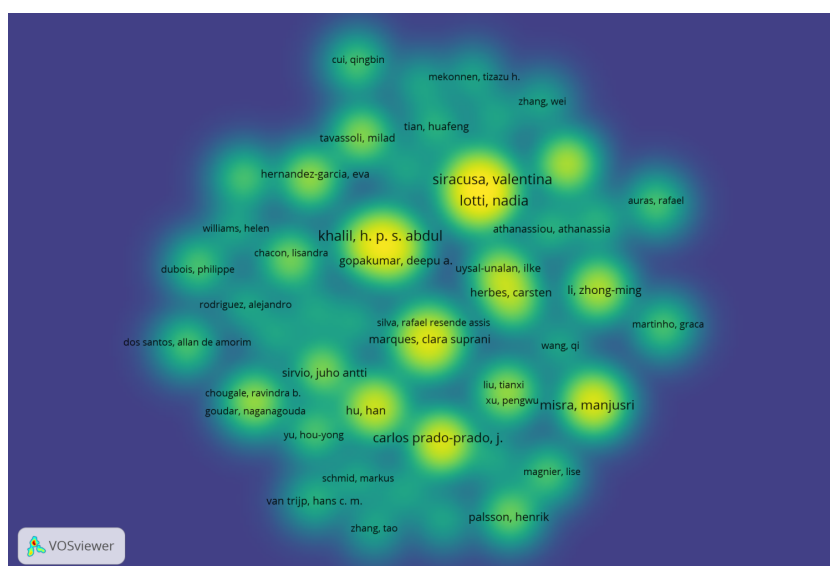


Figure 6. Author collaboration density visualization.

4.3.1. Co-Citation Analysis of References

Reference co-citation refers to the phenomenon in which two or more articles are simultaneously cited in other documents. It reveals the knowledge structure in the green packaging field, representing the research frontier and key literature. **Table 5** lists the top 15 most-cited references. Most of the co-cited papers were published in journals in the field of sustainable development, such as *SUSTAINABILITY* and *Journal of CLEAN Production*. There are two noteworthy points: (1) Among the 15 most co-cited articles, Boz Z's paper is the most cited (30 times). He reviewed the concept and development of sustainable packaging, highlighting the role of consumer behavior and market opportunities in driving sustainable packaging^[50]. (2) The papers by Ketelsen and Geyer ranked second and third (both with 29 citations). They discuss different themes. Ketelsen reviewed consumer reactions to eco-friendly food packaging and proposed solutions^[53], while Geyer used life cycle assessment to evaluate the environmental impact of plastic waste by 2050^[82]. It is evident that the themes researchers focus on in promoting green packaging solutions are diverse. These highly cited documents cover a broad range of topics, including consumer behavior, the sustainability of packaging design, and the environmental impact of plastic waste. This suggests that research on sustainable packaging needs to address not only consumer attitudes but also the lifecycle and environmental consequences of packaging.

Figure 7 illustrates the most influential clusters in

the document co-citation network, comprising 872 nodes and 2792 connections. Key findings include: (1) A significant portion of co-cited documents is related to eco-friendly packaging (#0), exploring consumer and business responses to sustainable packaging. Studies analyze how businesses improve supply chain management and promote recycling within a circular economy^[52,83], while others focus on consumer acceptance across different cultures^[1,60,84,85]. Researchers can further explore green packaging from both business management and marketing perspectives. (2) Thirteen highly co-cited articles in the eco-friendly packaging cluster (#0) provide foundational knowledge for subsequent research, with most published in the past five years, indicating the ongoing potential for exploration. (3) Other notable clusters include sustainability (#1), Poly (#2), packaging development (#3), sustainable film (#4), sodium alginate (#6), moisture sorption (#9), operational excellence (#10), and logistics (#13). For example, the sustainability cluster (#1) examines strategies for improving biodegradable polymers in food packaging^[86]; Poly (#2) focuses on the transport performance of carbon dioxide in amorphous polyethylene furanoate (PEF)^[87], highlighting interdisciplinary material science and environmental engineering topics. The packaging development cluster (#3) investigates how over-packaging influences brand perceptions^[88], while the sustainable film cluster (#4) discusses edible packaging advancements^[89]. The sodium alginate cluster (#6) explores cellulose nanostructures in food packaging^[90], and

the moisture sorption cluster (#9) addresses the sustainability of bio-based plastics^[91]. The operational excellence cluster (#10) reviews best practices for logistics service providers^[92], and the logistics cluster (#13) studies the

role of sustainable packaging logistics in manufacturing^[93]. These clusters form the foundation of the field, with key documents in each cluster offering valuable knowledge for further research.

Table 5. Top 15 co-cited references.

Ranking	Count	Reference	Source	Cluster ID
1	30	Boz Z	SUSTAINABILITY	0
2	29	Ketelsen M	J CLEAN PROD	0
3	29	Geyer R	SCI ADV	2
4	26	Steenis ND	J CLEAN PROD	0
5	25	Nguyen AT	J CLEAN PROD	0
6	25	Prakash G	J CLEAN PROD	0
7	23	Herbes C	J CLEAN PROD	0
8	21	Wandosell G	SUSTAINABILITY-BASEL	0
9	20	Guillard V	FRONT NUTR	0
10	20	Meherishi L	J CLEAN PROD	0
11	19	Wu F	PROG POLYM SCI	1
12	18	Hao Y	RESOUR CONSERV RECY	0
13	16	Orzan G	SUSTAINABILITY-BASEL	0
14	15	Otto S	J CLEAN PROD	0
15	15	Boesen S	J CLEAN PROD	0

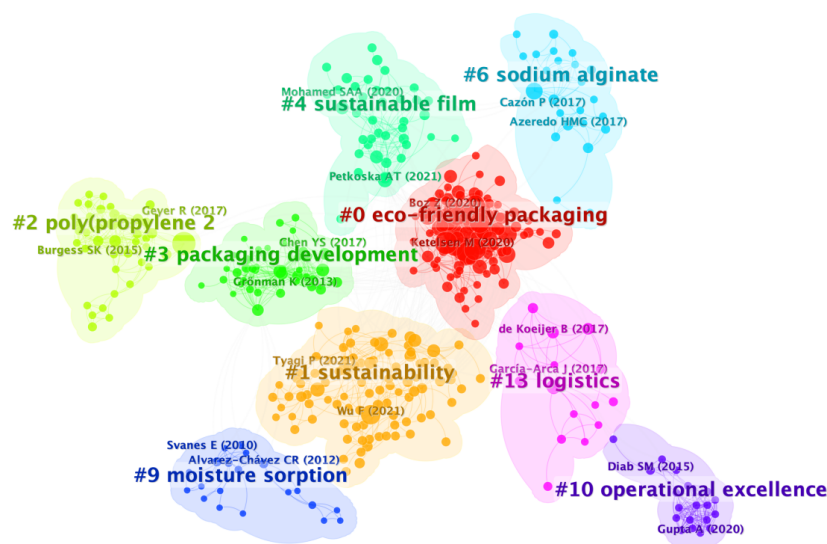


Figure 7. Reference co-citation network.

4.3.2. Journal Co-Citation Analysis

Journal co-citation refers to the situation where the same academic journal is cited in multiple documents, used to measure the academic connections and influence between journals. We list the top 15 most co-cited journals in **Table 6** and use CiteSpace to generate the map in **Figure 8**. Nine of these co-cited journals have an impact factor greater than 7, and five have an impact factor greater than 10, indicating that these journals with high academic influence play an important leading role in the field. Notably: (1) The top two

co-cited journals are clearly superior to the others. In terms of co-citation frequency, the top two journals have over 400 co-citations. In terms of impact factor, both of these journals have an impact factor greater than 10. This suggests that researchers in the green packaging field pay more attention to the authority of top-tier journals. (2) Journals with similar impact factors may show different co-citation patterns. For example, Journal of Applied Polymer Science (impact factor: 2.8) and Packaging Technology and Science (impact factor: 2.9) have similar impact factors, but their co-citation

counts differ by nearly 100. Similarly, International Journal of Biological Macromolecules (7.7) and ACS Sustainable Chemistry & Engineering (7.9) have similar impact factors, but their co-citation counts differ by 128. These four journals are all non-open access, and the co-citation differences are related to factors such as the disciplines they belong to and their publication volume. (3) The most co-cited journals tend to be multidisciplinary. For example, Journal of Cleaner Production covers environmental science, sociology, economics, etc.^[94–96]; Food Chemistry primarily focuses on the chemi-

cal composition, properties, and applications of food but also includes interdisciplinary research from other fields^[97–99]; Resource Conservation and Recycling covers environmental science, chemical engineering, and sustainability, among other disciplines^[60,100,101]. Finally, we recommend that researchers prioritize journals with high co-citation frequency and impact factor when choosing where to publish. When submitting, researchers should also consider the interdisciplinary nature of journals and select those that are related to their own field.

Table 6. Top 15 most co-cited journals.

Ranking	Count	Journey	5-Year IF	Year
1	416	Journey of CLEANer PRODUCTION	10.2	2010
2	402	CARBOHYD POLYM	10.3	2009
3	318	INTERNATIONAL JOURNAL OF BIOLOGICAL MACROMOLECULES	7.7	2016
4	310	JOURNAL OF APPLIED POLYMER SCIENCE	2.8	2005
5	275	POLYMERS	4.9	2018
6	267	FOOD HYDROCOLLOID	11.3	2009
7	229	TRENDS IN FOOD SCIENCE & TECHNOLOGY	16.4	2009
8	226	PACKAGING TECHNOLOGY AND SCIENCE	2.9	2003
9	223	INDUSTRIAL CROPS AND PRODUCTS	5.7	2015
10	220	FOOD CHEMISTRY	8.3	1998
11	219	SUSTAINABILITY	3.6	2019
12	207	FOOD PACKAGING AND SHELF LIFE	8.6	2017
13	200	RESOURCES CONSERVATION AND RECYCLING	12.1	2010
14	193	POLYMER	3.9	2007
15	190	ACS SUSTAINABLE CHEMISTRY & ENGINEERING	7.9	2017



Figure 8. Journal co-citation network.

4.3.3. Author Co-Citation Analysis

Author co-citation refers to the phenomenon where two or more authors are cited together in different documents. By analyzing author co-citation relationships, we can reveal the academic connections and collaboration networks between different authors in the field of academic research. In CiteSpace, if the same author is cited multiple times in the same document, it is counted as one.

Table 7 lists the top 15 authors with the highest co-citation frequency. RHIM JW is the most co-cited author, with 66 co-citations, and is also the earliest co-cited researcher. He discussed the application of bio-based nanocom-

posites in food packaging, focusing on their potential in improving packaging performance, biodegradability, antimicrobial properties, mechanical properties, and thermal performance, as well as the challenges and future development directions^[102]. Next are MAGNIER L (54 co-citations) and GEYER R (50 co-citations). MAGNIER L advocates for exploring consumer reactions to products made from recycled marine plastics^[103], while GEYER R's research topic also centers on plastic packaging^[60]. Therefore, we suggest that authors should broaden their research directions, increase their academic influence, maintain interdisciplinary collaboration, and provide insights for other scholars.

Table 7. Top 15 most co-cited authors.

Ranking	Count	Author	Year
1	66	Rhim Jw	2013
2	54	Magnier L	2018
3	50	Geyer R	2019
4	49	Steenis Nd	2018
5	49	Siracusa V	2015
6	44	Prakash G	2018
7	42	Martinho G	2019
8	40	Herbes C	2019
9	39	Verghese K	2010
10	38	Ajzen I	2009
11	38	Rokka J	2014
12	36	Lindh H	2017
13	36	Molina-Besch K	2017
14	32	Nordin N	2016
15	32	European Commission	2019

Figure 9 shows the author co-citation network, displaying 13 major clusters, representing different research focuses. (1) The most prominent cluster is “cellulose” (#0). This cluster has the largest scope, with the most scholars, and includes the most co-cited authors, RHIM JW and MAGNIER L. The research topics in this cluster include bio-based nanocomposites and consumer responses to sustainable packaging. In the network map, their nodes are large, indicating that these authors have significant influence in the academic field. (2) In addition to “cellulose” (#0), most authors also participate in the “e-commerce” (#1) and “logistics” (#2) clusters, which emerged earlier and mainly focus on green packaging research in the e-commerce and logistics sectors. Additionally, other cited authors have focused on “Thermal properties” (#2), flammability (#4), *Listeria monocytogenes* (#5), environmental performance (#6), Sustainable materials (#8), Green supply chain (#9), Edible coating (#10), soluble soybean polysaccharide (#13), Plastic carry bags (#15), and

assessment (#19). While these clusters also contain many co-cited authors, their average co-citation frequency is lower, indicating that the academic influence of these authors has not yet reached a high level. These findings provide an insight into which scholars should be paid attention to when focusing on the latest research progress in green packaging.

To summarize, the document co-citation analysis reveals the foundational literature and thematic clusters that shape current research on sustainable packaging. These clusters—ranging from eco-friendly materials to logistics and consumer behavior—highlight the multidisciplinary nature of the field. While co-citation analysis uncovers the structural backbone of the knowledge domain, keyword co-occurrence analysis offers a complementary perspective by identifying current research hotspots and emerging trends. Therefore, in the following section, we examine keyword co-occurrence patterns to better understand the thematic focus and evolution of scholarly attention in this area.

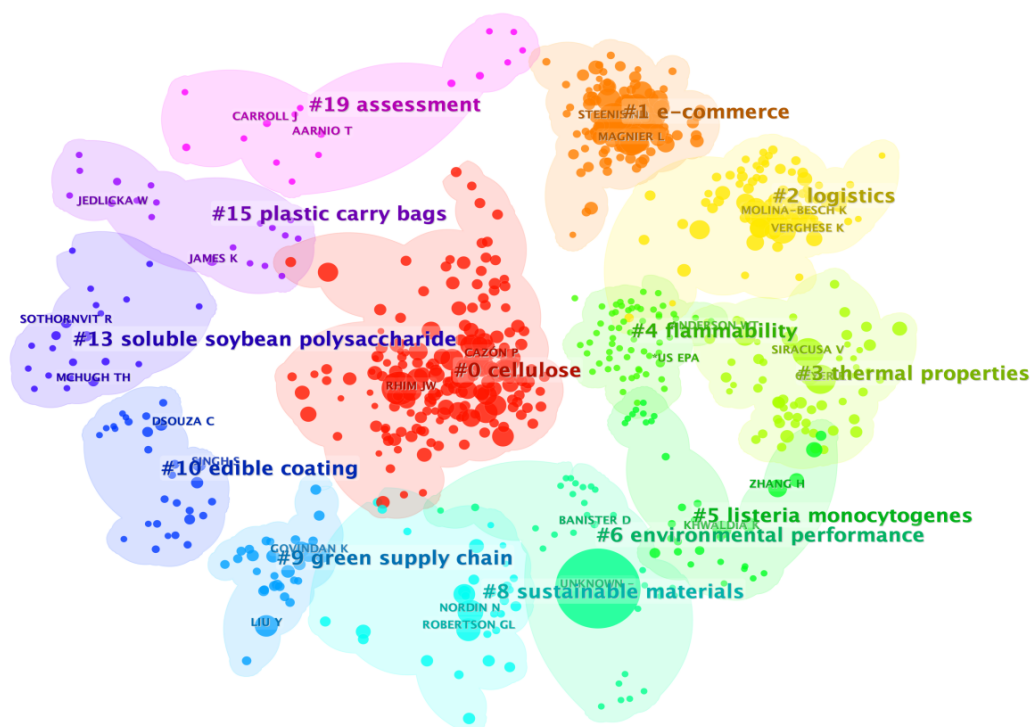


Figure 9. Author co-citation network.

4.4. Co-Occurrence Evolution

Co-occurrence analysis refers to the method of analyzing the co-occurrence relationships of words, authors, documents, or other elements within a specific context to reveal their associations and structure. The goal is to identify research hotspots, trends, and core relationships in a field by revealing patterns of co-occurrence, thus helping researchers understand the knowledge system of the field, discover potential collaborators, and explore emerging research directions^[26].

4.4.1. Keyword Co-Occurrence Analysis

We generated a keyword co-occurrence map (Figure 10) using CiteSpace. The map contains 521 nodes (N), 2880 links (E), and a network density of 0.0213. “Frequency” and “centrality” can be used to determine whether a keyword is a research hotspot. Specifically, “frequency” represents the number of studies on a topic, and “centrality” indicates the importance of the keyword. In other words, the higher the frequency and centrality of a keyword, the more it highlights the research hotspot in the field. After merging synonyms, we selected 30 keywords with high frequency and centrality, as shown in Table 8. We sort the keywords by frequency in descending order, the top 5 keywords are: sustainable

packaging, mechanical property, films, behavior, and green packaging. Their frequencies are 117, 116, 95, 81, and 61, respectively. Research related to these keywords has explored topics such as consumer attitudes, purchasing behavior, and the influencing factors regarding green packaging; the application of chitosan-based films in food packaging; the potential use of agricultural waste in green packaging; and the mechanical properties of bio-based biodegradable packaging materials^[104–108]. Additionally, it is worth noting that perceptions (co-occurring 36 times) and willingness to pay (co-occurring 32 times) are relatively less frequent, indicating that these keywords are closely related to green packaging and are potential future research hotspots.

From Table 8, we observe that high-frequency keywords do not necessarily have high centrality. For example, mechanical property has high frequency, but food has a higher centrality with lower frequency. This indicates that the relationship between frequency and centrality is not directly proportional. Generally, a centrality score of > 0.1 is considered the focus of research. We have sorted the co-occurring keywords by their centrality values, and the top 5 keywords are summarized in Table 9. These are: behavior, food, mechanical property, sustainable packaging, and edible films. Additionally, the keyword behavior has

the highest centrality (0.18), suggesting that consumer or business behavior is a research hotspot in green packaging. For example, at the consumer level, research has explored the influencing factors of consumer purchasing behavior regarding green packaging, including attitudes, subjective norms, perceived behavioral control, and environmental labels^[60,104,105]. At the business level, research has exam-

ined the different attitudes of medium and large companies toward adopting green packaging when implementing environmental management practices (EMPs) and environmental management systems (EMS)^[106]. These co-occurring keywords describe the research hotspots and areas in the field, providing scholars with key directions for academic research.

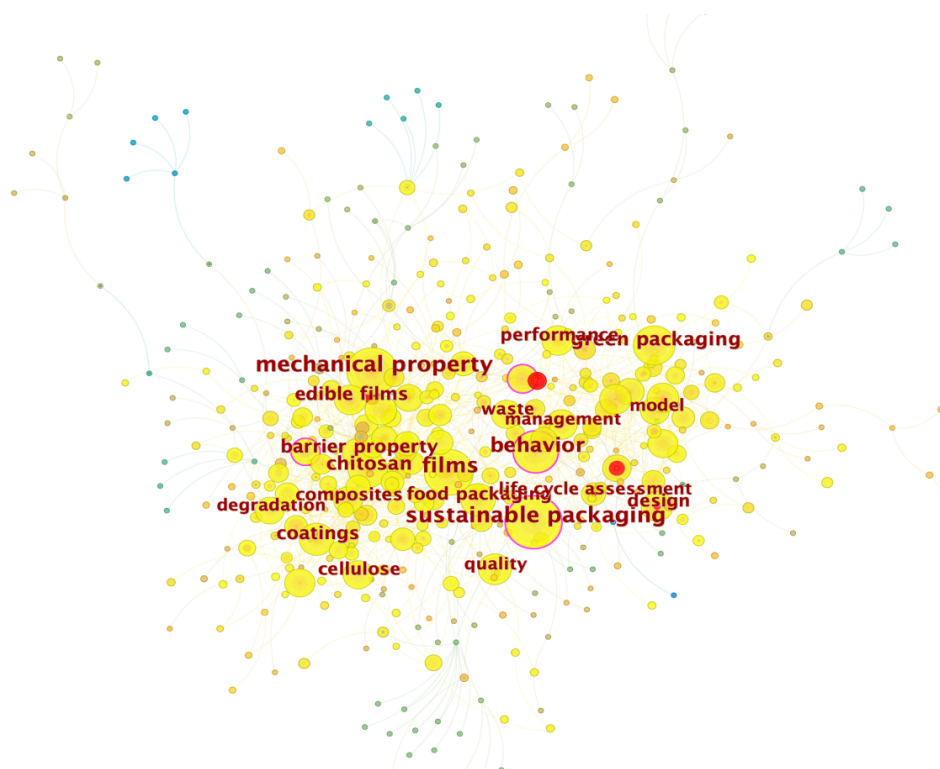


Figure 10. Keyword co-occurrence network.

Table 8. The high frequency keywords TOP30.

Frequency	Centrality	Keywords	Year
117	0.1	sustainable packaging	2006
116	0.11	mechanical property	2009
95	0.04	films	2009
81	0.18	behavior	1991
61	0.07	green packaging	2016
59	0.03	chitosan	2013
49	0.06	coatings	2009
48	0.07	barrier property	2009
47	0.1	edible films	2006
46	0.07	food packaging	2016
45	0.05	cellulose	2013
44	0.02	products	2016
43	0.04	design	2009
40	0.04	performance	2017
40	0.02	composites	2012
39	0.03	waste	2015
39	0.02	management	2009
38	0.09	life cycle assessment	2006
38	0.01	degradation	2017

Table 8. Cont.

Frequency	Centrality	Keywords	Year
36	0.12	food	2006
36	0.05	consumption	2016
36	0.02	perceptions	2019
35	0.01	antioxidant	2020
34	0.01	nanoparticles	2017
33	0.02	sustainability	2016
32	0.06	blends	2005
32	0.05	nanocomposites	2017
32	0.02	barrier	2013
32	0.02	willingness to pay	2006
31	0.04	acid	2013

Table 9. Keywords with centrality > 0.1.

Frequency	Centrality	Keywords	Year
81	0.18	behavior	1991
36	0.12	food	2006
116	0.11	mechanical property	2009
117	0.1	sustainable packaging	2006
47	0.1	edible films	2006

Figure 11 shows the keyword clustering map. The Q-cluster modularity value (Modularity) is 0.5197 (> 0.3), indicating a significant clustering structure. The S-cluster average silhouette value (Silhouette) is 0.814 (> 0.7), suggesting that the clustering results are significant. The clustering knowledge map effectively groups highly homogeneous keywords into the same clusters. A total of 10 clusters is displayed, with the topics divided into 3 main categories: (1) Some clusters focus on the development, application, and sustainability of materials, such as Active Packaging (#1), Mechanical Properties (#2), Alkali Treatment (#5), Fuzzy Techniques (#6), and Anatase (#7). Green packaging is beneficial to human health and environmental protection, so innovative packaging materials and their mechanical properties in different fields are widely discussed^[107–109]. These findings can guide regulatory bodies and industry stakeholders in setting performance standards and certification criteria for emerging biodegradable materials. (2) Some clusters emphasize food safety and bio-based materials, for example, *Listeria Monocytogenes* (#3), where an article discusses the antimicrobial properties of bio-based edible packaging materials in the food sector^[72], and Pork (#4), where an article evaluates the sustainability of biodegradable packaging materials compared to traditional packaging materials in storing fresh pork^[110]. Such research offers practical evidence for food safety authorities to support the adoption of antimicrobial and compostable packaging in perishable goods supply chains. (3) Some clusters focus on re-

search on green packaging governance from the perspectives of consumers, businesses, and governments. For example, Sustainability (#0) includes an article discussing how manufacturing companies reduce negative environmental impacts in the supply chain during packaging development^[111], and another article explores consumers' purchase intentions for bio-based packaging versus recyclable fossil-based plastic packaging^[112]. Success (#8) includes an article discussing the impact of green supply chain management on corporate social responsibility and corporate reputation^[43]. Another cluster, Solid Waste (#9), includes articles examining how recycling pricing can effectively promote household recycling behaviors from a government perspective^[113]. These clustering results provide valuable guidance for future research directions and practical applications of green packaging, especially in how technological innovations and policy support can further promote the widespread adoption and development of green packaging.

4.4.2. Research Hotspot Analysis

In keyword co-occurrence, each node (keyword) is displayed in different time zones based on the year of its first appearance. By analyzing the time zone map, we can observe which fields are gradually becoming the focus of attention and which keywords are gradually fading out, helping us understand the evolution process of academic research or industrial fields. **Figure 12** shows the keyword time zone map in the field of green packaging. The main hotspots are

distributed across four time zones: (1) In the late 1990s, research in this field focused on “behavior”, a topic that continues to appear frequently over time. This trend is closely related to the widespread adoption of green packaging. Consumer acceptance and awareness of eco-friendly products directly influence the market promotion of green packaging materials. (2) In 2006, “sustainable packaging” emerged as a core theme, and “edible films” also appeared in the same year. This indicates that research at this time not only explored the environmental performance of green packaging materials but also addressed their practical application in food safety. (3) Keywords such as “mechanical property”, “barrier property”, “coatings” and “films” became research hotspots in

2009, signaling that the focus of research at that time was more on the mechanical properties and barrier performance of packaging materials. Additionally, researchers began to pay more attention to the long-term environmental impact of green packaging and how innovative coating technologies could enhance packaging performance. (4) After 2013, there was increased focus on keywords like “chitosan” and “green packaging”, reflecting the ongoing research into bio-based packaging materials. This evolution signals actionable opportunities for governments and industries to accelerate the transition toward biodegradable packaging by integrating such materials into public procurement policies, food contact safety standards, and green certification systems.

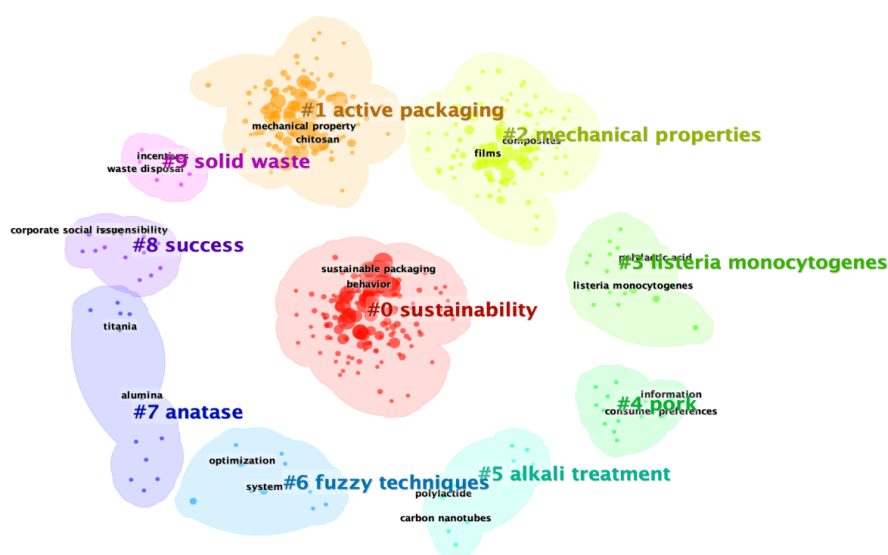


Figure 11. Keyword co-occurrence clusters.

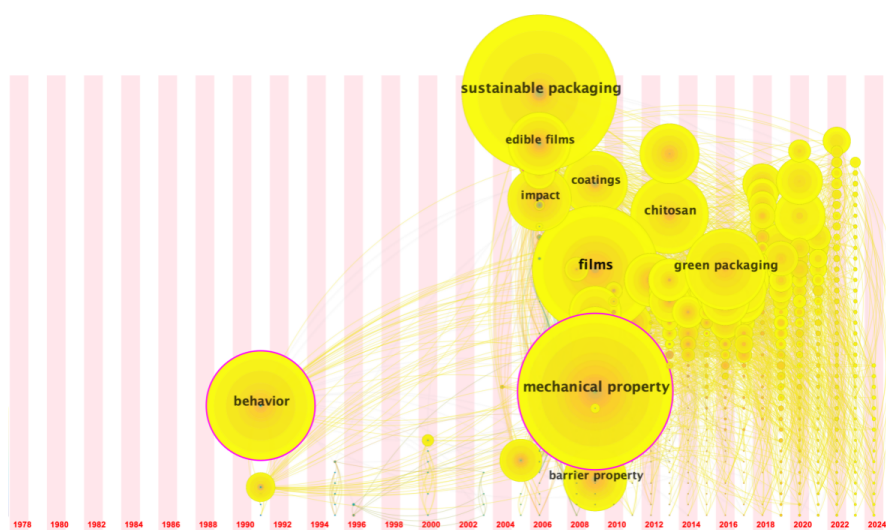


Figure 12. Keyword time zone.

In summary, the focus of green packaging research has gradually shifted from the fundamental properties of materials to their environmental benefits and the impact of consumer behavior. Future research is likely to further focus on the practical applications of green packaging and its influence on consumer choices. Meanwhile, with the continuous development of new technologies, innovations in coating technologies and sustainable materials may become important directions for future research. Therefore, researchers should pay attention to the dynamic changes in these topics to promote the further development of the green packaging field.

4.4.3. Keyword Burst Analysis

Figure 13 shows the top ten keyword bursts in the field of green packaging. Keyword burst refers to the rapid increase in the frequency or attention of a keyword within a specific time period, helping us grasp new trends in green packaging. Specifically, there are four key points worth noting: (1) The earliest keyword burst occurred with “life cycle assessment” in 2006, and it is also the longest-lasting keyword, continuing for 12 years. This indicates that life cycle assessment has had important continuity and stability in research on green packaging and sustainability. As an analytical tool, life cycle assessment helps researchers and companies evaluate the environmental impacts of products or services throughout their entire life cycle, from raw material collection to disposal. Its long-term presence and sustained burst reflect the academic and industrial community’s high

regard for comprehensive environmental impact assessments. (2) In 2013, two burst keywords appeared: “permeability” and “morphology”. The former lasted for 3 years, while the latter lasted for 7 years. This suggests that as green packaging research deepens, there is increasing attention on the functionality and structural properties of packaging materials. (3) The keyword with the highest burst strength is “design” (5.42), indicating its high level of attention. The future of green packaging depends not only on the material properties but also on finding a balance between functionality and environmental friendliness. The keyword with the lowest burst strength is “poly” (3.6), possibly due to a shift in research focus towards bio-based and biodegradable materials. (4) The most recent burst keywords are “thermal property” (2018), “willingness to pay” (2019), and “strategy” (2020), all of which lasted around 3 years. This trend suggests that future green packaging research will increasingly combine market and technological considerations, promoting the overall development of the packaging industry in terms of environmental, economic, and social benefits. These burst keywords highlight actionable entry points for public and private stakeholders. For example, the rising attention to “willingness to pay” can inform policymakers designing eco-incentive schemes or product labeling programs, while the emergence of “strategy” underscores the need for integrated corporate sustainability planning in packaging innovation. The convergence of technical and behavioral themes indicates that future interventions must be cross-sectoral, bridging material science, market dynamics, and policy support.

Top 10 Keywords with the Strongest Citation Bursts

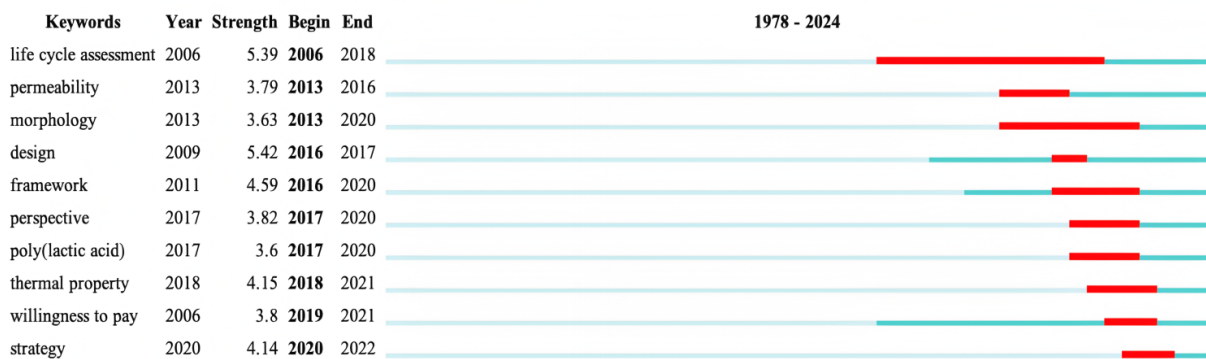


Figure 13. Top 10 keywords with strong citation bursts.

4.5. Knowledge Structure

Through the analysis of green packaging, it is clear that the development of this field is diverse and complex. With the increasing awareness of environmental protection and the promotion of sustainability, green packaging has gradually become an important research direction. As new technologies continue to develop, research on green packaging will deepen, and more innovative solutions may emerge in the future to reduce the negative impact of packaging materials on the environment, promoting more sustainable packaging designs and consumption patterns. Although some studies have reviewed specific topics within green packaging (e.g., 44, 45), they have not reflected interdisciplinary research

collaboration or formed a systematic knowledge framework. This has resulted in a fragmented understanding of the green packaging field, lacking a comprehensive perspective on the relationships between different research directions, limiting the emergence of new technologies and ideas, and failing to provide clear guidance and reference for future research. Therefore, establishing an interdisciplinary and systematic knowledge framework is essential.

Figure 14 presents a comprehensive theoretical framework for green packaging research, clearly showing the overall research connections, key stakeholders, and potential future research directions, offering valuable references for future studies in green packaging.

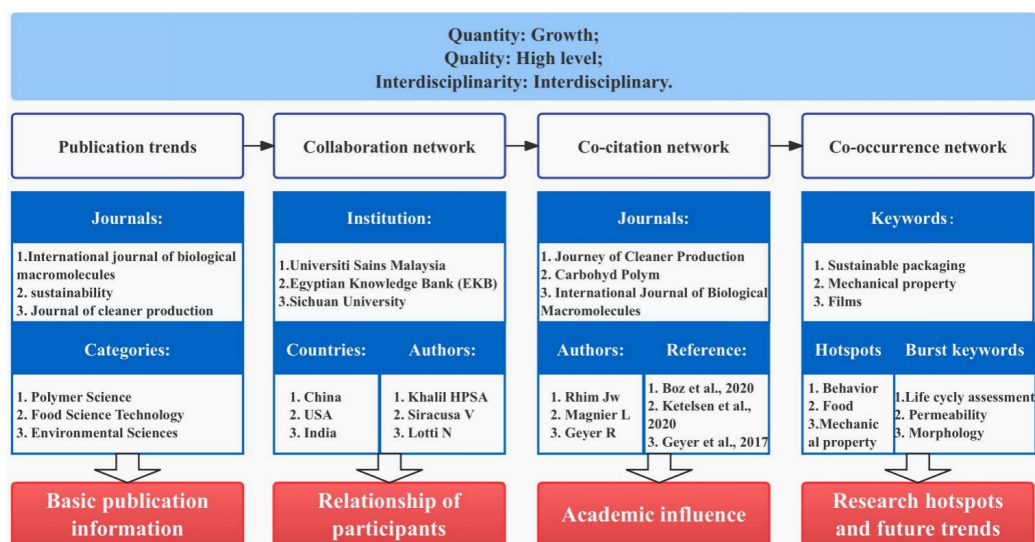


Figure 14. Knowledge framework.

(1) Publication analysis is the foundation of the entire analytical framework, providing insights into the development trends in the green packaging field and helping researchers understand which journals and academic platforms are leading in this area. From the trend of annual publication growth, the field is showing promising development prospects and is currently in an explosive phase, with frequent interactions across disciplines. The three journals with the highest publication volumes are Journal of Biological Macromolecules, Sustainability, and Journal of Cleaner Production.

(2) Cooperation analysis examines the collaboration between different countries, institutions, and authors, providing reference points for researchers in selecting collaborators,

platforms, and research areas. China, the United States, and Malaysia are the most influential regions in this field. Meanwhile, Universiti Sains Malaysia in Malaysia, Sichuan in China, and the Chinese Academy of Sciences are the most active cooperation platforms. Among the authors, Khalil HPSA, Siracusa V, Lotti N, and Soccio M are the most active collaborators with the greatest impact.

(3) Co-citation analysis delves into the core literature, influential journals, and scholars in this field from multiple dimensions, providing researchers with an in-depth knowledge map to understand mainstream academic ideas. The mainstream co-cited journals include Journal of Cleaner Production, Carbohydrate Polymers International, and Journal of Biological Macromolecules. Notable co-cited authors

include RHIM JW, MAGNIER L, and GEYER R. Boz Z, Ketelsen M, and Geyer R have written important articles published in Sustainability, Journal of Cleaner Production, and SCI ADV. These renowned articles focus on the innovative development and market application of packaging materials, especially in the food industry and the development of plastic material alternatives.

(4) Co-occurrence evolution is a deep analysis of research dynamics in the green packaging field, helping scholars understand academic hotspots and their evolution, capturing emerging topics and rapidly developing research trends, and providing strong guidance for future research. Popular themes include the development, market application, and sustainability of green packaging. It is worth noting that these themes are most favored in the food and logistics industries. Recent hot topics include the performance of biodegradable packaging materials, consumers' willingness to pay, and companies' strategic planning.

5. Conclusions and Prospects

5.1. Key Findings

This study analyzes the vast body of literature in the green packaging field using CiteSpace and VOSviewer analysis software, conducting bibliometric analysis of the research achievements and developments in this area. Firstly, we analyzed the publication trends, subject categories, and popular journals in the field. Overall, green packaging is a gradually developing field. Since 2018, research on green packaging has shown exponential growth, and the publications cover areas such as environment, food, and business, indicating the widespread recognition and rapid development of green packaging in various fields. Secondly, after analyzing the cooperation network, we found that China and Malaysia hold significant positions in the green packaging field, with Chinese institutions accounting for 40% of the top five cooperative institutions. However, global author cooperation is relatively weak, and more cross-disciplinary and cross-regional collaboration should be encouraged. Next, we analyzed the co-citation network, revealing that highly cited journals generally have greater influence, and most of these journals are interdisciplinary. The most cited references cover different topics, and co-cited authors, such as GEYER R, have numerous co-cited references. Lastly, through the

keyword co-occurrence network, we found that the main areas of current research in green packaging are mechanical properties, consumer behavior, supply chain management, technology of bio-based biodegradable packaging materials, and green packaging applications in the food sector. Life cycle assessment is a commonly used analysis method in the green packaging field. Future research may focus on consumer payment behavior, corporate strategy formulation, and the performance of innovative materials. Researchers can understand keyword meanings, grasp research directions, and create high-quality research outcomes by tracking the dynamic changes in these fields.

5.2. Implications

The results of this study provide several important implications for both researchers and practitioners in the green packaging field. First, the increasing volume of publications and expanding range of subject categories indicate that green packaging is not only a pressing environmental issue but also a growing interdisciplinary research area. The integration of environmental science, materials science, supply chain management, and consumer studies suggests that green packaging is no longer confined to technological innovation but now encompasses broader socio-economic and behavioral dimensions. Second, the identification of major contributing countries and institutions offers valuable insights into global research leadership and collaboration dynamics. The prominent role of China and Malaysia in institutional cooperation highlights the importance of emerging economies in driving sustainable packaging innovation. However, the generally weak global author collaboration suggests the need for more international and cross-disciplinary research networks to accelerate knowledge transfer and capacity building. Third, the dominance of keywords related to bio-based materials, consumer behavior, and life cycle assessment illustrates the field's shift from exploratory material development toward application-oriented and impact-driven research. This indicates a growing emphasis on not just developing sustainable packaging technologies, but also understanding their real-world adoption, lifecycle impacts, and interactions with market and consumer dynamics. Such findings can guide policy initiatives, such as implementing EPR schemes or consumer education campaigns, and support industry decisions on material investment based on emerging research trends.

5.3. Limitations and Future Work

Despite the rapid growth and diversification of green packaging research, several challenges continue to hinder its practical advancement. One of the key limitations lies in material innovation. While significant progress has been made in developing biodegradable and bio-based materials, improving their mechanical performance, durability, and cost-effectiveness while maintaining environmental compatibility remains a major technical obstacle. Many existing materials face trade-offs between sustainability and functionality, making them difficult to scale for commercial use. Moreover, the industrialization and commercialization of green packaging technologies are still in their early stages. Although academic research has produced promising results, large-scale adoption is constrained by high production costs, complex manufacturing processes, and low market readiness. As a result, traditional packaging solutions remain dominant in many industries, creating resistance to the transition. In addition, current recycling and reuse systems for green packaging are often underdeveloped or fragmented. Variability in recycling infrastructure, limited consumer participation, and inconsistent policy implementation across regions have weakened the effectiveness of green packaging initiatives. On a global level, the lack of harmonized policies, technical standards, and shared platforms further impedes international cooperation and knowledge exchange.

Furthermore, this study has some limitations related to the data sources and language scope. The bibliometric analysis was conducted using only the Web of Science Core Collection, which may have excluded relevant studies indexed in other databases or regions. Additionally, the analysis is limited to English-language publications, which may overlook research published in other languages that could provide valuable insights, particularly from non-English-speaking regions.

Therefore, future research should aim to address these issues through a combination of material science innovation, systems-level thinking, and interdisciplinary collaboration. Studies focusing on developing low-cost, high-performance, and scalable materials are essential. Likewise, greater attention should be paid to consumer behavior, corporate environmental strategy, and policy design, particularly in relation to incentives, subsidies, and education campaigns. Equally

important is the push toward global standardization and the establishment of collaborative mechanisms that can facilitate knowledge sharing, technology transfer, and coordinated action. Only by bridging the gap between research and real-world application can green packaging truly fulfill its potential in advancing sustainable development goals.

Author Contributions

Conceptualization, L.J. and B.H.; methodology, L.J., B.H., and N.B.; software, L.J.; formal analysis, L.J., B.H., and N.B.; resources, L.J.; data curation, L.J.; writing—original draft preparation, L.J.; writing—review and editing, L.J., and B.H.; visualization, L.J.; supervision, B.H.; project administration, L.J. and B.H. All authors have read and agreed to the published version of the manuscript.

Funding

This work received no external funding.

Institutional Review Board Statement

Not applicable.

Informed Consent Statement

Not applicable.

Data Availability Statement

The data used in this study were obtained from the Web of Science Core Collection. Access to this database requires a subscription and is subject to licensing restrictions. No new data were created or analyzed in this study that can be publicly shared.

Acknowledgments

Not applicable.

Conflicts of Interest

The authors declare no conflict of interest.

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