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Supply Chain Management and Industry 4.0

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ABSTRACT

Industry 4.0 has moved from a manufacturing slogan to a central concern of supply chain management (SCM). This review synthesises the literature on the two topics using 1,638 journal articles and reviews indexed in Scopus between 2017 and 2026, and it combines a reading of the most influential studies with the bibliometric evidence produced for this project (science mapping in Biblioshiny). Five conclusions emerge. First, research output has grown from 10 documents in 2017 to 301 in 2025, with a cumulative citation count of 88,572. Second, the field is organised around a motor theme of supply chains, decision making and artificial intelligence, surrounded by large clusters on sustainability and the circular economy and by smaller clusters on the Internet of Things (IoT), blockchain and resilience. Third, the most cited work is conceptual, review-based or survey-based, and few studies test technology effects with longitudinal or experimental designs. Fourth, scholarship from emerging economies, above all India and China, now dominates by volume, which has shaped the field's attention to adoption barriers and sustainability. Fifth, the field is moving from Industry 4.0 towards Industry 5.0, where resilience, sustainability and human-centricity are treated together. The paper closes with a future research agenda.

Keywords: *Supply Chain Management, Industry 4.0, Digital Supply Chain, Sustainability, Circular Economy, Resilience, Blockchain, Internet of Things Artificial Intelligence and Bibliometric Analysis*

1. INTRODUCTION

Supply chains move goods, money and information between many firms, and every handover is a place where a delay, a stock-out or an extra cost can appear. Industry 4.0 refers to the linking of physical production with sensors, data, computation and automation, through technologies such as the Internet of Things (IoT), cloud computing, big data analytics, artificial intelligence (AI), blockchain and digital twins (Kamble, Gunasekaran and Gawankar, 2018). Supply chain management (SCM) is where these technologies meet the everyday problems of coordination: how much stock to hold, whom to buy from, and what to do when a supplier fails. In recent years there has been increasing interest in applying Industry 4.0 to supply chains, and the topic is now a major area of interest within operations and production research.

The resulting literature is large and scattered across production, environmental, information-systems and management journals. Existing reviews tend to take one technology or one outcome at a time: IoT (Ben-Daya, Hassini and Bahroun, 2019; Rejeb et al., 2020), blockchain and sustainability (Saberi et al., 2019; Esmaeilian et al., 2020), AI (Toorajipour et al., 2021) and resilience (Spieske and Birkel, 2021). Less attention has been paid to how these strands relate to each other across the field as a whole, and to where the field is concentrated, who produces it and what it leaves out.

This study therefore set out to map the research on Supply Chain Management and Industry 4.0 using bibliometric analysis. It has four objectives: to describe how publication output has changed over time; to identify the leading sources and countries; to establish the main themes and how they connect; and to find the gaps that future research could address.

The remainder of this paper proceeds as follows. The Literature Review summarises the most cited studies by theme. The Research Methodology explains the search, screening and analytical procedure. The Data Analysis reports publication trends, leading sources and countries, thematic maps, conceptual structure and the co-word network. The Future Research Agenda sets out six research priorities drawn from these results, and the Conclusion brings the findings, limitations and implications together.

2. LITERATURE REVIEW

This section reviews the literature in two parts. The first sets out the concepts on which the field rests, and the second reviews the studies by theme. Counts of topic mentions given below are approximate indicators of attention and not exact classifications, because one paper can address several topics (see the Research Methodology).

2.1 Conceptual foundations

2.1.1 From Industry 4.0 to digital supply chains

In the supply chain literature, Industry 4.0 is treated less as a single technology than as a bundle of digital capabilities applied across planning, sourcing, production, logistics and returns. Reviews of the manufacturing context find that the applications studied are concentrated in production scheduling and control, with much less research on other life-cycle processes (Zheng et al., 2021). Studies of supply chain performance report positive links with Industry 4.0 adoption (Fatorachian and Kazemi, 2021), and work on innovation argues that the real change lies in how supply chains are organised, not only in the tools used (Hahn, 2020). Other contributors examine specific functions such as procurement (Bienhaus and Haddud, 2018) and the integration of supply chain and marketing (Ardito et al., 2019), and the knowledge-management foundations of digitisation (Schniederjans et al., 2020). A recurrent message is that technology alone is not sufficient: data sharing, skills, organisational routines and inter-firm trust decide whether digital tools improve supply chain outcomes.

2.1.2 Sustainability and the circular economy

The sustainability thread begins with the framing of Industry 4.0 as a route to sustainable operations (Kamble et al., 2018). It connects with the circular economy, which is treated as a distinct sustainability paradigm with its own concepts and tools (Geissdoerfer et al., 2017). The two topics were initially separate, and the argument for integrating them gave the field one of its most cited agendas (Lopes de Sousa Jabbour et al., 2018).

2.1.3 Resilience and viability

The third foundation is the study of disruption. The idea of the ripple effect, in which a local failure spreads through a network, links supply chain risk analytics to digitalisation (Ivanov et al., 2019). After 2020, resilience became the lens through which many digital technologies were evaluated, and the later notion of viability extends it to long-run survival under repeated shocks (Ivanov, 2023).

2.2 Thematic review of the literature

2.2.1 Technology-enabled supply chains: IoT, sensing and smart factories

The IoT is the most frequently studied enabling technology, appearing in roughly 400 of the 1,638 records. An early and heavily cited review of IoT in SCM classifies the literature by method, industry sector and supply chain process and concludes that most work conceptualises the impact of IoT, with limited analytical modelling and empirical testing (Ben-Daya et al., 2019). Later reviews tie IoT to sustainability, ERP integration and Industry 4.0 requirements (Manavalan and Jayakrishna, 2019), to smart factories (Soori et al., 2023) and to sensors and their applications (Javaid et al., 2021). A bibliometric study of IoT in SCM and logistics confirms the growth of this stream (Rejeb et al., 2020). Taken together, these works describe what IoT can do for visibility and automation, but they say less about the costs, data governance and interoperability problems that firms face in deployment.

2.2.2 Blockchain for transparency, coordination and sustainability

Blockchain appears in about 280 records and has its own cluster in the thematic maps. Early work set out the relationship between blockchain and sustainable supply chains (Saberi et al., 2019). Later contributions deepen it from several angles. One review evaluates the capabilities of Industry 4.0 for sustainability and then the added value of blockchain for incentives, visibility and traceability (Esmaeilian et al., 2020). A comprehensive review treats blockchain as a response to security and privacy weaknesses of centralised architectures (Bodkhe et al., 2020). Modelling studies move beyond conceptual claims: one develops a dynamic model of smart-contract design and execution in the supply chain (Dolgui et al., 2020), and another uses agent-based simulation to analyse resilience strategies and the ripple effect in blockchain-coordinated chains (Lohmer et al., 2020). The balance of evidence is therefore more analytical than in the IoT stream, but most results still come from simulation and conceptual models and not from observed implementations.

2.2.3 Artificial intelligence, big data and decision making

AI and machine learning appear in over 300 records and big data in over 200. A systematic review shows that AI is applied across SCM functions (Toorajipour et al., 2021). Empirical work asks why firms adopt it: a study of automotive firms, based on institutional theory and the resource-based view, explains how institutional pressure and resources lead firms to adopt big data analytics powered by AI, which in turn supports sustainable manufacturing and circular economy capabilities (Bag et al., 2021). A survey of Chinese manufacturers finds that digital supply chain platforms mediate the effect of digital technologies on both economic and environmental performance, and that environmental dynamism moderates it (Li et al., 2020). These studies illustrate the move from asking what the technologies are to asking under which conditions they pay off. They also help explain why artificial intelligence and decision making sit in the motor cluster in the thematic maps.

2.2.4 Digital twins, cloud platforms and connectivity

Digital twins appear in about 114 records. The notion of a digital supply chain twin, a computerised model that represents the state of a network in real time, was proposed as a way to manage disruption risk and to ensure visibility, with the pandemic providing evidence of the need (Ivanov and Dolgui, 2021). The same research group extended the idea to a cloud supply chain in which Industry 4.0 and digital platforms are combined in a "Supply Chain-as-a-Service" (Ivanov et al., 2022) and examined the role of 5G in providing flexibility, end-to-end connectivity and real-time visibility (Dolgui and Ivanov, 2022). These contributions show that visibility, not automation, is the main value argument in the more recent literature.

2.2.5 Resilience and disruption

Resilience terms appear in about 290 records, and COVID-19 in about 100. Two mutually reinforcing findings stand out. Conceptual work links digitalisation to the ripple effect and to risk analytics (Ivanov et al., 2019). Empirical work examines actual disruptions: a mixed-method study of the automobile and airline industries combines recovery-time and financial-impact analysis with a survey of 145 respondents to draw lessons on short- and long-term responses to COVID-19 (Belhadi et al., 2021). A systematic review written under the impression of the pandemic synthesises how Industry 4.0 can improve resilience (Spieske and Birkel, 2021). The evidence is persuasive about the potential of digital tools, yet the studies are mostly cross-sectional, which limits what can be said about whether digitally enabled supply chains actually recovered faster.

2.2.6 Sustainability and the circular economy

The circular economy appears in about 215 records, and the sustainable development cluster is one of the three largest in the thematic map. The roadmap by Lopes de Sousa Jabbour et al. (2018) proposed that digital and advanced manufacturing technologies can unlock the circularity of resources within supply chains. Later work gives it concrete form: a business model that uses Industry 4.0 and additive manufacturing to reuse and recycle scrap metal and e-waste (Nascimento et al., 2019); research frameworks for the links among Industry 4.0, sustainable manufacturing and the circular economy (Bag and Pretorius, 2022); evidence on operational excellence in reverse supply chains (Dev et al., 2020); and an analysis of barriers to sustainable operations (Kumar et al., 2021). Systematic reviews organise the potential of Industry 4.0 within the triple bottom line of sustainability (Birkel and Müller, 2021) and examine how digital capabilities strengthen circular, sustainable supply chains (Liu et al., 2023). A feature of this stream is its heavy use of frameworks and multi-criteria decision methods. These produce useful priorities, but they rest on expert judgement and seldom measure actual environmental outcomes.

2.2.7 Adoption: drivers, barriers and the role of context

A large group of studies asks why firms adopt Industry 4.0 and what holds them back. A qualitative study based on 26 interviews with senior managers compares multinational and small and medium-sized firms and finds that the desire for control and efficiency drives adoption, while barriers differ with firm size (Horváth and Szabó, 2019). Studies set in emerging economies identify and rank challenges to Industry 4.0 for supply chain sustainability in Indian manufacturing (Luthra and Mangla, 2018), analyse the influential strength of drivers of sustainability diffusion (Luthra et al., 2020) and propose frameworks for overcoming sustainable supply chain challenges in the automotive industry (Yadav et al., 2020). These studies fit the country pattern reported in the Data Analysis: the places that publish the most are also the places where adoption is still unfolding and where structural barriers are most visible. They also explain the prominence of decision-modelling and survey methods in the dataset. The weakness of this stream is that findings are specific to a country or a sector and are seldom replicated.

2.2.8 Towards Industry 5.0

The most cited document in the dataset is a survey of Industry 5.0 (Maddikunta et al., 2022), which presents it as the next stage, aimed at combining the creativity of human experts with intelligent machines to obtain resource-efficient and user-preferred manufacturing. For supply chains, Industry 5.0 is conceptualised through the viability perspective as an integration of resilience, sustainability and human-centricity (Ivanov, 2023). About 90 records mention it. The shift matters because it moves the debate away from technology adoption towards the purposes technology should serve, and it brings together the three threads of this review: digitalisation, sustainability and resilience.

3. RESEARCH METHODOLOGY

This study uses bibliometric analysis, supported by a reading of the most cited papers. Bibliometric analysis applies statistical and visual methods to publication data, such as authors, sources, countries, keywords and citations, to describe the structure and development of a research field (Aria and Cuccurullo, 2017). The qualitative reading of the most cited documents was used to explain what the statistical clusters mean.

3.1 Data source and search strategy

The data were taken from the Scopus database (Elsevier, 2026) on 1 October 2026. Scopus was chosen because it indexes peer-reviewed journals across production, environmental, information-systems and management research, which are the areas where this literature appears. The search string was “Supply Chain Management AND Industry 4.0”, and it returned 3,136 records.

3.2 Selection of records

Records were selected in four steps that follow the Identification, Screening, Eligibility and Inclusion logic of the PRISMA 2020 statement (Page et al., 2021). A record was kept only if it met all four criteria.

In the identification stage, the search returned 3,136 records. In the screening stage, the first criterion was publication between 2017 and 2027, chosen to cover the period in which the use of Industry 4.0 technologies in supply chain management expanded. This removed 14 records and left 3,122. The second criterion was document type: only articles and review articles were kept, so that the dataset consists of peer-reviewed journal work. This removed 1,447 records and left 1,675. In the eligibility stage, only records written in English were kept, for consistency and accessibility, which removed 25 records and left 1,650. The last criterion was publication in a journal, which removed 12 records and left 1,638. In the inclusion stage, the 1,638 records (1,368 articles and

270 reviews, all published between 2017 and 2026) were exported for analysis. Figure 1 shows the number of records at each stage.

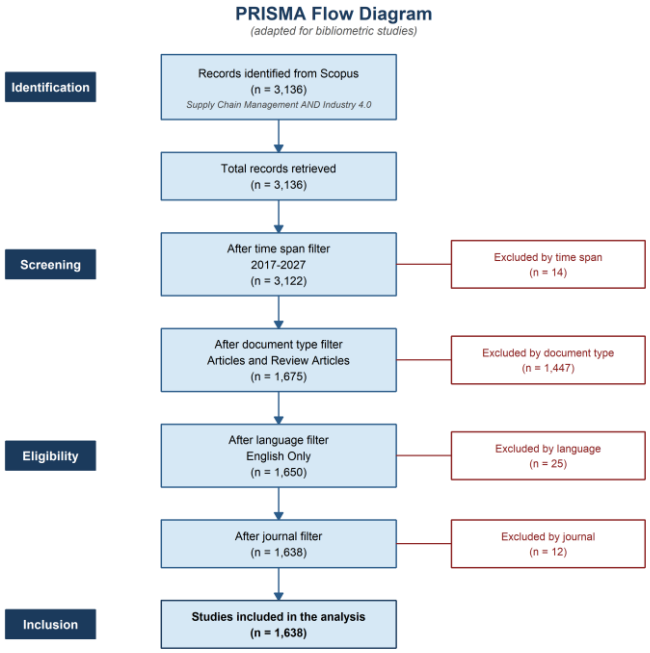

Figure -1: PRISMA flow diagram of the selection of records, adapted for bibliometric studies.

3.3 Data processing and tools

The export was saved in RIS and CSV formats. The CSV file was loaded into Biblioshiny, the web interface of the bibliometrix package in R (Aria and Cuccurullo, 2017), following the procedure described by Aria and Cuccurullo (2026) and Aria et al. (2024). Biblioshiny removed one record with a duplicated title, so all counts in the Data Analysis are based on 1,637 documents. The export contained no cited references, so analyses that depend on them, such as co-citation analysis, could not be run.

3.4 Analytical techniques

Six analyses were run. First, a summary of the dataset reports the number of sources, authors and keywords, the collaboration index and the citation counts. Second, annual scientific production was plotted and compared with linear, exponential, second-order and third-order polynomial trendlines, using R^2 to judge fit. Third, sources were ranked by number of documents, and countries by the number of times they appear in author affiliations. Fourth, a thematic map was built on Keywords Plus (Cobo et al., 2011; Callon et al., 1991), which places each keyword cluster according to its centrality and density. The map was drawn with four clustering algorithms, namely Louvain (Blondel et al., 2008), leading eigenvector (Newman, 2006), walktrap (Pons and Latapy, 2006) and spinglass (Reichardt and Bornholdt, 2006), to test whether the themes depend on the algorithm. Fifth, multiple correspondence analysis was used to examine the conceptual structure of the keywords. Sixth, a co-word network of the 50 most frequent keywords (Callon et al., 1983) was described with betweenness (Freeman, 1977), closeness (Freeman, 1978) and PageRank (Brin and Page, 1998).

The counts of topic mentions in the Literature Review and the Future Research Agenda were obtained by searching the titles, abstracts and author keywords of the same records. They are approximate indicators of attention and not exact classifications, because one paper can address several topics.

4. DATA ANALYSIS AND RESULTS

4.1 Dataset overview

The analysis was carried out according to the procedure used by (Aria and Cuccurullo, 2026; Aria et al., 2024) and was run in Biblioshiny (Aria and Cuccurullo, 2017) on records exported from Scopus (Elsevier, 2026) on 1 October 2026. The export holds 1,638 records, of which 1,368 are articles and 270 are reviews. All records are in English and were published between 2017 and 2026. Biblioshiny retained 1,637 documents after removing one record with a duplicated title, and this figure is used for all counts below. Together the records have received 88,572 citations, a mean of 54.1 per document (median 17).

Biblioshiny's main information summary gives an overview of the dataset. A total of 1,637 documents published between 2017 and 2026 were retrieved from 597 sources (596 once the two spellings of Sustainability (Switzerland) are merged, see Table 1), and output grew at an annual rate of 43%. On average, the documents have 3.73 co-authors each, and the collaboration index, calculated as the number of authors of multi-authored documents divided by the number of multi-authored documents, is 3.94. Only 107 of the 4,770 authors have written a single-authored document, and together they account for 114 of the 1,637 documents. Almost two-fifths of the documents (39.58%) involve international co-authorship. The documents contain 3,926 distinct author keywords, and the average document is 2.81 years old. No cited references were detected in the export, so the reference count is 0 and analyses that depend on cited references, such as co-citation analysis, could not be run. Overall, these results indicate that the field is recent and strongly collaborative.

4.2 Publication trends over time

Figure 2 shows an overview of the annual production of 1,637 documents between 2017 and 2026. The most striking result to emerge from the data is that output grew from 10 documents in 2017 to 301 in 2025, an annual growth rate of 43.0% over the full period (53.0% over the complete years 2017 to 2025). Growth was fastest in 2018 and 2019 (160.0% and 161.5%) and fell below 20% a year from 2023. A linear trendline fitted to the annual counts gives $y = 33.50x - 20.53$ ($x = 1$ for 2017) with an R^2 of 0.925, so about 33 documents were added each year. As shown in Figure 2, curved models fit better: the exponential model has the lowest R^2 (0.802), the second-order polynomial gives 0.956, and the third-order polynomial gives the highest R^2 (0.992), with the equation $y = -1.079x^3 + 15.38x^2 - 22.02x + 18.87$. The third-order polynomial is the trendline drawn in Figure 2. A note of caution is due here since the 2026 figure covers only the period up to 1 October, so the fall to 250 documents in 2026 is a coverage effect, and the cubic model uses four parameters for ten data points, so it describes the observed pattern but should not be used to project future output.

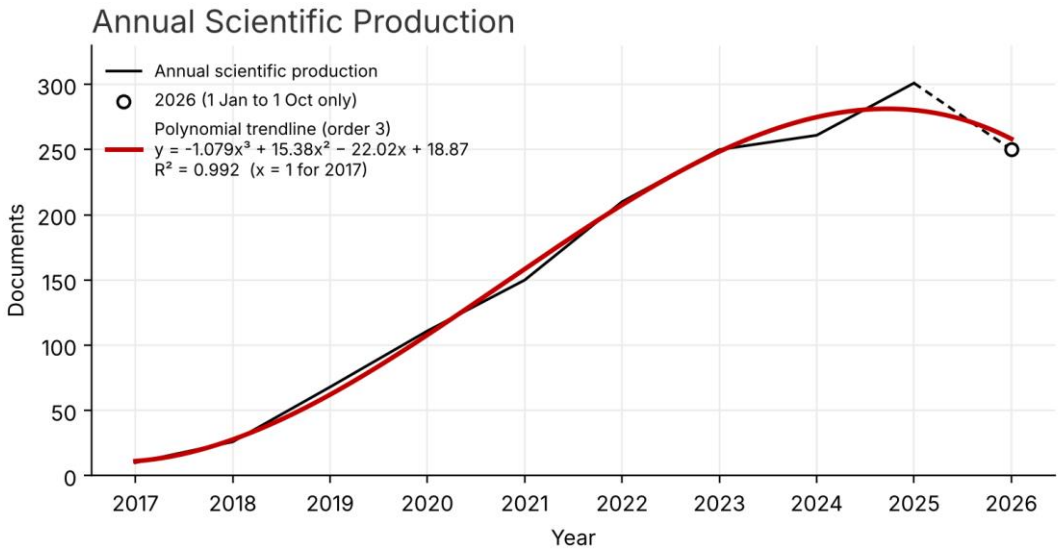

Figure -2: Annual scientific production with a third-order polynomial trendline. The open marker for 2026 covers part of the year.

4.3 Most relevant sources

The 1,637 documents were published in 596 sources. Table 1 lists the sources with at least 24 documents. This cutoff yields ten sources, a common size for such a table, and it leaves a gap of five documents to the next source (Logistics, with 19). Less than a quarter of the documents (392 of 1,637; 23.9%) were published in these ten sources, so the remaining 586 sources publish 1,245 documents, about 2.1 each. The distribution therefore has a long tail, with a few sources carrying a large part of the field and most sources contributing only once or twice.

Table -1: Most relevant sources (cutoff: at least 24 documents). Scopus lists Sustainability (Switzerland) under two spellings (127 and 10 records); the counts were combined.

Rank	Source	Documents	Share (%)	Cumulative share (%)
1	Sustainability (Switzerland)	137	8.4	8.4
2	International Journal of Production Research	41	2.5	10.9
3	Business Strategy and the Environment	33	2.0	12.9
4	Computers and Industrial Engineering	28	1.7	14.6
5	Technological Forecasting and Social Change	28	1.7	16.3
6	Benchmarking	27	1.6	18.0
7	International Journal of Production Economics	25	1.5	19.5
8	Production Planning and Control	25	1.5	21.0
9	Applied Sciences (Switzerland)	24	1.5	22.5
10	Journal of Cleaner Production	24	1.5	23.9

What can be clearly seen in Table 1 is the dominance of Sustainability (Switzerland), which holds 137 documents (8.4% of the dataset), more than three times the count of the second source, the International Journal of Production Research (41). Closer

inspection of the table shows that the gap between the first and second source is far larger than any other gap in the list. Sustainability and Applied Sciences (24) are both open-access titles published by MDPI (Applied Sciences, no date; Sustainability, no date), a publisher with a high annual volume, which may partly explain their position in the list. The other eight sources are specialist journals in production and operations (International Journal of Production Research, International Journal of Production Economics, Production Planning and Control, Computers and Industrial Engineering), in sustainability and the environment (Business Strategy and the Environment, Journal of Cleaner Production), in technology management (Technological Forecasting and Social Change) and in management practice (Benchmarking). This spread over production, environmental and technology journals matches the three groups of keywords found in the thematic map below.

4.4 Thematic map

Thematic mapping places each cluster of keywords on a two-dimensional diagram according to its relevance degree (centrality) and its development degree (density) (Cobo et al., 2011). Centrality measures the strength of a cluster's links with other clusters and shows its importance for the field. Density measures the strength of the links among the keywords inside a cluster and shows how well developed it is. Clusters in the upper right quadrant are motor themes, those in the upper left are niche themes, those in the lower right are basic themes, and those in the lower left are emerging or declining themes (Callon et al., 1991). The map was built in Biblioshiny with Keywords Plus as the unit of analysis (Aria and Cuccurullo, 2017)

The default clustering method in Biblioshiny is the Louvain algorithm, which groups terms by maximising modularity through repeated local moves and merging (Blondel et al., 2008). It clustered 250 terms, and five broad themes emerged from the analysis (Figure 3, Table 2). Because the cluster structure can depend on the algorithm, the map was drawn again with three other methods: leading eigenvector, which splits the network using the leading eigenvector of the modularity matrix (Newman, 2006), shown in Figure 4 (called leading eigenvalues in the Biblioshiny menu); walktrap, which uses short random walks on the idea that a walk tends to stay inside a densely connected group (Pons and Latapy, 2006), shown in Figure 5; and spinglass, which comes from a statistical-physics model (Reichardt and Bornholdt, 2006), shown in Figure 6. Table 3 compares the four maps.

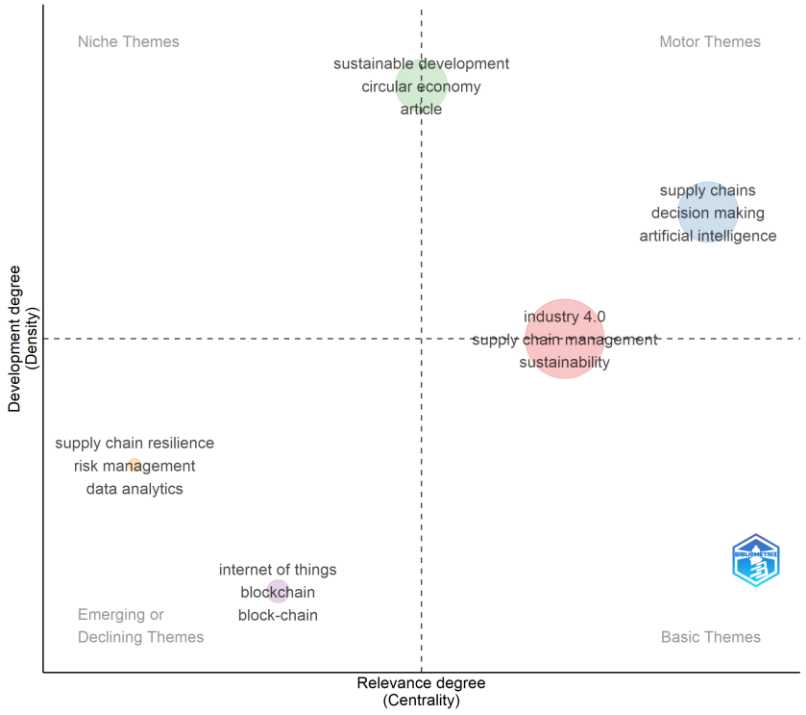

Figure -3: Thematic map, Louvain algorithm (Biblioshiny default).

Table -2: Clusters identified by the Louvain algorithm. Positions were read from Figure 3.

Cluster	Label	Keywords	Occurrences	Leading keywords (occurrences)	Position on map
1	industry 4.0	69	3,999	industry 4.0 (955); supply chain management (721); sustainability (275)	Basic / motor boundary
2	supply chains	73	2,243	supply chains (329); decision making (150); artificial intelligence (144)	Motor
3	sustainable development	69	1,713	sustainable development (202); circular economy (152); article (63)	Niche / motor boundary
4	internet of things	18	681	internet of things (136); blockchain (134); block-chain (65)	Emerging or declining

Cluster	Label	Keywords	Occurrences	Leading keywords (occurrences)	Position on map
5	supply chain resilience	21	505	supply chain resilience (47); risk management (44); data analytics (39)	Emerging or declining
	Total	250	9,141		

4.4.1 Motor themes

The most important result is that the supply chains cluster is the clearest motor theme. Its leading keywords are supply chains (329 occurrences), decision making (150) and artificial intelligence (144), followed by information management (70), machine learning (65), smart manufacturing (63) and industry 5.0 (61). High centrality together with high density means that these terms are well connected to the rest of the field and also tightly linked to each other. This finding is consistent with the most cited documents in the dataset. Two of the three most cited documents deal with digital technology and supply chain disruption, namely (Ivanov et al., 2019) with 1,779 citations and (Ivanov and Dolgui, 2021) with 1,424. The first examines how digital technology and Industry 4.0 relate to the ripple effect and to supply chain risk analytics, and the second proposes a digital supply chain twin for managing disruption risks and resilience. Several reports have shown that artificial intelligence is applied across supply chain functions (Toorajipour et al., 2021), which fits artificial intelligence and decision making appearing in the same cluster. The most cited document overall, a survey of Industry 5.0 (Maddikunta et al., 2022), links to the industry 5.0 keyword in this cluster.

This cluster stays in the motor quadrant in all four maps, whichever term joins supply chains and decision making: artificial intelligence (Figures 3 and 6), digital technologies (Figure 4) or industry 4.0 (Figure 5).

4.4.2 Other themes

The industry 4.0 cluster is the largest, with 69 keywords and 3,999 occurrences. Its leading terms are industry 4.0 (955), supply chain management (721), sustainability (275), supply chain (184) and digital transformation (125). It lies to the right of the centrality midline and level with the density midline in Figure 3, which marks it as a basic theme at the border with the motor quadrant: central to the field but loosely developed inside, probably because it works as an umbrella term for many topics. This agrees with the framing of Industry 4.0 as a route to sustainable operations (Kamble et al., 2018).

The sustainable development cluster combines sustainable development (202), circular economy (152), waste management (53) and life cycle (45). It lies at the top of the map on the centrality midline, so it is well developed but only moderately tied to the other themes. Circular economy is treated in the literature as a sustainability paradigm with its own concepts and tools(Geissdoerfer et al., 2017), which is consistent with the high density of this cluster. The term “article” (63) is a generic indexing label and carries no thematic content. It appears among the leading keywords of this cluster in all four maps.

The internet of things cluster (136 occurrences for the leading term) and the supply chain resilience cluster (47) fall in the emerging or declining quadrant. The position alone cannot show whether a theme is rising or falling. Blockchain research on supply chains is relatively recent (Saberi et al., 2019), which points to an emerging theme, but several questions remain unanswered at present, and the thematic evolution analysis is needed to confirm this reading. The terms “blockchain” (134) and “block-chain” (65) were counted separately, so a cleaning step that merges the two spellings would raise the weight of this cluster.

4.4.3 Comparison across clustering algorithms

Table 3 summarises where the main themes fall in the four maps. The four maps share a number of key features. The number of clusters ranges from three (Figure 5) to five (Figures 3 and 6), yet supply chains and decision making occupy the motor quadrant under every algorithm. Internet of things and blockchain remain in the emerging or declining quadrant in the three maps where they form a cluster (Figures 3, 4 and 6); in Figure 5 they are not among the leading keywords of any cluster.

The Louvain map differs from the other three in a number of respects. It is the only map with a separate supply chain resilience cluster, and it places the industry 4.0 cluster on the boundary between the motor and basic quadrants, whereas the industry 4.0 cluster is basic in Figures 4 and 6 and moves into the motor quadrant in Figure 5, where industry 4.0 is merged with supply chains and decision making. What is surprising is that artificial intelligence changes position with the method: it is part of the motor cluster in Figures 3 and 6, but sits with the internet of things and blockchain in the emerging or declining quadrant in Figure 4. One interesting finding is that digital technologies, big data and digitalization form a separate cluster only in Figure 6. What emerges from the results reported here is that the motor theme and the emerging technology theme are stable across methods, whereas the position of industry 4.0, sustainability and artificial intelligence depends on how finely the keywords are divided. Statements about these three themes should be read with that in mind.

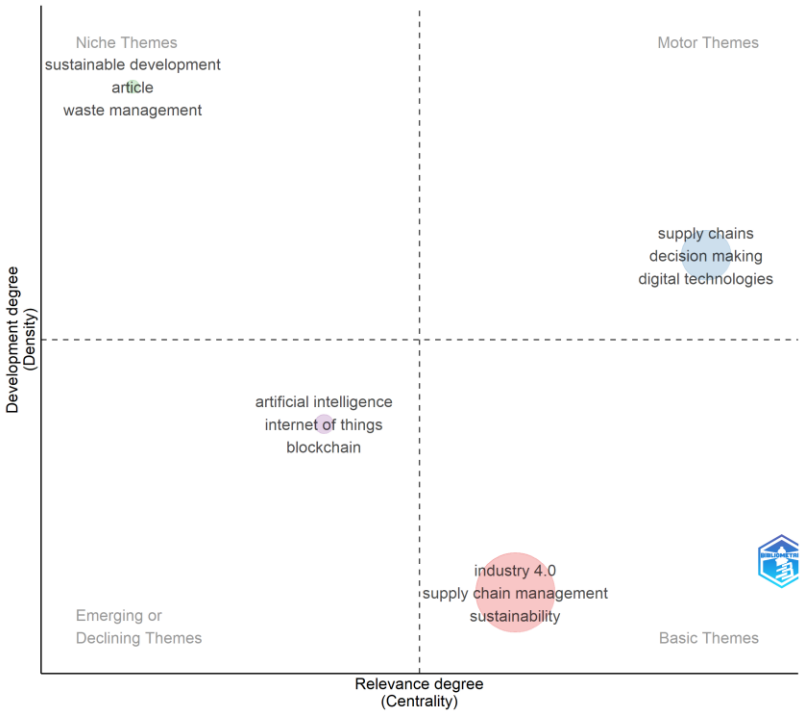

Figure -4: Thematic map, leading eigenvector algorithm (4 clusters).

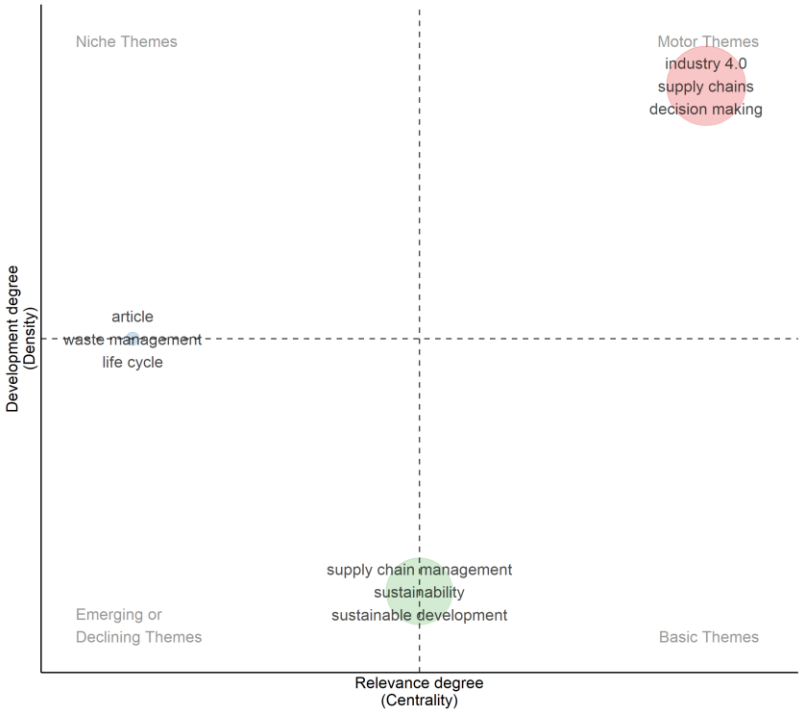

Figure -5: Thematic map, walktrap algorithm (3 clusters).

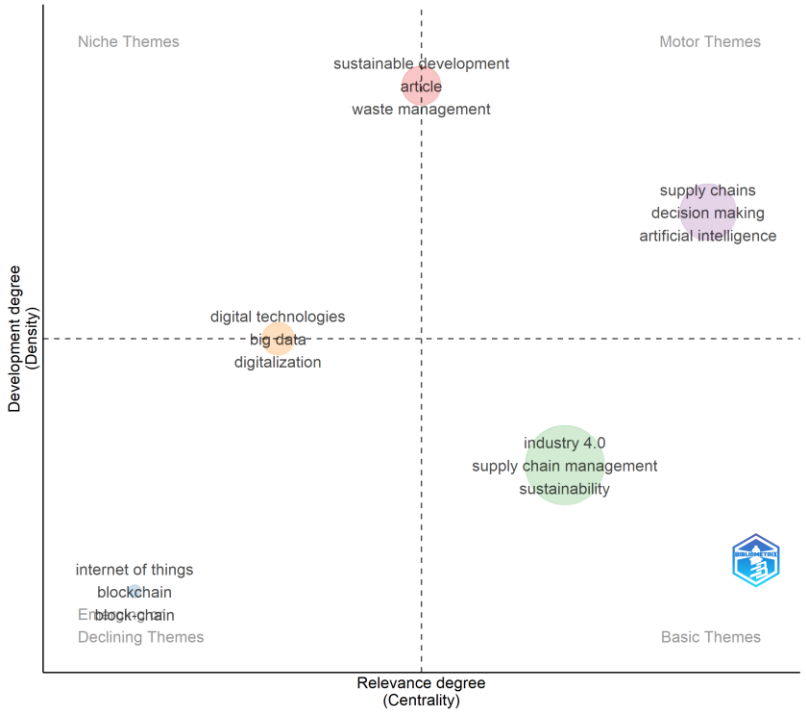

Figure -6: Thematic map, spinglass algorithm (5 clusters).

Table -3: Position of the main themes in the four thematic maps. Positions were read from the maps; Biblioshiny does not export centrality and density values.

Theme	Louvain (Figure 3)	Leading eigenvector (Figure 4)	Walktrap (Figure 5)	Spinglass (Figure 6)
Supply chains, decision making	Motor (with artificial intelligence)	Motor (with digital technologies)	Motor (with industry 4.0)	Motor (with artificial intelligence)
Industry 4.0, supply chain management, sustainability	Basic / motor boundary	Basic	Industry 4.0 joins the motor cluster; supply chain management and sustainability form a basic / emerging boundary cluster	Basic
Sustainable development, waste management	Niche / motor boundary (with circular economy)	Niche	Niche / emerging boundary (with life cycle)	Niche / motor boundary
Internet of things, blockchain	Emerging or declining	Emerging or declining (with artificial intelligence)	Not among the leading keywords	Emerging or declining
Supply chain resilience, risk management	Emerging or declining	Not among the leading keywords	Not among the leading keywords	Not among the leading keywords
Digital technologies, big data, digitalization	Not a separate cluster	With the motor cluster (digital technologies)	Not among the leading keywords	Niche / emerging boundary

4.5 Conceptual structure (factorial analysis)

Factorial analysis was used to examine the conceptual structure of the keywords from a second angle. Multiple correspondence analysis (MCA) reduces the co-occurrence of keywords to two dimensions, so that keywords that tend to appear in the same documents are plotted close together, and the keywords are then grouped into clusters from their coordinates (Aria and Cuccurullo, 2017). Figure 7 shows the resulting map and Figure 8 the dendrogram on which the clusters are based. The first dimension explains 23.02% of the variance and the second 14.72%, so the two axes together account for 37.7%.

What is striking in Figure 7 is how unevenly the keywords are divided. One cluster holds almost all the keywords, and a second cluster holds only four: machine learning, big data analytics, artificial intelligence and supply chain 4.0. These four lie in the lower left of the map, well below the other keywords on the second dimension. Closer inspection of Figure 8 shows why. The four keywords join the rest only at a height of about 2.9, while all other keywords have merged by about 2.4, and the dashed cut line (about 2.65) falls between the two values. The two-cluster result therefore follows from the chosen cut height and should not be read as the only grouping in the data.

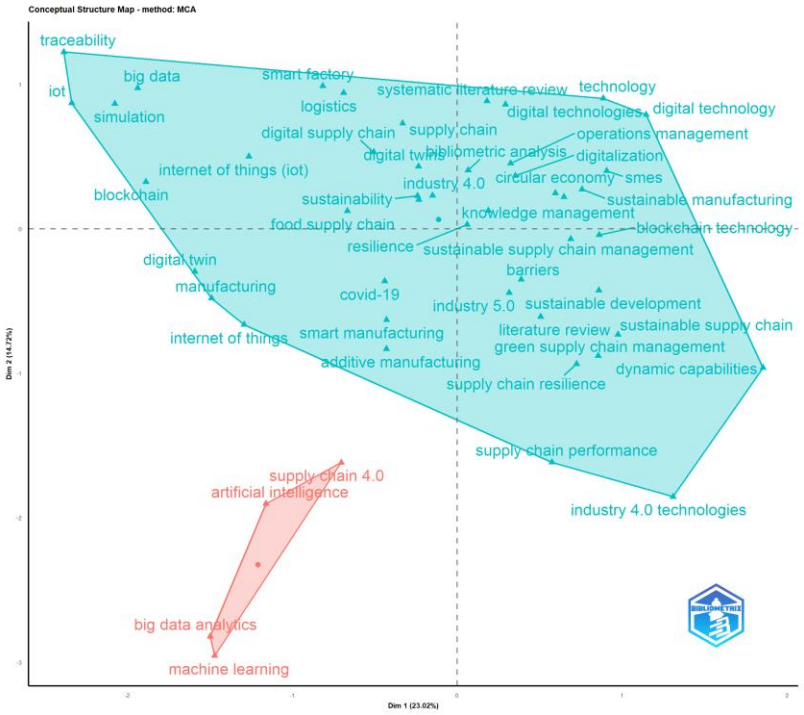

Figure -7: Conceptual structure map, MCA method (Dim 1 = 23.02%, Dim 2 = 14.72%).

Below the cut line, the dendrogram separates smaller groups that are easier to interpret. Technology terms (iot, big data, simulation, traceability, blockchain) join at a low height and lie on the left of the map, together with manufacturing terms such as smart manufacturing, additive manufacturing and digital twin. Sustainability and management terms (green supply chain management, sustainable supply chain, circular economy, sustainable development, smes, dynamic capabilities) lie on the right. The first dimension therefore appears to separate technology-oriented keywords from sustainability and management keywords, which is consistent with the separate technology and sustainability clusters in the thematic maps (Table 3). This reading is based on the position of the keywords and was not tested.

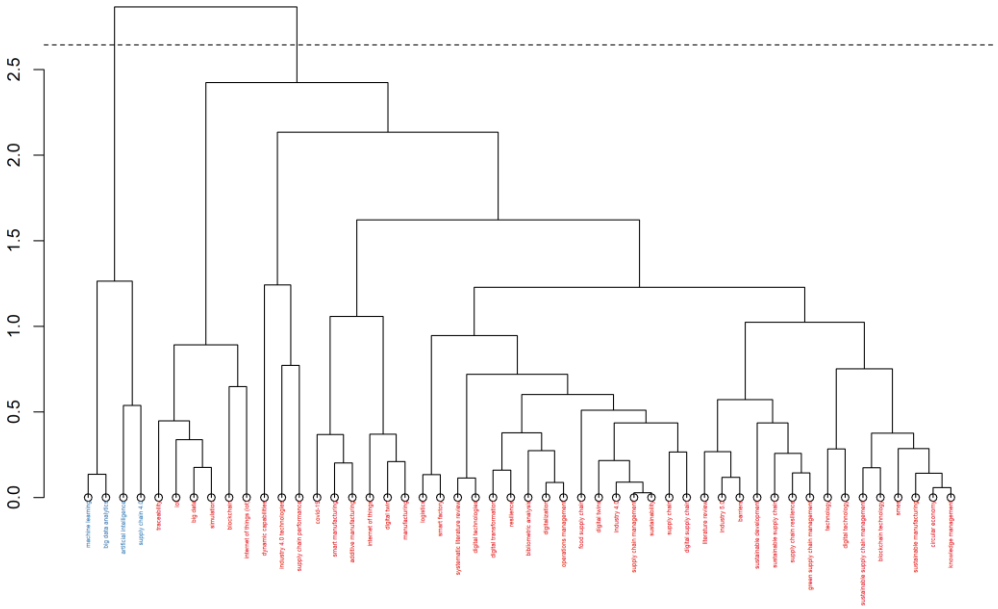

Figure -8: Topic dendrogram of the keywords. The dashed line marks the cut that gives two clusters.

A note of caution is due here since the two dimensions explain less than 40% of the variance, so distances on the map are an incomplete picture of the keyword relations. Variants of the same term were also plotted as separate points, for example iot, internet of things (iot) and internet of things, digital twin and digital twins, and blockchain and blockchain technology. This splits the occurrences of one concept across several points. The position of artificial intelligence deserves attention, because it belongs to the group furthest from the rest in Figure 7 and it changes position with the method in Figure 4. A keyword at the edge of the keyword space may be assigned to different clusters when the grouping method changes, but this explanation was not tested.

4.6 Country scientific production

Figure 9 shows an overview of the countries that contribute to the 1,637 documents, and the results are presented in Table 4. Biblioshiny identified 92 countries, and their frequencies add up to 4,276, which is more than the number of documents because a document with authors from several countries is counted for each of them. The most striking result to emerge from the data is that India leads with 692 occurrences (16.2% of the total), followed by China with 399 (9.3%) and the United Kingdom with 301 (7.0%). What is striking about the figures in Table 4 is that the five leading countries account for 41.3% of all occurrences and the ten leading countries for 58.4%, while 13 of the 92 countries appear only once. Overall, these results indicate that the field is led by a small number of countries in Asia, Europe and the Americas, with a long tail of countries that contribute very little.

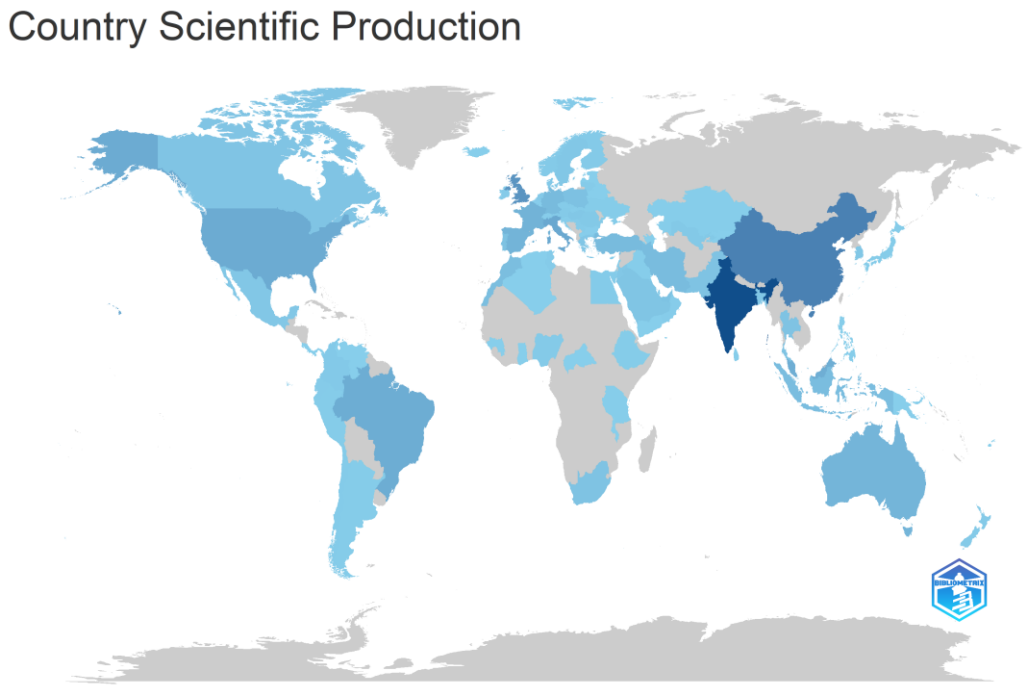

Figure -9: Country scientific production. Darker shading indicates more documents; grey indicates no documents.

Table -4: Ten most productive countries. Occurrences are counts of countries in the author affiliations, so they add up to more than the number of documents. The shares are calculated from the total of 4,276 occurrences.

Rank	Country	Occurrences	Share (%)	Cumulative share (%)
1	India	692	16.2	16.2
2	China	399	9.3	25.5
3	United Kingdom	301	7.0	32.6
4	Italy	193	4.5	37.1
5	USA	180	4.2	41.3
6	Brazil	171	4.0	45.3
7	Malaysia	161	3.8	49.0
8	France	139	3.3	52.3
9	Spain	135	3.2	55.4
10	Australia	126	2.9	58.4

4.7 Co-word network

The co-word network links keywords that appear together in the same documents (Callon et al., 1983). Figure 10 shows the network of the 50 keywords selected by Biblioshiny, and the results are presented in Table 5. The keywords fall into four clusters, which contain 20, 17, 9 and 4 keywords. Three measures describe the position of each keyword: betweenness, which counts how often a keyword lies on the shortest path between two other keywords (Freeman, 1977); closeness, which shows how near a keyword is to all the others (Freeman, 1978); and PageRank, which gives more weight to keywords that are linked to other well-connected keywords (Brin and Page, 1998).

The most striking result to emerge from the data is that industry 4.0 and supply chain management dominate the network. They have the highest betweenness (131.18 and 93.61) and the highest PageRank (0.1222 and 0.1017), and both belong to cluster 1, together with sustainability, sustainable development, circular economy and digital transformation. In cluster 2, supply chains has the highest betweenness (25.47), followed by artificial intelligence (7.30), decision making (4.72), blockchain (4.51) and internet of things (3.15). What is surprising is that internet of things and blockchain fall in the same cluster as supply chains, artificial intelligence and decision making, whereas the Louvain thematic map (Figure 3) separates them, which may reflect the different clustering settings. Cluster 3 groups digital technologies, big data, digitalization and the resilience and risk management terms, and cluster 4 contains only four keywords, two of which (article and human) are generic indexing labels. Closeness differs little between keywords (0.013 to 0.020), so it separates them less clearly than betweenness, which ranges from 0.05 to 131.18.

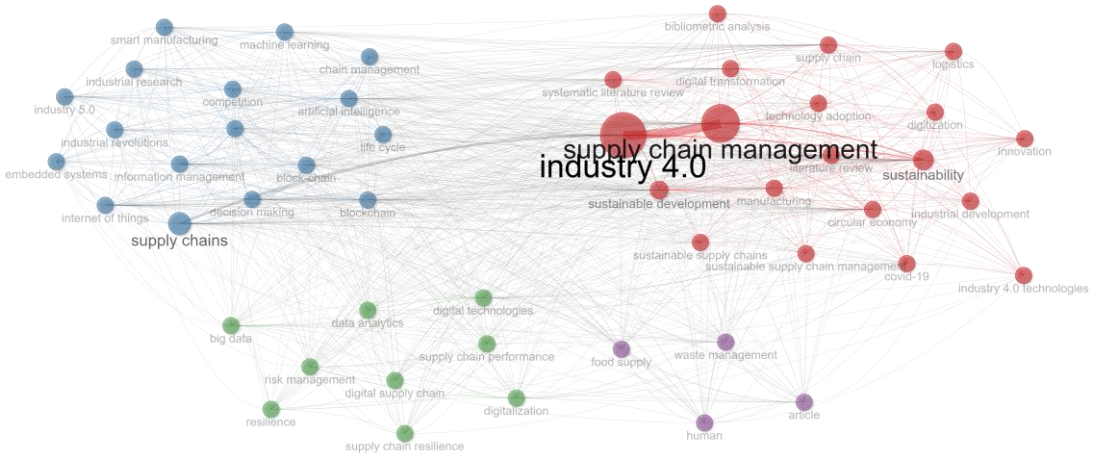

Figure -10: Co-word network of the 50 selected keywords. Colours show the four clusters; the labels of the leading keywords are given in Table 5.

Table -5: Ten keywords with the highest betweenness in the co-word network. Cluster numbers are those given by Biblioshiny.

Rank	Keyword	Cluster	Betweenness	Closeness	PageRank
1	industry 4.0	1	131.18	0.0204	0.1222
2	supply chain management	1	93.61	0.0204	0.1017
3	supply chains	2	25.47	0.0200	0.0553
4	sustainability	1	15.72	0.0204	0.0467
5	sustainable development	1	12.61	0.0204	0.0423
6	artificial intelligence	2	7.30	0.0204	0.0286
7	decision making	2	4.72	0.0196	0.0291
8	blockchain	2	4.51	0.0204	0.0273
9	supply chain	1	4.06	0.0185	0.0267
10	circular economy	1	4.02	0.0192	0.0269

4.8 Findings

(1) Output grew from 10 documents in 2017 to 301 in 2025, an annual growth rate of 43.0% over 2017 to 2026 (53.0% over complete years). Growth slowed after 2020, and the 2026 count is incomplete.

(2) The third-order polynomial ($R^2 = 0.992$) describes the annual counts better than the second-order (0.956), linear (0.925) and exponential (0.802) models, but it should be used only to describe the past pattern.

(3) Sustainability (Switzerland) is the leading source with 137 documents (8.4%). The ten leading sources account for 23.9% of the dataset, and the other 586 sources average about two documents each.

(4) Supply chains, decision making and artificial intelligence form a motor theme that appears in the motor quadrant under all four clustering algorithms.

(5) Internet of things and blockchain keywords sit in the emerging or declining quadrant, while the position of industry 4.0 and artificial intelligence changes with the algorithm.

(6) A factorial analysis (MCA, 37.7% of the variance on two dimensions) separates machine learning, big data analytics, artificial intelligence and supply chain 4.0 from all other keywords, and places technology keywords on the left and sustainability keywords on the right of the first dimension.

(7) India (692 occurrences), China (399) and the United Kingdom (301) are the three most productive countries, and the five leading countries account for 41.3% of the 4,276 country occurrences.

(8) The co-word network has four clusters, and industry 4.0 and supply chain management have the highest betweenness (131.18 and 93.61) and PageRank (0.1222 and 0.1017).

Limitations of this section. These findings may be somewhat limited by the use of one database (Scopus). Biblioshiny does not export the centrality and density of each cluster, so quadrants were read from the maps, and clusters that touch a dashed line are described as boundary cases. Generic indexing terms such as “article” were not removed before clustering, and variant spellings of the same term were not merged before the factorial analysis. The country counts add up to more than the number of documents because a document with authors from several countries is counted more than once, and the country series are cumulative, with 2026 incomplete.

5. DISCUSSION AND IMPLICATIONS

5.1 Findings

(1) The field has grown explosively: publications increased from 10 in 2017 to 301 in 2025, an increase of 43% per annum, and the 1,637 documents have attracted 88,572 citations. A slowdown is evident after 2020.

(2) Publication is diffuse: the ten sources with the largest share of documents account for only 23.9% of the documents. The lead is taken by Sustainability (Switzerland) with 137 items, suggesting a shift in emphasis to the environmental pillar.

(3) Supply chains, decision-support systems and artificial intelligence are the only motor theme that has been identified consistently across all four clustering algorithms. Industry 4.0 has emerged as a generic theme, but it is under-developed.

(4) Resilience dominates the citation ranking, but it is under-developed: two of the three most-cited papers focus on disruption, and the theme only appears in the 'emerging' or 'dying' categories.

(5) Technology and sustainability are two camps: the first factorial analysis places keywords associated with technology and keywords associated with sustainability on two opposite sides of the first axis.

(6) Performance is poorly evidenced: out of the 165 items that include "performance" in the title, 100 use surveys of managerial perceptions, while only five employ either longitudinal or secondary data.

5.2 Discussions

Supply chain management and Industry 4.0 have become one of the fastest-growing fields in operations research, and the bibliometric analysis offers insight into its structure, with implications for scholarship and practice. The main finding is that the field focuses on potential rather than performance: the most-cited paper on performance proposes a conceptual model that does not go beyond the discussion of indicators (Fatorachian & Kazemi, 2021). At the same time, the analysis of ripple effects and digital supply chain twin stands out as the most influential research in the field (Ivanov et al., 2019). The COVID-19 pandemic has triggered a surge in studies of supply chain resilience (Spieske & Birkel, 2021), but this concept has proved to be elusive. A similar observation can be made on the relationship between Industry 4.0 and the circular economy: they have been presented as completely separate concepts at the early stage of development (Lopes de Sousa Jabbour et al., 2018). This tendency appears to continue, as shown by the factorial analysis. At the same time, small and medium-sized enterprises appear to lag far behind large companies in adopting new technologies (Horváth & Szabó, 2019). This gap is especially pronounced in emerging economies, including India (Luthra & Mangla, 2018).

5.3 Implications

The implications of this study reach out to researchers, practitioners and policymakers who are interested in a comprehensive understanding of the field, rather than a specific technology or a particular industry. Five areas of scholarly inquiry have been identified that may advance the discourse on supply chains and Industry 4.0. First, there is a need for studies that assess the actual performance of Industry 4.0: a comparison of adopters and non-adopters at a similar level of development is likely to yield valuable insights. Second, only 15 items out of 1,637 include the word 'explainability' in the title or abstract, and the study of decision-making algorithms is in its infancy. Particular attention should be paid to when managers should rely on intuition or artificial intelligence (Ahmed et al., 2025). This is especially urgent given the ongoing research on large language models (Frederico, 2023; Zhang et al., 2026). Third, the study of supply chain resilience should be expanded to incorporate the free-rider dilemma: a company may be reluctant to share information on disruptions if its competitors can use this information to their advantage (Lohmer et al., 2020). Fourth, only ten items mention energy consumption, and a comprehensive assessment of the carbon footprint of digital technologies is required to evaluate their impact on the circular economy (Esmaeilian et al., 2020). In this respect, studies on small businesses and Industry 5.0's human-centric approach (Ivanov, 2023) may offer new insights. Fifth, future bibliometric analyses should combine Scopus and Web of Science and employ a more sophisticated approach by keeping cited references and keywords together. In particular, the present study's thematic evolution analysis should be expanded to identify whether blockchain and the Internet of Things represent emerging or declining trends (Wamba & Queiroz, 2022).

6. CONCLUSION

This study set out to map the research on Supply Chain Management and Industry 4.0 and to find what the evidence base still lacks. A Scopus search run on 1 October 2026 returned 3,136 records. After four screening steps, 1,638 journal articles and reviews published between 2017 and 2026 remained, and 1,637 documents were analysed in Biblioshiny after one duplicated title was removed. All conclusions below rest on this dataset.

The publication trends show a young field that grew fast and is now growing more slowly. Output rose from 10 documents in 2017 to 301 in 2025, an annual growth rate of 43.0% over the full period (53.0% over the complete years 2017 to 2025). Growth was fastest in 2018 and 2019 (160.0% and 161.5%) and was below 20% a year from 2023. A third-order polynomial fits the annual counts best ($R^2 = 0.992$), ahead of the second-order (0.956), linear (0.925) and exponential (0.802) models. This describes the past pattern only. The 2026 count of 250 covers the period up to 1 October, and the cubic model uses four parameters for ten data points, so it should not be used to project future output.

The thematic analyses answer the question of what the field is about. Supply chains, decision making and AI form a motor theme that stays in the motor quadrant under all four clustering algorithms (Louvain, leading eigenvector, walktrap and spinglass). The industry 4.0 cluster is the largest, with 3,999 keyword occurrences, but it sits at the boundary between basic and motor themes, which suggests that it works as an umbrella label more than as a specific domain. IoT with blockchain, and supply chain resilience with risk management, fall in the emerging or declining quadrant, and the maps alone cannot show which direction they are moving. Multiple correspondence analysis separates technology keywords from sustainability and management keywords on its first dimension, although the two dimensions explain only 37.7% of the variance. In the co-word network, industry 4.0 and supply

chain management have the highest betweenness (131.18 and 93.61) and PageRank (0.1222 and 0.1017), so they connect most of the other concepts. The positions of industry 4.0, sustainability and AI change with the algorithm, and statements about them should be read with that in mind.

The most important conclusion comes from the Future Research Agenda. The field describes what digital technologies could do for supply chains much more often than it measures what they have done. Of the 165 documents with "performance" in the title, 100 mention a survey, questionnaire or structural equation model in the abstract, and only five mention longitudinal, panel or secondary data. Only 15 of the 1,637 abstracts mention explainability or interpretability, and only 10 discuss the energy use or footprint of digital systems. Resilience is cited heavily (two of the three most cited documents concern disruption) but forms a small cluster of 47 occurrences for its leading keyword. The study therefore proposes six priorities: whether Industry 4.0 pays, who decides between managers and algorithms, resilience across the network, net sustainability, the inclusion of small firms, and the quality of the evidence base.

These findings carry implications for four groups. Academically, the study gives a structured map of a literature that is large and scattered, and it shows where a new study would add most, namely outcome-based work using longitudinal or quasi-experimental designs. For managers, the dominance of survey-based evidence means that reported gains from Industry 4.0 should be treated with care, and decisions about stock, suppliers and disruption response are a safer starting point than the technology label. Socially, India and China lead the output while the most cited barrier studies ask whether multinational and small firms have equal opportunities (Horváth and Szabó, 2019), so the cost of participation for small suppliers deserves attention. For policy, new European reporting requirements and the carbon charge on imports will make supplier-level emissions data more available, which would allow the net sustainability question to be tested.

Further research should combine Scopus with Web of Science, retain cited references, merge keyword variants and run a thematic evolution analysis, which would show whether blockchain and IoT are rising or fading. What is now needed is evidence on outcomes: studies that compare adopting and non-adopting firms over time, include the cost of failed projects, and measure emissions after the energy use of the digital systems is counted. The field has grown quickly and has a clear centre in decision making with data. Whether that centre improves cost, service, resilience and emissions in practice is the question it has yet to answer.

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