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Knowledge Mapping and Research Trends in Sustainable Supply Chains in the Petrochemical Industry: A Bibliometric Analysis

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Highlights

- This study provides the first comprehensive science mapping of sustainable supply chain research specifically within the petrochemical industry, based on an analysis of 906 Scopus-indexed documents published between 2000 and 2025.
- The field exhibits a clear transition from growth to maturity after 2019, revealing well-defined research trajectories and influential intellectual foundations.
- Network analyses identify the United States, China, and the United Kingdom as central knowledge hubs, while Iran, Malaysia, and Brazil emerge as increasingly active contributors to the global collaboration network.
- Three major thematic clusters are identified: sustainability and supply chain management, life-cycle environmental assessment, and emission- and energy-related sustainability.
- Trend-topic analysis highlights rapidly growing research frontiers, including circular economy models, hydrogen storage technologies, low-emission systems, and alternative energy integration.

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Abstract

This study aims to map the knowledge structure and elucidate research trends related to sustainable supply chains in the petrochemical industry. To this end, 906 documents indexed in the Scopus database from 2000 to 2025 were collected and subjected to bibliometric analysis using VOSviewer and Biblioshiny. The results indicate that scientific output in this field has grown significantly since 2010 and entered a stage of maturity after 2019. Collaboration network analysis highlights the prominent roles of the United States, the United Kingdom, and China in shaping the literature in this domain, alongside the gradually increasing contributions of countries such as Iran, Malaysia, and Brazil. Keyword co-occurrence analysis reveals several well-established thematic clusters and interdisciplinary linkages among engineering, management, and environmental research. By providing a comprehensive overview of the intellectual, conceptual, and social structures of the field, the findings of this study can serve as a foundation for guiding future research and supporting practical decision-making aimed at enhancing sustainability in petrochemical supply chains.

Keywords: Bibliometric analysis, Biblioshiny, Petrochemical industry, Sustainable supply chain, VOSviewer

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1. Introduction

In recent years, the intensification of climate-related crises, increasing social and regulatory pressures, and the imperative transition toward a low-carbon economy have underscored the need for a fundamental reassessment of industrial production and supply practices (Phole, 2025). In response, industries have been compelled to adopt strategies that preserve economic efficiency while simultaneously addressing environmental and social requirements (Moradi et al., 2024). Within this framework, increasing attention has been directed toward the organization of production activities and interfirm interactions, particularly in segments of the value chain associated with substantial environmental and social impacts (Cavallieri et al., 2025). Consequently, supplier relationship management and performance monitoring have assumed greater importance, with issues such as risk, resilience, environmental responsibility, and social integrity becoming increasingly prominent in interorganizational interactions (Moradi et al., 2021a). Decisions related to sourcing methods, transportation, inventory management, and supplier performance influence not only costs and operational efficiency but also energy consumption, pollutant emissions, and exposure to social risks. These developments have contributed to the emergence of sustainable supply chain management (SSCM), which emphasizes the alignment of economic objectives with environmental and social requirements across all stages of the supply chain (Moradi et al., 2021b). In this study, sustainability within the SSCM framework is defined according to three interrelated dimensions: economic, environmental, and social. This definition provides the conceptual basis for the subsequent bibliometric analysis by delineating the analytical scope within which sustainability-related themes and research streams are examined.

Given the importance of SSCM, certain industries require particularly strong integration of sustainability principles into their supply structures, with the petrochemical industry representing a prominent example (Tilsted et al., 2023). The sector's reliance on sensitive raw materials, the energy-intensive nature of its processes, the complexity of transporting hazardous substances, and the potential environmental impacts associated with production create heightened sustainability concerns. Accordingly, the integration of sustainability considerations into procurement processes, supplier management, and sustainable supplier selection constitutes a critical operational mechanism within SSCM (Aryanasl et al., 2017). Furthermore, stringent global regulations and increasing societal expectations regarding transparency and accountability have compelled petrochemical firms to manage supplier relationships with greater rigor (Anaba et al., 2024). Within this context, sustainable supplier selection has emerged as an important subdomain of SSCM. In high-risk industries such as petrochemicals, it functions not only as a source of competitive advantage but also as a core mechanism for risk mitigation and organizational continuity (Wu et al., 2021).

In this study, the petrochemical industry is operationally distinguished from the broader oil and gas sector and refers specifically to downstream activities involving chemical production and transformation processes. This distinction is important because the sustainability challenges, supply chain structures, and environmental requirements of the petrochemical sector differ substantially from those associated with upstream oil and gas operations. Despite the growing importance of this topic, existing studies have primarily focused on decision-making methods, evaluation criteria, and case-specific analyses, while providing limited insight into the overall knowledge structure of SSCM in the

petrochemical industry (Mirzaee and Ashtab, 2024). To date, relatively limited attention has been devoted to systematically examining the conceptual and intellectual structure of SSCM research with a specific focus on the downstream petrochemical industry, including its evolution, collaboration networks, dominant research streams, and emerging themes. The absence of such an analysis limits the systematic identification of future research directions, focal areas, and knowledge gaps, thereby constraining the ability of researchers and policymakers to make evidence-based decisions.

In response to this research gap, the present study employs a bibliometric approach to analyze 906 documents indexed in the Scopus database between 2000 and 2025, with the aim of providing a comprehensive and systematic overview of the state of knowledge on SSCM in the petrochemical industry. To this end, VOSviewer and Biblioshiny were used to examine three main dimensions of the knowledge system: the social structure, represented by scientific collaboration networks; the conceptual structure, represented by keyword co-occurrence patterns and thematic clusters; and the intellectual structure, represented by citation patterns and influential works. Based on this analytical framework, the present study makes the following key contributions:

- Maps the knowledge structure of SSCM in the petrochemical industry and analyzes macro-level publication trends from 2000 to 2025.
- Identifies established conceptual clusters and emerging themes through keyword co-occurrence analysis.
- Examines patterns of scientific collaboration among researchers, organizations, and countries and characterizes the social structure of research in this field.
- Assesses the foundational works and intellectual trajectories that have shaped this domain through citation analysis and the identification of influential documents and authors.
- Highlights research gaps and proposes future directions for the development of models, frameworks, and innovative approaches to sustainability in petrochemical supply chains.

These contributions provide an analytical foundation for research planning, industrial policymaking, and the formulation of sustainability strategies in petrochemical supply chains. The remainder of this paper is organized as follows. Section 2 identifies the research gaps; Section 3 presents the methodology; Section 4 reports the bibliometric results; Section 5 discusses the findings; and Section 6 concludes the study and presents recommendations for future research.

2. Domain analysis and research approaches

Existing studies in this field can be categorized into two main domains: first, studies focusing on the oil and gas industry as the primary subject area; and second, studies distinguished by their methodological approaches, particularly bibliometric analysis. Within the first domain, various studies have assessed the existing literature on sustainable supply chain management (SSCM).

2.1. Sustainable supply chain in the oil, gas, and petrochemical sectors

A substantial body of research on sustainable supply chain management (SSCM) in the oil, gas, and petrochemical industries has focused on identifying barriers, examining policy frameworks, and elucidating the role of emerging technologies. This body of literature generally conceptualizes energy industries as a unified domain and examines various dimensions of sustainability, ranging from environmental considerations and risk management to institutional factors, governance, and energy transition, within analytical frameworks and decision-making models. The primary focus of these studies has been on explaining the relationships among sustainability drivers, barriers, and outcomes.

However, a significant proportion of this research has treated the petrochemical sector as an extension of the oil and gas industry rather than as an independent knowledge domain. Consequently, a clear conceptual boundary between upstream oil and gas activities and the process-oriented supply chains of the petrochemical industry has not been adequately articulated. The existing literature therefore tends to present a generalized view of SSCM in energy industries rather than reflecting the distinctive knowledge structure of the petrochemical sector.

One stream of research has primarily focused on identifying internal barriers, operational risks, and managerial factors influencing supply chain sustainability. These studies have generally sought to prioritize key factors and develop decision-making frameworks. For example, Chofreh et al. (2025), by combining thematic analysis with the best–worst method, identified technological innovation and cleaner production as the principal sustainability priorities in oil industry logistics. Despite their conceptual value, these studies have largely focused on general supply chain structures within the oil and gas industries.

A second stream of the literature focuses on institutional factors, external pressures, green governance, and the role of top management in enhancing supply chain sustainability. These studies indicate that managerial commitment, green innovation, and a sustainable organizational culture play decisive roles in improving sustainable supply chain performance (Sharma et al., 2025; Krimi et al., 2025). In addition, the importance of stakeholder pressure and institutional stability in shaping sustainability strategies has been emphasized (George et al., 2016; Ahmad et al., 2017).

Another body of literature is devoted to assessing the environmental impacts of supply chains in the oil, gas, and petrochemical industries. These studies focus on reducing greenhouse gas emissions, managing pollution, and complying with regulatory requirements, demonstrating that environmental considerations play a critical role in shaping sustainable supply chain strategies (Bisogno et al., 2025; Odion et al., 2025; Ren et al., 2015).

In line with this approach, several studies employing optimization models and advanced analytical frameworks have examined the interactions among environmental regulations, technological innovation, and economic efficiency, emphasizing the feasibility of simultaneously improving sustainability and supply chain performance (Ford et al., 2014; Azadeh et al., 2015; Aghajani et al., 2025). Finally, another stream of research focuses on macro-level resilience, energy security, and green transition scenarios, demonstrating that the development of smart systems and clean energy sources can play a significant role in reducing long-term risks in energy supply chains (Yao et al., 2025; Banihabib and Assadi, 2023). Although modeling-based approaches, such as fuzzy multi-objective optimization, are methodologically rigorous and valuable for addressing decision-oriented sustainability problems, they do not provide a comprehensive view of knowledge evolution, thematic dynamics, or patterns of scholarly communication within the field. Overall, despite the growing volume of SSCM research in the oil and gas industries and the implicit inclusion of petrochemical-related studies, explicit and systematic attention to the knowledge structure and distinctive characteristics of petrochemical supply chains remains limited. This gap underscores the need for a focused, industry-specific bibliometric analysis, which is addressed in the following section.

Building on this categorization, a closer examination of the literature reveals clear methodological patterns. Quantitative approaches dominate the field, accounting for approximately 52% of studies, and primarily rely on mathematical optimization, multicriteria decision-making (MCDM) techniques, and simulation models. This prevalence reflects the technical and engineering-oriented nature of the petrochemical industry, in which decision problems are typically structured and model-driven. In contrast, qualitative studies, accounting for approximately 15% of the literature, mainly employ case

studies and interviews to explore organizational and institutional aspects, whereas mixed-method designs, representing nearly 10%, seek to combine analytical rigor with contextual depth.

This methodological distribution suggests that knowledge production in this field is largely driven by model-based and optimization-oriented research, reflecting the structured decision environment of the petrochemical industry. In contrast, empirically grounded and field-based investigations remain comparatively limited. This imbalance indicates that, although decision-support modeling is well developed, the contextual and organizational dimensions of sustainability have received comparatively less systematic attention.

2.2. Research gaps and limitations of previous studies

The review of the literature indicates that, despite the substantial growth of research on supply chain sustainability, significant gaps remain in the context of sustainable supply chain management (SSCM) in the petrochemical industry. First, reviews conducted in the oil and gas industries, while providing a general overview of sustainability in energy supply chains, have not systematically examined the petrochemical sector as an independent industry with distinct operational characteristics and risk profiles (Sahebi et al., 2024; Okeke, 2024). Therefore, directly generalizing their findings to the petrochemical sector is subject to important limitations. Second, existing reviews of SSCM, such as Özcan and İndap (2024), although addressing broader sustainability trends, lack an industry-specific focus and do not explicitly capture the unique challenges and drivers of petrochemical supply chains. Third, although several bibliometric studies have been conducted in the broader energy and oil and gas domains, an independent and industry-specific analysis of the knowledge structure of SSCM in the downstream petrochemical sector, encompassing its conceptual, intellectual, and scientific collaboration structures, has not yet been systematically undertaken. Consequently, the thematic evolution of the field, established research clusters, and emerging research streams have not been coherently mapped. Accordingly, by analyzing 906 Scopus-indexed documents published between 2000 and 2025 and applying advanced bibliometric methods with a specific focus on the petrochemical industry, the present study addresses these gaps and provides a complementary perspective to the broader reviews of the energy and oil and gas literature.

3. Methodology

The present study employs a bibliometric analysis approach to examine the knowledge structure, publication trends, and conceptual clusters related to SSCM in the petrochemical industry. Through the use of quantitative indicators, co-occurrence analysis, and network analysis, bibliometric methods enable the systematic assessment of scientific patterns, researcher collaboration networks, thematic orientations, and the evolutionary trajectory of a research field. Compared with traditional literature reviews, this approach offers greater objectivity, reproducibility, and comprehensiveness while reducing the potential for researcher bias. The study was conducted through a seven-step process, as illustrated in Figure 1.

Stage 1: Initial retrieval of articles

Keywords related to “sustainability,” “supply chain,” and the “oil, gas, and petrochemical industry” were used in the initial search. The search was conducted within article titles, abstracts, and keywords for the period from 2000 to November 2025, resulting in the retrieval of 1,377 articles (Table 1). To ensure comprehensive coverage, general oil- and gas-related keywords were initially included to capture petrochemical studies that employed broader industry terminology. Subsequently, content-based screening was conducted, and studies focusing exclusively on upstream activities, such as

extraction, drilling, and transportation, without a direct connection to downstream petrochemical processes and supply chains were excluded.

In the present study, the Scopus database was selected as the primary source for retrieving scientific documents because it provides extensive coverage of peer-reviewed journals in engineering, energy, environmental science, and management, consistent with the interdisciplinary nature of sustainable supply chain management (SSCM) in the petrochemical industry. Moreover, the standardized and integrated structure of bibliometric data in Scopus facilitates the application of network-based and co-occurrence analyses with greater accuracy and consistency.

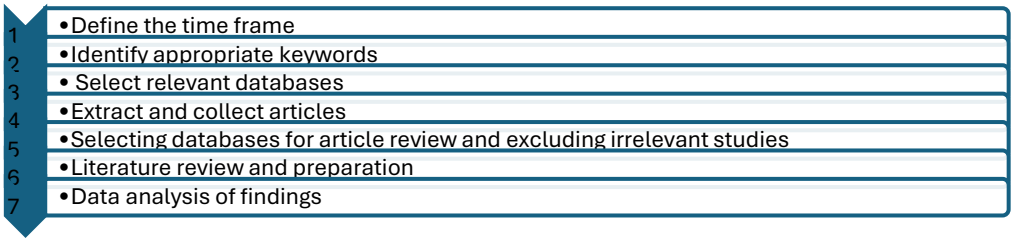

Figure 1

Steps of the systematic review process (Moradi and Meybodi, 2023)

Stage 2: Preliminary screening

The retrieved records were preliminarily screened according to the following criteria: publication between 2000 and 2025, publication in English, and classification as journal articles (Table 1).

Table 1

Summary of the search strategy in the Scopus database

Keyword	Field	Type of document	Language	Quantity
("sustainable" OR "sustainability" OR "environmental" OR "green") AND ("supply chain" OR "supply network") AND ("Oil and Gas" OR "petroleum" OR "petrochemical")	All	All	All	**100370**
	All	All	English	**98210**
	All	Article	English	**62212**
	Title, Abstract, Keyword	All	All	**1931**
	Title, Abstract, Keyword	All	English	**1863**
	Title, Abstract, Keyword	Article	English	**1377**

Stage 3: Content screening

At this stage, the documents were evaluated based on their direct relevance to supply chain sustainability in the oil, gas, and petrochemical industries. Articles addressing unrelated industries or focusing solely on general management and supply chain issues without a sustainability dimension or a clear industrial focus were excluded. In addition, studies focusing exclusively on upstream oil and gas activities, such as extraction and transportation, without relevance to downstream petrochemical processes were excluded. Ultimately, 906 documents were retained for the final bibliometric analysis (Table 2).

Table 2

Content screening

Quantity of article		
Data base	**2nd stage**	**3rd stage**
Scopus	1377	906

According to the bibliometric framework, the present study addresses four key research questions:

1. How has scientific output in the field of sustainable supply chain management (SSCM) within the petrochemical industry evolved over time, and what temporal patterns can be observed?
2. Which countries, institutions, journals, and researchers have played the most significant roles in advancing SSCM research in the petrochemical sector?
3. What conceptual structures and thematic clusters shape this research domain, and how are they organized?
4. What emerging topics and future-oriented research trajectories have appeared in recent years?

3.1. Data analysis

Bibliometric analyses were conducted using complementary analytical tools. VOSviewer was employed for network-based analyses, including bibliographic coupling of documents, journal co-citation analysis, and international collaboration mapping. In parallel, Biblioshiny, the R-based interface of the bibliometrix package, was used for descriptive, temporal, and evolutionary analyses, including publication and citation trends, identification of core journals based on Bradford's law, assessment of author productivity using Lotka's law, trend-topic analysis, and life-cycle evaluation using a logistic growth model.

4. Findings and discussion

The results of the bibliometric analysis are presented in five main sections: document analysis, country analysis, journal analysis, author analysis, and keyword analysis.

4.1. Publication trends and research lifecycle

Analysis of Scopus-indexed publications from 2000 to 2025 indicates sustained growth in research on sustainable supply chain management within the petrochemical industry. A total of 906 documents were identified, with an annual growth rate of 17.75%, reflecting the rapid expansion of this research domain. The average document age of 6.05 years and a mean of 32.03 citations per document suggest that the literature is both relatively recent and academically influential. Taken together, these patterns indicate a transition from an emerging research topic toward a more mature and consolidated scholarly field.

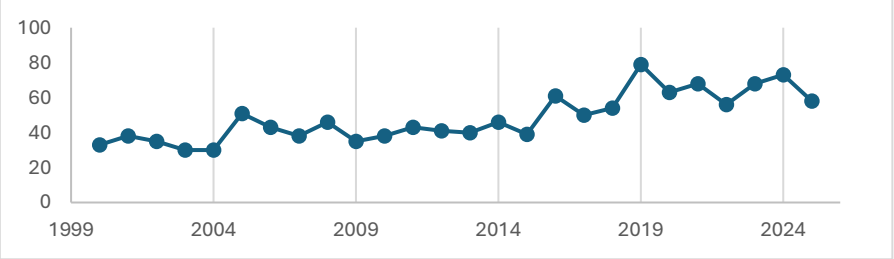

Figure 2

Publication trends in sustainable supply chain management within the petrochemical industry

Figure 2 illustrates the publication growth trajectory in this field, showing a gradual acceleration after 2010 and a clear transition toward scientific maturity after 2019. This maturation can be interpreted in parallel with the increasing global emphasis on sustainability and the institutionalization of policy frameworks and reporting standards related to climate change. Growing institutional and regulatory pressures on energy-intensive industries, including the petrochemical sector, have contributed to a shift in research from predominantly descriptive approaches toward more in-depth and industry-specific analyses. In addition, the distribution of publications across 26 Scopus subject areas highlights the inherently interdisciplinary nature of this research stream, positioning sustainable supply chain management in the petrochemical industry at the intersection of engineering, management, and environmental disciplines. In this context, Table 3 presents the most highly cited documents in the field. Seminal studies, such as Alvarez et al. (2018), with 756 citations, and Yue et al. (2014), with 647 citations, have played a pivotal role in shaping the theoretical and empirical foundations of subsequent research.

Table 3

Most cited documents in the field based on global citations and impact indicators

Reference	Total citations	TC per year	Normalized TC
(Alvarez et al., 2018)	756	94.5	16.7718711
(Yue et al., 2014)	647	53.9166667	7.18888889
(Zhu et al., 2008)	526	29.2222222	6.11627907
(Matos and Hall, 2007)	516	27.1578947	4.58327165
(Martínez-Jurado and Moyano-Fuentes, 2014)	482	40.1666667	5.35555556
(Silvestre, 2015)	420	38.1818182	5.6899147
(Zhu et al., 2007)	417	21.9473684	3.70392302
(Matassa et al., 2016)	313	31.3	6.06085754
(Economides and Wood, 2009)	297	17.4705882	7.87959184
(Shukla and Karki, 2016)	277	27.7	5.3637621

To gain deeper insight into the intellectual structure of the field, bibliographic coupling analysis was conducted using VOSviewer. In this analysis, documents were selected as the unit of analysis to map the scientific network with a high level of precision. According to the classical definition of bibliographic coupling, a link is established between two documents when they share one or more references, and the strength of the link increases with the number of shared references. By applying a minimum threshold of one citation for inclusion, 803 of the initial 906 documents met the eligibility criterion, providing a sufficiently large dataset for network-based bibliometric analysis.

In the map shown in Figure 3, each node represents a research article. Node size reflects the article's citation impact, whereas node color indicates the thematic cluster formed based on shared references. This network facilitates the identification of the core research structure and foundational studies within the field. Table 4 presents the 12 leading documents ranked by total link strength.

Citation analysis (Table 3) identifies the documents with the greatest cumulative scholarly impact, whereas bibliographic coupling analysis (Table 4) captures the structural connectedness of documents within the current knowledge core. Consequently, a high total link strength does not necessarily correspond to a high citation count; rather, it reflects the role of particular documents in shaping active research streams and emerging research fronts.

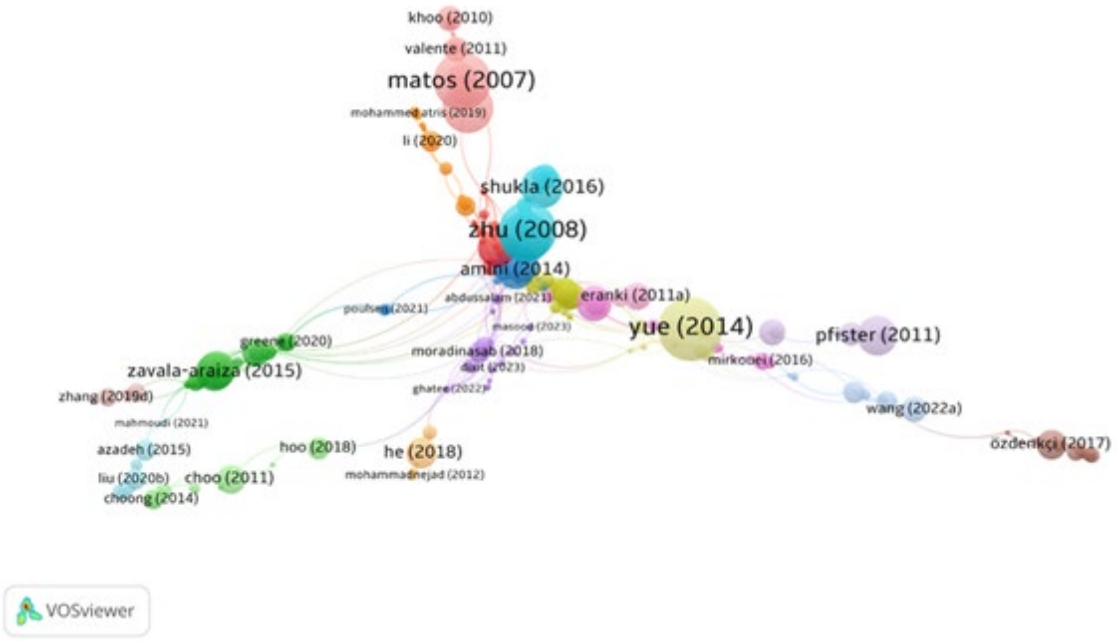

Figure 3

The bibliographic coupling network map of documents

Table 4

The top 12 documents based on total link strength

Document	Citations	Total link strength	Document	Citations	Total link strength
(Abdussalam et al., 2021)	22	8	(Crow et al., 2019)	47	6
(Gardas et al., 2019)	93	7	(Abdussalam et al., 2023)	5	6
(Ahmad et al., 2016)	50	7	(Al Haderia & Siamb, 2019)	1	6
(Sun et al., 2023)	11	7	(B. Chen et al., 2023)	14	6
(Zhu et al., 2008)	526	6	(Narimissa et al., 2020)	48	6
(Singh et al., 2023)	81	6	(Afghah et al., 2023)	19	5

4.2. Analysis of core publication sources

The analysis of publication sources facilitates the identification of influential journals and dominant knowledge production streams, thereby providing insights into the maturity, concentration, and conceptual orientation of a scientific field. The results indicate that, from 2000 to November 2025, a total of 445 academic journals contributed to the publication of 903 documents related to sustainable supply chain management in the petrochemical industry, underscoring the interdisciplinary nature of this research domain. Among these outlets, the 10 most productive journals are reported in Table 5. Journals such as *Journal of Cleaner Production*, *Sustainability*, *Energy*, *Applied Energy*, and *Science of the Total Environment* have played central roles in shaping the literature in this field. The concentration of publications in these journals indicates that knowledge production is largely situated at the intersection of energy systems, environmental science, engineering, and sustainable development.

Table 5

Leading journals based on the number of published articles on petrochemical supply chain sustainability

Sources	Articles	Percent of 906
Journal of Cleaner Production	65	7.20620843
Sustainability (Switzerland)	29	3.21507761
Energy	24	2.66075388
Applied Energy	23	2.54988914
Science of the Total Environment	20	2.2172949
Environmental Science and Technology	18	1.99556541
Energies	15	1.66297118
Journal of Environmental Management	14	1.55210643
Energy Policy	13	1.44124169
International Journal of Hydrogen Energy	13	1.44124169

To further examine the temporal dynamics of the core journals, the publication trends of the top five sources are illustrated in Figure 6. The results show a marked increase in publication volume after 2014, with the *Journal of Cleaner Production* exhibiting the most pronounced growth. This trend underscores the journal's central role in advancing research on sustainability, green management, and assessment models within energy-intensive and petrochemical industries.

Another journal-level analytical approach is co-citation analysis, which reveals shared referencing patterns and the citation network structure of the field. Based on the applied citation threshold, the resulting network shown in Figure 7 consists of several distinct clusters, each representing a dominant scholarly orientation within the SSCM literature on the petrochemical industry. Interpretation of the journal co-citation network suggests that these clusters do not necessarily represent rigid thematic boundaries; rather, they reflect scholarly orientations derived from co-referencing patterns. For example, clusters that include journals such as *Energy Policy* are primarily associated with policy-oriented and strategic studies, whereas clusters dominated by journals such as the *Journal of Cleaner Production* emphasize managerial, operational, and methodological approaches to sustainability and supply chain optimization. Other clusters capture linkages between techno-environmental assessments and system-level analyses, further highlighting the interdisciplinary structure of the field.

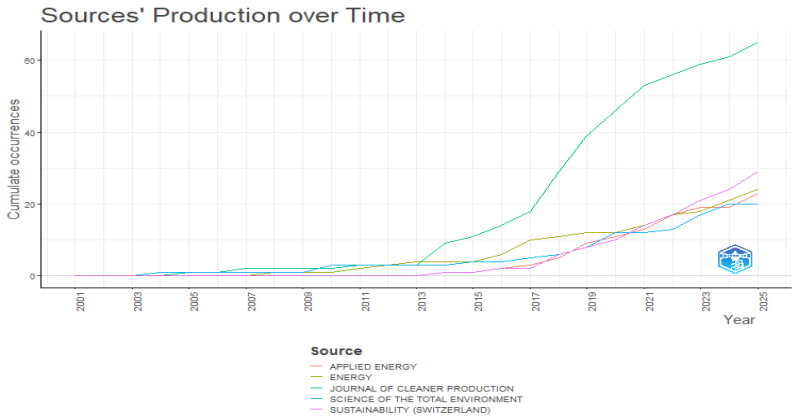

Figure 6

Annual publication trends of the top five journals in the field of petrochemical supply chain sustainability

To evaluate the degree of concentration or dispersion of research across journals, Bradford's law was applied. The results, illustrated in Figure 8, indicate a strong concentration of publications within the

core zone. Journals such as *Journal of Cleaner Production*, *Sustainability*, *Energy*, *Applied Energy*, and other highly productive outlets account for the largest share of publications in this zone. This concentration reflects the emergence of a cohesive and consolidated body of knowledge within a relatively limited set of key journals that play a central role in shaping the research trajectory of the field.

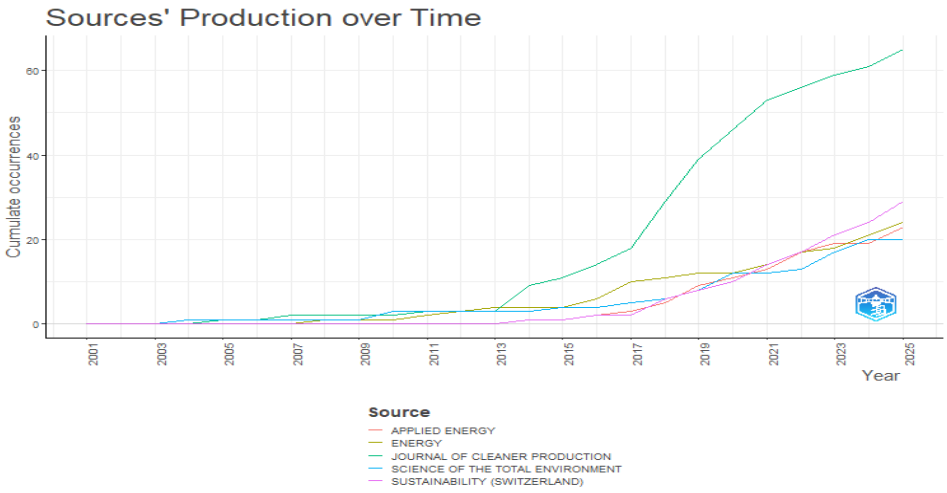

Figure 7

Co-citation network of journals related to petrochemical supply chain sustainability

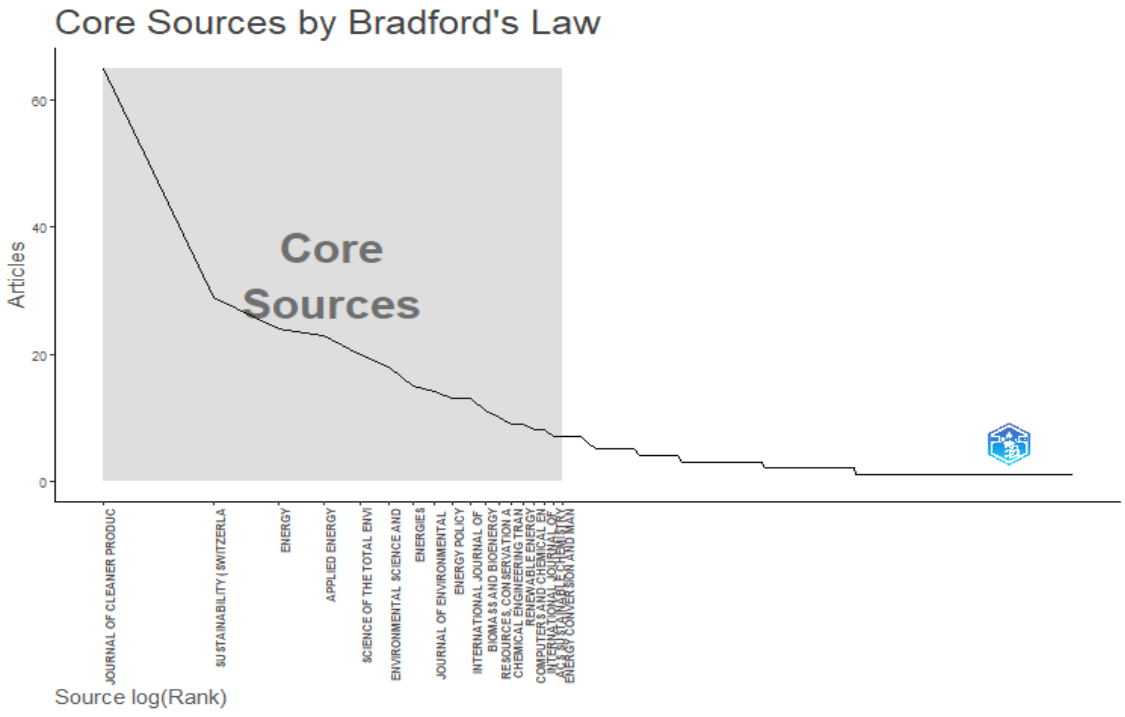

Figure 8

Classification of journals based on Bradford's law: core, middle, and peripheral zones

4.3. Comprehensive author analysis

Author analysis constitutes a core component of bibliometric research, enabling the identification of intellectual leaders and the assessment of the maturity and network structure of a scientific field. The

results indicate that, over the period from 2000 to 2025, a total of 3,165 researchers contributed to the production of 903 documents related to sustainable supply chain management in the petrochemical industry, highlighting the interdisciplinary and network-oriented nature of this research domain. Among all contributors, only 90 authors, representing less than 3%, published single-authored papers, indicating the predominance of collaborative research. The average number of authors per article was 4.32, and approximately 30.45% of the documents involved international scientific collaboration. This level of cross-border interaction underscores the importance of knowledge sharing, the development of research networks, and the field's strong reliance on extensive global collaboration.

Table 6

Leading authors based on the number of publications and fractionalized contribution

Authors	Articles	Articles fractionalized	Authors	Articles	Articles fractionalized
(Y. Wang et al., 2023)	13	3.19258976	(Lu et al., 2023)	10	2.59444444
(Y. Chen et al., 2017)	12	2.02071988	(Liu et al., 2025)	9	1.63571429
(C. Wang and Mu, 2014)	11	1.19157509	(Y. Wang et al., 2025)	9	2.12424242
(W. Zhang et al., 2024)	11	1.96233766	(X. Zhang and Yousaf, 2020)	9	1.70757576
(Li et al., 2024)	10	2.11111111	(B. Chen et al., 2023)	8	2.13333333

Table 6 presents the 10 most prolific authors based on both publication count and the fractional counting index. The results indicate that Wang et al. (2023), with 13 publications, is the most productive contributor in the field, followed by Chen et al. (2017) and C. Wang and Mu (2014), with 12 and 11 publications, respectively. The fractional counting index confirms this pattern, demonstrating that, even after adjusting for the effects of multi-authorship, the central role of this relatively small group of scholars remains evident. These findings suggest that a substantial portion of the literature is driven by a limited but highly active core of researchers who have played a critical role in shaping theoretical streams and advancing research in the field.

An examination of the temporal patterns of author activity further reveals that most publications by leading scholars were produced between 2021 and 2025. This period coincides with the field's overall annual growth rate of 17.75%, indicating a phase of accelerated expansion and increasing scientific maturity. In this context, the growing productivity of prominent authors has contributed substantially to strengthening and extending the scholarly trajectory of the field.

To examine author productivity patterns more precisely, the distribution of published documents was analyzed using Lotka's law. For this purpose, both the empirical distribution of author productivity presented in Table 7 and the comparative Lotka plot shown in Figure 10 were used. Combining these numerical and graphical representations enables a clear comparison between the observed distribution of author productivity and the theoretical pattern predicted by Lotka's law.

According to the results presented in Table 7, a total of 2,757 authors have published only one document, accounting for approximately 87.1% of the entire research community. In addition, 263 authors have published two documents, while authors with more than five publications account for less than 1% of the total. This pattern is broadly consistent with the theoretical distribution predicted by Lotka's law, indicating that scientific output in this field is generated predominantly by a large group of low-productivity authors and a relatively small group of highly prolific contributors.

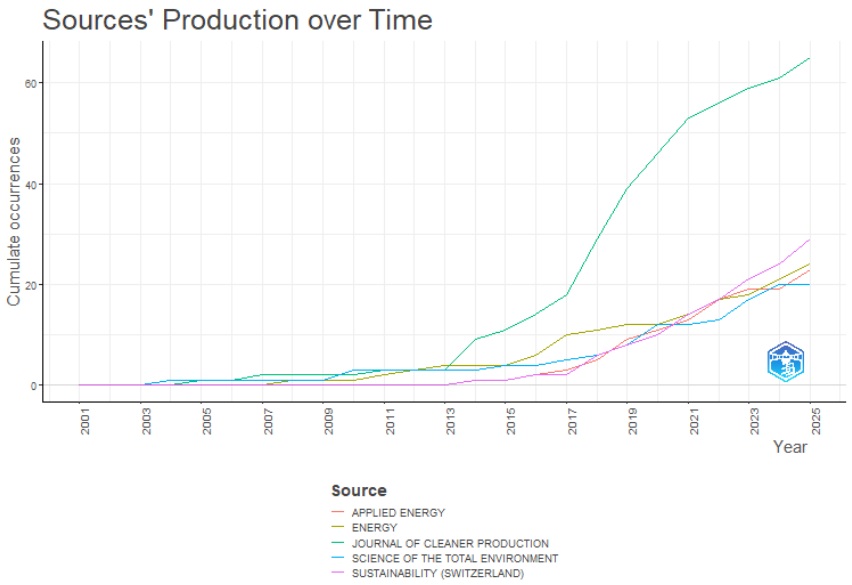

Figure 9

The temporal trend of author productivity

Table 7

Distribution of author productivity according to Lotka's law

Documents written	Number of authors	Proportion of authors	Theoretical
1	2757	0.87109005	0.63658027
2	263	0.08309637	0.15914507
3	66	0.02085308	0.07073114
4	41	0.01295419	0.03978627
5	18	0.0056872	0.02546321
6	6	0.00189573	0.01768279
7	3	0.00094787	0.01299143
8	2	0.00063191	0.00994657
9	3	0.00094787	0.00785902
10	2	0.00063191	0.0063658
11	2	0.00063191	0.00526099
12	1	0.00031596	0.0044207
13	1	0.00031596	0.00376675

Figure 10 illustrates this pattern visually. As shown, the steep decline in the number of authors as the number of publications increases reflects the predominance of less prolific and newly contributing researchers within the field. The relatively small difference between the empirical distribution and the theoretical Lotka curve indicates that the structure of scientific productivity in this domain is broadly consistent with classical productivity models and suggests that the field remains in a developmental stage.

4.4. Country analysis

The bibliometric data reveal that research participation in sustainable supply chain management within the petrochemical industry is extensive and geographically diverse. A total of 87 countries have contributed to scientific output in this area, reflecting substantial international participation and the

involvement of diverse research systems. The spatial distribution of publications, presented in Figure 11, provides a comprehensive overview of the global landscape of research activity in this domain.

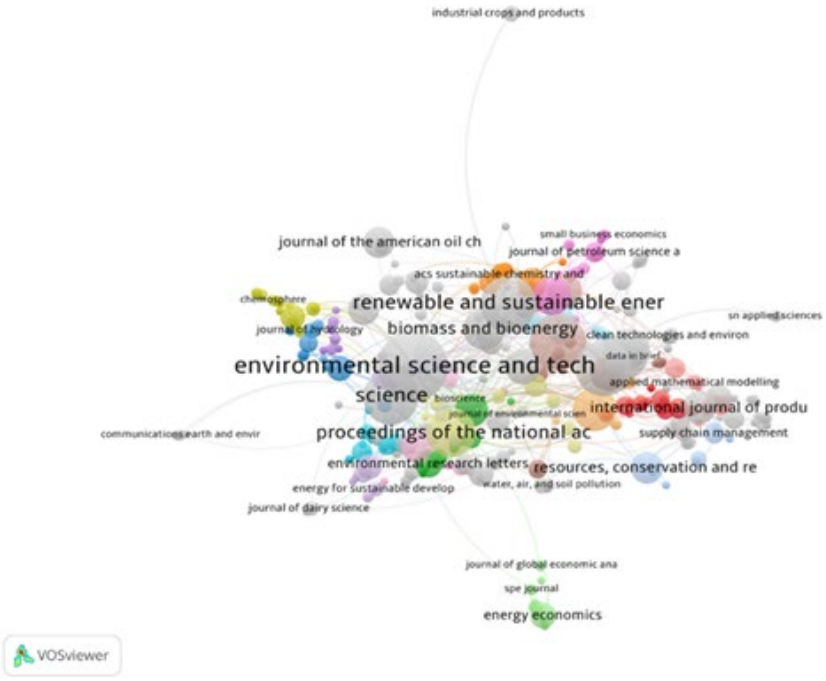

Figure 10

Comparative plot of Lotka's law

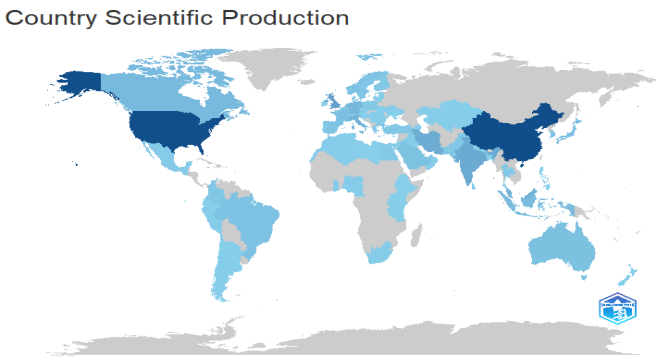

Figure 11

Global distribution of scientific output

The results for the leading countries based on quantitative and qualitative research indicators are presented in Table 8. According to the extracted data, the United States exhibits the greatest scientific impact in this domain, with a total of 6,173 citations and an average of 53.7 citations per article, ranking first in terms of scholarly influence. China follows with 5,197 citations, accounting for a substantial share of the overall scientific output. Notably, certain countries, such as Canada, demonstrate strong citation performance despite having a comparatively smaller number of publications. Specifically, Canadian articles have an average citation rate of 68.1 citations per article, exceeding that of all countries with higher publication volumes. This finding indicates that the relationship between publication volume and scientific impact is not necessarily linear and that, in some cases, research impact may outweigh publication quantity. In addition, European countries such as the United

Kingdom, France, Italy, and Sweden, although positioned within the medium-output tier, maintain notable levels of scientific influence.

Table 8

Leading countries by number of publications and citations

Region	Frequency	Country	Total citations	Average article citations
China	390	Usa	6173	53.7
USA	388	China	5197	36.3
Uk	133	Canada	1976	68.1
India	105	United Kingdom	1346	27.5
Iran	95	Italy	846	27.3
Italy	81	Netherlands	814	50.9
Malaysia	80	Iran	758	16.5
Germany	65	Malaysia	669	22.3
Canada	57	Switzerland	615	87.9
Netherlands	54	India	601	17.7
Indonesia	51	Korea	565	51.4
Japan	44	Germany	544	34.0
France	41	United Arab Emirates	543	67.9
Australia	39	Belgium	476	119
Norway	38	Spain	431	39.2
Saudi Arabia	35	France	378	37.8
Brazil	34	Japan	375	25.0
South Korea	32	Norway	367	28.2
Spain	28	Greece	297	24.8
Sweden	26	Australia	296	21.1

The temporal analysis of scientific output across countries indicates that several nations have maintained a consistent and steadily increasing presence in this field since the early 2000s. The United States, China, and the United Kingdom have emerged as leading contributors, demonstrating sustained and dynamic growth in scholarly output. In recent years, the contribution of developing countries, particularly those in Asia, has also increased noticeably. This trend reflects the growing global emphasis on sustainability in petrochemical supply chains and highlights the increasing participation of a broader range of countries in scientific research and scholarly discourse within this domain.

To examine scientific interactions among countries, an international collaboration network was constructed based on co-authorship patterns. As illustrated in Figure 6, the network includes countries that have published more than 30 articles in the field. In the map, node size represents publication volume, whereas the thickness of the connecting lines reflects the intensity of scientific collaboration. The results indicate that the United States, China, Canada, the United Kingdom, and Germany serve as the principal hubs of international research collaboration in this domain. The network structure further suggests that international partnerships are predominantly organized into regional and technology-oriented clusters, with several countries acting as important bridges connecting different groups within the global collaboration network.

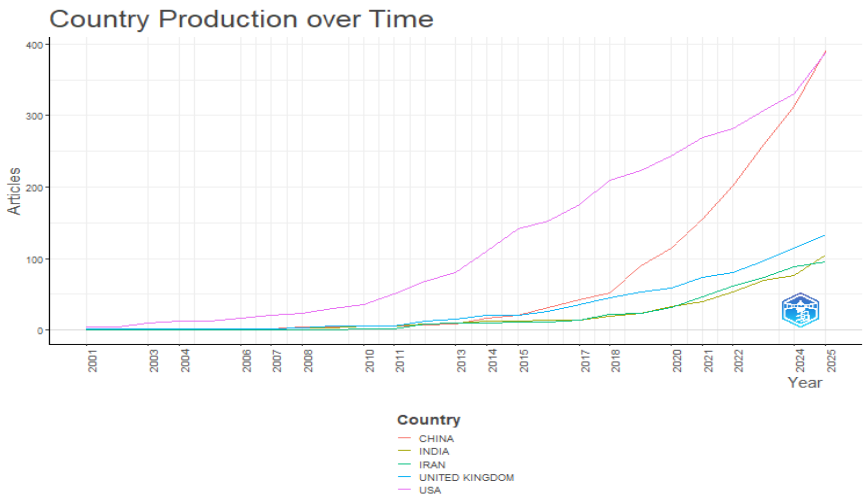

Figure 12

Annual scientific output by country

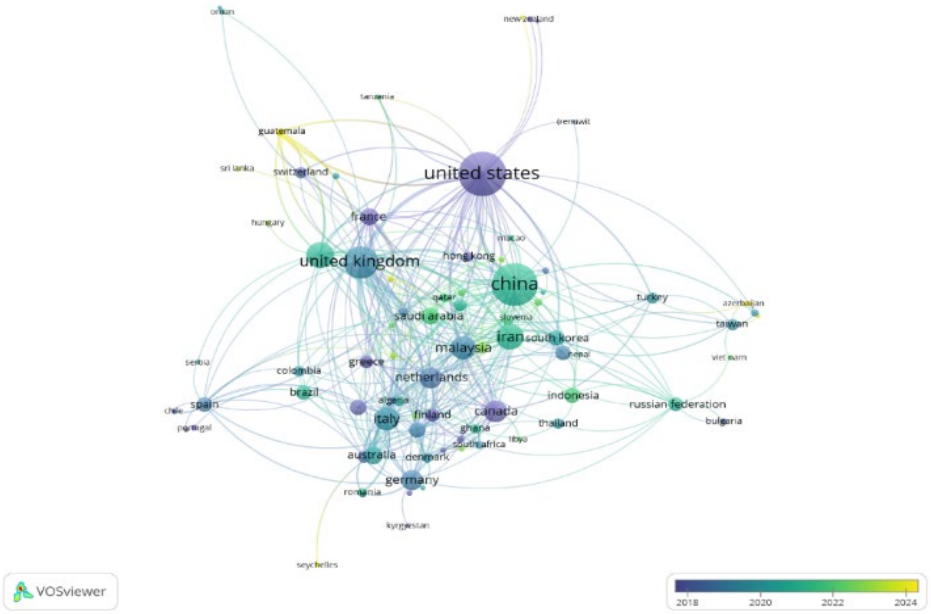

Figure 13

Interaction and contribution of countries to knowledge production on sustainable suppliers in the petrochemical industry

The strength of scientific linkages and the intensity of collaboration among the five leading countries are reported in Table 9. The results indicate that countries with a larger share of scientific output generally exhibit more extensive collaboration networks. Among these countries, the United States, China, and Japan demonstrate the highest levels of international collaboration, while countries in the Asia–Pacific region, including Australia and New Zealand, also play active roles within the network. This pattern suggests that knowledge production and exchange in the field of sustainable supply chain management are largely driven by a relatively small group of influential countries in North America and East Asia.

In this context, despite Iran's relatively strong position in terms of scientific output (Table 8), its international collaboration pattern within the co-authorship network (Table 9) appears more

concentrated. Specifically, Iran's collaborative ties are primarily established with a limited number of countries, most notably Japan. This finding suggests that Iran's scientific participation in this field is characterized predominantly by targeted bilateral collaborations rather than broad integration into the major multicenter collaboration clusters led by countries such as the United States and China.

Table 9

Strength of international collaboration links

From	To	Frequency
Usa	New Zealand	171.4849
China	Japan	138.0309
Indonesia	Japan	138.0309
Iran	Japan	138.0309
United Kingdom	Japan	138.0309
Canada	Australia	134.4910

4.5. Conceptual analysis and thematic structure based on frequent keywords and terms

To gain a deeper understanding of the knowledge foundations and thematic trends within this research domain, keyword analysis was conducted in two parts: established themes and emerging themes. This approach enables the identification of concepts that have shaped the core structure of the field while also highlighting emerging intellectual streams that may influence future research trajectories.

4.5.1. Established themes and conceptual structure

The conceptual analysis of the literature began with an examination of keyword data, with an initial focus on the frequency of recurring terms. The results of this analysis, presented visually as a word cloud in Figure 14, show that terms such as sustainability (507 occurrences), supply chain (462), oil industry (457), and petroleum industry (357) are among the most frequently occurring keywords. This pattern underscores the dominant emphasis of the literature on sustainability, supply chain management, and the oil and petrochemical sectors. These frequency patterns indicate that, over the past two decades, scholarly discourse has largely converged on the intersection of sustainability principles, environmental requirements, and supply chain processes within the petrochemical industry. In addition, keywords such as carbon emissions, green procurement, environmental risk, energy efficiency, and supplier selection appear prominently, indicating substantial research attention to environmental risk management, energy performance, and the role of suppliers within the broader framework of sustainable supply chain management.

To construct a more detailed representation of the conceptual structure, a keyword co-occurrence analysis was performed. The results indicate that the literature is organized into three major clusters:

Cluster 1: Sustainability, supply chain, and the oil industry. This cluster includes sustainability, supply chain, oil industry, petroleum industry, and supplier selection. It reflects the dominant orientation of the literature toward integrating sustainability principles with supply chain management and oil-system operations. The high PageRank scores of sustainability and supply chain confirm their central positions within the conceptual network. The inclusion of supplier selection in this cluster indicates that a portion of the literature on sustainable supply chains in the petrochemical industry has addressed supplier evaluation and selection. However, its node size and link strength remain smaller than those of the core terms. This pattern suggests that supplier selection functions as a complementary or subsidiary theme within the broader literature.

Figure 14

Word cloud

Cluster 2: Life-cycle assessment and environmental analysis. This cluster comprises life cycle, carbon dioxide, carbon emissions, carbon footprint, and global warming. It represents research focused on assessing environmental impacts, conducting life-cycle evaluations, and examining climate change-related issues.

Cluster 3: Greenhouse gases, bioenergy, and economic analysis. This cluster includes greenhouse gases, biomass, biofuels, biodiesel, feedstocks, cost–benefit analysis, and economic analysis. This segment of the literature focuses on the environmental and economic implications of emissions, as well as the role of alternative energy technologies and resource inputs.

Overall, the structure of the keyword co-occurrence network shown in Figure 15 indicates that the literature on sustainable supply chains in the petrochemical industry is not fragmented but is instead organized around three coherent conceptual dimensions. On the one hand, studies focus on managerial aspects and the integration of sustainability into supply chain management (Cluster 1). On the other hand, they employ life-cycle-based analytical frameworks to assess environmental impacts (Cluster 2), while also addressing challenges related to emissions, energy, and economic considerations (Cluster 3). This structure clearly reflects both the internal coherence of the clusters and their functional differentiation within the conceptual network of the field.

4.5.2. Emerging themes and new research frontiers

To examine emerging research streams in sustainable supply chain management within the petrochemical industry, the Trend Topics function in Biblioshiny was employed. This tool analyzes the temporal distribution of keywords and calculates the third-quartile year (Q3), thereby enabling the tracking of recent conceptual developments in the literature. The Q3 indicator represents the year by which 75% of publications associated with a given keyword have appeared. Accordingly, keywords with higher Q3 values are more strongly concentrated in recent years and can therefore be interpreted as emerging or expanding topics. Within this framework, the fourth research question (Q4) is addressed by identifying keywords whose publication activity is concentrated in recent years and that exhibit higher Q3 values.

The results indicate that, between 2023 and 2025, a group of concepts related to alternative energy, emission reduction, recycling, and the circular economy gained substantial prominence in the literature. Terms such as petroleum tar, mineral oils, low emission, hydrogen storage, circular economy, and alternative energy, all with Q3 values of 2025, have recently emerged as developing focal points in petrochemical research. The increasing prevalence of these terms suggests that contemporary studies

have progressively moved beyond traditional approaches toward issues associated with the energy transition, low-emission technologies, and the design of material recirculation systems.

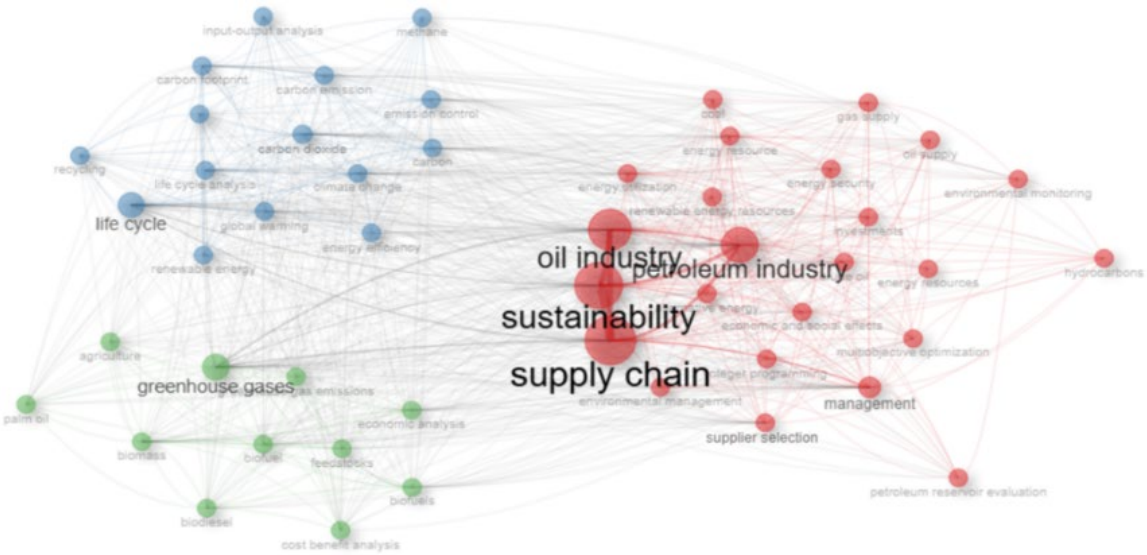

Figure 15

All keywords in a co-occurrence network map

In addition, keywords such as resilience, greenhouse gas emissions, uncertainty, and carbon emissions, with Q3 values concentrated in 2023 and 2024, highlight a range of interdisciplinary research topics. These include supply chain resilience, uncertainty management in industrial decision-making, and more detailed analyses of pollutant behavior within petrochemical supply chains. Such terms are primarily associated with studies seeking to model supply chains in a more dynamic and realistic manner or to assess complex environmental scenarios.

Conversely, terms such as biofuels, policy, refining, hydrocarbons, and environmental monitoring, which exhibit lower Q3 values, occur more frequently in earlier periods of the literature. Although these concepts continue to represent important components of the field, their relative prominence has declined in more recent publications, and they now function primarily as foundational elements within established theoretical and methodological frameworks.

Overall, the observed evolution of keywords indicates that the literature on sustainable supply chain management in the petrochemical industry is transitioning from relatively static and policy-oriented themes toward more technological, systemic, and uncertainty-oriented approaches. The simultaneous prominence of concepts such as low emission, hydrogen storage, and circular economy, alongside terms such as resilience and uncertainty, suggests that recent studies increasingly conceptualize sustainability not merely as an environmental objective but as a dynamic issue closely linked to the resilience of supply chain structures. From this perspective, emerging research fronts are closely connected to the conceptual clusters identified through keyword co-occurrence analysis. In particular, the growing emphasis on emission reduction and alternative energy pathways reinforces life-cycle-based analytical themes, which, in turn, support the development of more integrated sustainability frameworks for petrochemical supply chains.

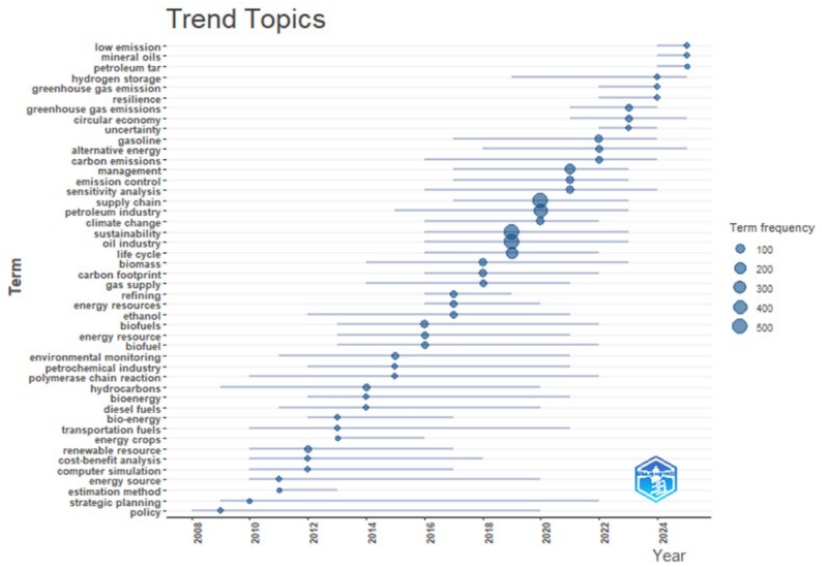

Figure 16

Trend of topics

5. Discussion

In accordance with the bibliometric framework of the present study, this section interprets the findings in relation to the research questions. With respect to the first research question, the findings indicate that scientific output in the field of sustainable supply chain management in the petrochemical industry has exhibited a sustained upward trend over the past two decades. The gradual increase in publication volume, together with the relatively high average citation rate, suggests that this research domain has progressed beyond its initial formative stage and entered a phase of consolidation and conceptual development. This evolution reflects a gradual shift in research orientation from general SSCM frameworks toward more industry-specific approaches in which environmental requirements, institutional structures, and the technological complexities of the petrochemical industry play central roles.

Regarding the second research question, the results show that the development of SSCM literature in the petrochemical industry has been largely driven by a relatively limited but influential group of countries, academic institutions, scientific journals, and researchers. The concentration of scientific output in countries with strong research infrastructures and well-developed petrochemical industries indicates that institutional capacity and university–industry linkages have played important roles in shaping the scientific networks of this field. The central positions of journals such as *Journal of Cleaner Production* and *Sustainability* further suggest that knowledge dissemination in this domain occurs at the intersection of technical, managerial, and policy-oriented research. Moreover, the presence of both developed and developing countries among the leading contributors reflects the globalization of sustainability concerns in petrochemical supply chains, although patterns of participation and scientific impact remain uneven. In particular, in some developing countries, such as Iran, growth in scientific output has not necessarily been accompanied by extensive integration into multicenter collaboration networks, and collaboration patterns remain relatively concentrated and bilateral.

Furthermore, comparison of the social structure of research with the conceptual structure derived from keyword co-occurrence analysis indicates that leading researchers are not concentrated within a single conceptual cluster but instead contribute across several major thematic streams, including environmental impact management, life-cycle assessment, and integrated sustainability. This pattern

reflects a dispersed and inherently interdisciplinary structure of knowledge production within the SSCM literature on the petrochemical industry. Accordingly, the findings related to the first two research questions suggest that the observed growth patterns and network structures reflect underlying characteristics of the petrochemical industry. The following subsections address the remaining research questions by examining the conceptual structure and emerging research themes.

5.1. Leading research themes

Regarding the identification of dominant research streams in recent years, the conceptual analysis indicates that the literature on sustainable supplier selection in the petrochemical industry converges around three core thematic areas. Each of these research streams is discussed in detail below.

5.1.1. Environmental impact management and emission control

One of the dominant research streams focuses on the environmental impacts associated with the extraction, production, and distribution stages of the petrochemical industry. These studies increasingly emphasize the implementation of systematic strategies for emission reduction and environmental impact mitigation, demonstrating that the adoption of energy management practices, optimization of industrial processes, and enhanced coordination across the supply chain can reduce the magnitude of these impacts. This research stream also incorporates an institutional dimension, as compliance with international standards and regulatory requirements has become a determining factor in the design and implementation of emission reduction policies. Consequently, environmental impact management in the petrochemical industry is not viewed merely as a matter of social responsibility; rather, within a high-risk and highly regulated environment, it constitutes a critical mechanism for maintaining institutional legitimacy, ensuring operational continuity, and securing sustainable access to global markets.

5.1.2. Comprehensive impact assessment through life-cycle approaches

The second research stream focuses on the growing application of comprehensive life-cycle-based approaches to assess environmental and operational impacts. Within this stream, the effects of industrial activities from raw material supply through end-of-life stages are evaluated within an integrated framework, enabling the identification of critical points throughout the life cycle and the development of evidence-based improvement policies. The integration of product design, technology selection, and operational policies promotes a systemic perspective that is essential for managing complex energy supply chains. Overall, the increasing emphasis on life-cycle approaches suggests that life cycle assessment (LCA)-based decision-making has emerged as an analytical response to supply chain complexity, translating environmental and institutional pressures into actionable indicators for operational and strategic decision-making.

5.1.3. Integrated sustainability in the supply chain

The third conceptual stream focuses on institutionalizing sustainability as a comprehensive framework within the petrochemical supply chain. This perspective considers the simultaneous integration of environmental, social, and economic dimensions, together with the incorporation of alternative energy sources, not as an optional choice but as a strategic necessity. Existing studies indicate that achieving sustainability in the petrochemical and energy industries requires concurrent attention to operational resilience, information transparency, and the management of risks arising from environmental and economic volatility. Moreover, economic evaluation methods, including cost–benefit analysis of alternative energy options, enable the joint assessment of environmental and economic outcomes. Within this stream, sustainability extends beyond a single-dimensional concern and becomes a

dominant decision-making logic that integrates economic efficiency, risk management, and sustainability requirements, thereby supporting the formulation of long-term strategies and policies.

Overall, these three conceptual streams should not be interpreted in isolation; rather, they represent interconnected components of a unified structure within the literature on sustainable petrochemical supply chains. The keyword co-occurrence map shows that environmental impact management, life cycle assessment, and integrated sustainability exhibit substantial overlap and structural interconnections, forming a shared conceptual pathway. Within this pathway, environmental impact management serves as an initial driving force, life cycle assessment functions as an intermediary analytical mechanism, and integrated sustainability provides a stabilizing framework at the strategic level. From an applied perspective, these interconnections indicate that decision-making in petrochemical supply chains is inherently integrated, requiring managers to simultaneously consider environmental criteria, life cycle assessment outcomes, and economic sustainability considerations in supplier selection, supply network design, and risk management. Reliance solely on traditional cost and quality indicators, without accounting for life cycle impacts and regulatory pressures, may lead to short-term and high-risk decisions. From an industrial perspective, these conceptual clusters closely correspond to the operational and strategic realities of the petrochemical industry. The prominence of environmental impact management and emission control reflects the sector's increasing emphasis on decarbonization and regulatory compliance. The life cycle assessment cluster corresponds to the need for comprehensive measurement of emission intensity and environmental impacts across the value chain. In addition, the increasing prominence of concepts such as alternative energy sources, circular economy, and low-emission systems indicates that the literature is increasingly addressing chemical recycling and resource recirculation, thereby reflecting ongoing transformation pathways within the industry.

5.2. Emerging research themes

In response to the fourth research question and based on the Trend Topics analysis conducted in Biblioshiny, the most recent conceptual wave in the sustainable petrochemical and energy literature is characterized by a set of emerging topics with the highest Q3 values, indicating a strong concentration of research activity during the 2023–2025 period. These themes are primarily situated at the intersection of the clean energy transition, circular economy strategies, and emission reduction and are summarized below.

5.2.1. Low-carbon fuels and petroleum derivatives (petroleum tar and mineral oils)

Recent studies reflect a growing reassessment of heavy petroleum derivatives aimed at reducing emission intensity while maintaining compatibility with existing petrochemical infrastructure. This research stream emphasizes low-emission alternatives and the optimization of refining processes to improve energy efficiency and environmental performance. From a supply chain perspective, this trend suggests a shift in supplier selection criteria toward carbon intensity, technological compatibility, and regulatory compliance, alongside traditional considerations of cost and quality.

5.2.2. Emission reduction and transition toward low-emission systems (low emission)

Low-emission systems have emerged as one of the most prominent research themes in recent years and account for a substantial share of the topics with high Q3 values. This theme encompasses the development of low-carbon fuels, optimization of industrial processes, and implementation of pollutant control technologies. In the petrochemical industry, particular emphasis is placed on reducing greenhouse gas emissions and improving energy efficiency through advanced catalysts, energy-saving

technologies, and digital emission monitoring systems. This trend indicates that emission reduction is progressively becoming an essential criterion in supply network design and supplier performance evaluation.

5.2.3. Hydrogen storage and alternative energy (hydrogen storage, alternative energy)

The emergence of hydrogen as a key energy carrier has directed increasing research attention toward the development of safe, efficient, and industry-compatible storage mechanisms. These studies primarily focus on advanced materials and hydrogen-adsorbing structures. At the same time, renewable energy sources are increasingly considered complementary pathways for the energy transition, contributing to reduced structural dependence on fossil fuels. The integration of hydrogen storage with renewable energy can facilitate a more stable energy supply but also introduces challenges related to supply security, long-term investment, and technological coordination across the supply chain. These issues have thus far received comparatively limited attention within SSCM frameworks.

5.2.4. Circular economy and sustainable resource utilization (circular economy)

The Trend Topics analysis indicates that the circular economy in the petrochemical literature is shifting from a predominantly policy-oriented concept toward implementation and industrial application. By emphasizing advanced recycling, reprocessing, and resource reuse, this approach seeks to reduce waste and promote regenerative production systems. From a supply chain management perspective, the expansion of circular economy practices in petrochemical supply chains requires the redefinition of supplier–producer relationships and the development of evaluation indicators that extend beyond traditional linear supply chain logic. Furthermore, the linkage between the conceptual and social structures of the literature indicates that this research stream is primarily driven by a limited group of leading countries, including China, the Netherlands, Finland, and Italy, as well as key institutions associated with process industries and sustainability, such as Delft University of Technology in the Netherlands, the Chinese Academy of Sciences and Tsinghua University in China, and Aalto University in Finland. This concentration highlights the dependence of knowledge advancement in this area on specific institutional and research capacities.

Overall, the results indicate that SSCM research in the petrochemical industry has shifted toward technologically advanced and environmentally intensive themes, accompanied by growing attention to uncertainty-related supply chain dimensions and dynamic, transition-oriented approaches. This evolution suggests that the literature increasingly frames supplier selection and investment decisions within multicriteria and long-term sustainability perspectives. Furthermore, recent thematic developments reveal a growing association between sustainable supply chain concepts and economic resilience under the complex, unstable, and uncertainty-driven conditions characteristic of the petrochemical sector. Rather than being positioned solely as environmental initiatives, sustainability practices are increasingly discussed within broader frameworks of resilience building, risk management, and adaptive capacity in economically volatile environments. This shift suggests that sustainability is increasingly conceptualized not only as an environmental objective but also as a strategic mechanism for strengthening adaptive capacity under market volatility.

5.3. Managerial and policy implications

The bibliometric results provide clear implications for managers, policymakers, and supply chain designers in the petrochemical industry. The dominance of the environmental impact management cluster suggests that regulatory pressure has become a key driver of supply-related decisions. Accordingly, policymakers can influence supplier behavior by establishing transparent and measurable

environmental standards. Moreover, the prominence of life-cycle-based approaches and integrated sustainability highlights the need to adopt long-term, multicriteria perspectives in investment decisions and supply network design. Finally, the analysis of scientific collaboration networks indicates that identifying central actors, particularly leading countries such as the United States and China, can inform the design of targeted incentive policies. Instruments such as joint research grants, support for research consortia, and university–industry collaboration can be used to strengthen international knowledge exchange in high-potential areas.

5.4. Life-cycle analysis of the field using the logistic growth model

To examine the dynamics of knowledge production in the field of sustainable supplier selection in the petrochemical industry, a logistic growth model was employed. The application of this model is based on the assumption that knowledge production in scientific fields, following a period of rapid growth, gradually approaches relative saturation. This assumption is supported by the observed S-shaped pattern in the cumulative publication trend shown in Figure 17. The logistic model enables estimation of the ultimate knowledge production capacity, the timing of the maximum publication growth rate, and the duration of the field's growth phase.

The results of fitting the model to the annual publication data, as presented in Figure 17 and Table 10, indicate that the ultimate knowledge production capacity (K) is estimated at approximately 2,185 documents and that 2027 represents the point of maximum publication growth, with an expected annual output of approximately 102 articles. In addition, the duration of the field's growth phase before approaching saturation is estimated at approximately 23.4 years, reflecting a relatively compact life cycle and rapid expansion of this interdisciplinary research domain. The coefficient of determination (R^2) of 0.985 indicates a strong goodness of fit for the logistic model.

Alternative models, including exponential growth, Gompertz, and Bass diffusion models, have also been proposed in the literature on scientific field life cycles. However, in the present study, the logistic model is employed as an interpretive framework for examining the overall dynamics of the field rather than as a tool for definitive forecasting. Accordingly, the results suggest that, by 2025, a substantial portion of the field's growth trajectory had been completed and that the field was approaching an early stage of maturity. Model extrapolation further indicates that, if the current trend continues, the field could reach more than 90% of its projected knowledge production capacity by approximately 2039. Nevertheless, these estimates should be interpreted as approximate and scenario-based projections.

Table 10

Key indicators of the topic life-cycle model and future trend forecasting

Indicator	Value	Description
Theoretical saturation point (K)	2,185.66 publications	Maximum predicted knowledge production capacity in the field
Peak year ($t\square$)	2027	Year predicted to exhibit the highest annual publication rate
Peak annual publications	102.59 articles/year	Maximum number of publications expected at the growth peak
Growth duration ($\Delta\square$)	23.40 years	Estimated time required for the field to reach the saturation phase
Model fit (R^2)	0.985	Indicator of accuracy and goodness-of-fit of the logistic model
Current status	Rapid growth phase	Current position of the field relative to its final capacity

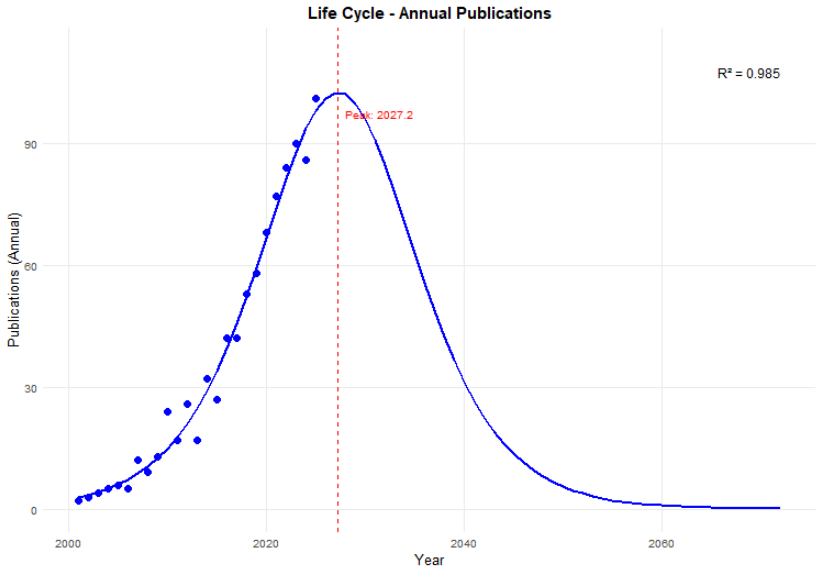

Figure 17

Life-cycle curve of the field based on the logistic growth model

Overall, the life-cycle analysis indicates that research on sustainable suppliers in the petrochemical industry is transitioning from a phase of rapid growth toward early maturity. Despite a gradual decline in the growth rate, the field still retains substantial potential for conceptual and analytical development. Its current position within the life cycle provides an interpretive framework for understanding the conceptual patterns identified in the preceding sections, as research attention is gradually shifting from the articulation of broad issues toward the development of analytical tools, the integration of methodological approaches, and the refinement of key concepts. The concurrence of this stage with the emergence of interconnected clusters related to environmental impact management, life cycle assessment, and integrated sustainability suggests that the observed conceptual overlap reflects a transition from fragmented development toward greater analytical coherence and more system-oriented decision-making in petrochemical supply chains.

5.5. Future research questions

The analysis of thematic trends and conceptual clusters presented in Section 5.2 indicates that, although research related to emission reduction, the circular economy, and hydrogen-related technologies in petrochemical supply chains has increased in recent years, a substantial proportion of these studies remains conceptual or descriptive. Bibliometric evidence suggests that only approximately 15% of the identified studies have employed quantitative tools such as life cycle assessment (LCA), while the proportion of studies that have operationalized these concepts through decision-oriented indicators and analytical models is considerably smaller. Accordingly, the following research questions are proposed to address these quantitative gaps:

- **Low-emission performance:** Although emission reduction-related concepts are addressed in only approximately 7–8% of the identified studies, most of this research does not focus on the quantitative operationalization of supplier emission-reduction strategies. What quantitative frameworks and indicators can be developed to enable comparative evaluation of low-emission performance among suppliers in petrochemical supply chains?
- **Hydrogen and supply chain resilience:** Although hydrogen-related studies account for approximately 9–10% of the overall literature, only about 5% of studies address supply chain

resilience, and the overlap between these two research streams remains limited. How can the effects of integrating hydrogen technologies on the resilience of petrochemical supply chains be measured quantitatively using appropriate indicators?

- **Circular economy in supplier evaluation:** Although circular economy concepts appear in only approximately 5% of the identified studies, their operationalization within quantitative supplier evaluation and selection models remains largely unexplored. What quantitative approaches and analytical models can support meaningful comparisons between linear and circular supply chain structures in the petrochemical industry?

5.6. Practical implications and recommendations for key stakeholders

This bibliometric analysis translates the principal research patterns, including the dominance of environmental and LCA-related clusters, the concentration of collaboration networks, and the prevalence of quantitative modeling, into targeted recommendations for major stakeholder groups.

For policymakers: Given the strong emphasis on emission reduction and life cycle assessment, policymakers should strengthen sector-specific low-emission regulations and promote standardized LCA-based reporting across petrochemical supply chains. In addition, supporting collaborative research initiatives that connect leading research hubs with underrepresented contributors could enhance knowledge diffusion and accelerate the adoption of sustainable technologies.

For industry practitioners: The predominance of decision-support and optimization-based studies indicates the need for a more structured integration of sustainability into operational decision-making. Firms should adopt multicriteria supplier evaluation frameworks that incorporate carbon intensity and resilience indicators and implement life-cycle-based performance measurement systems to move beyond predominantly cost-driven procurement strategies.

For researchers: The methodological imbalance favoring quantitative modeling over empirical validation highlights the need for more mixed-method and field-based studies. Future research should also expand longitudinal investigations, particularly as the field approaches early maturity according to the logistic growth model, and further operationalize emerging themes such as circular economy integration.

6. Conclusions

Sustainability in petrochemical supply chains has gradually evolved over the past decade from a peripheral concern into a central theme of research and policymaking. Despite the substantial growth of the related literature, knowledge regarding the current state of research, the trajectory of knowledge development, and the interconnections among studies has remained fragmented and, at times, inconsistent. To address this gap, the present study provides an evidence-based overview of the literature on sustainable suppliers and, through the application of bibliometric and network analysis methods, clarifies the structure and dynamics of this research field. The findings indicate that the field has recently entered a phase of conceptual maturation and that, alongside established research topics, emerging themes such as emission reduction, the circular economy, alternative energy sources, and life cycle assessment are gaining increasing prominence. Network analysis further reveals the formation of coherent clusters of active researchers, journals, and institutions, providing a structured map of knowledge production flows that can inform scientific collaboration and the selection of publication outlets. In addition, life-cycle analysis suggests that the literature on sustainable supply chains in the petrochemical industry is approaching an early stage of maturity and that, despite a gradual decline in growth rates, research activity is expected to remain dynamic in the coming years. This pattern indicates

that the field retains substantial potential for theoretical development while maintaining strong practical relevance in addressing environmental pressures and energy transition challenges in the petrochemical industry.

6.1. Methodological limitations and suggestions

Despite the robustness of the bibliometric approach employed in this study, several methodological considerations warrant clarification to ensure accurate interpretation of the results. As in comparable studies, bibliometric outcomes are partly influenced by threshold selection, clustering algorithms, and visualization settings; however, the analytical framework adopted in this study is grounded in established and widely accepted practices. In addition, reliance on the Scopus database and English-language publications may have excluded some regionally focused or non-indexed studies, although Scopus is widely regarded as a comprehensive and reliable source for bibliometric research. Accordingly, future studies may extend the present findings by broadening the range of data sources, applying complementary analytical techniques, or integrating bibliometric results with qualitative and empirical investigations.

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Nomenclature

K	Theoretical saturation point
LCA	Life cycle assessment
MCDM	Multi-criteria decision-making
R^2	Coefficient of determination
SSCM	Sustainable supply chain management
TC	Total citations
TC per year	Total citations per year
t□	Peak year
Δt	Growth duration

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