ANALYSIS ON CIRCULAR ECONOMY AND TECHNOLOGY INNOVATION TOWARDS SUSTAINABILITY IN THE MANUFACTURING SECTOR: A BIBLIOMETRIC ANALYSIS

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ABSTRACT

There has been a growing recognition of the imperative to transition towards more sustainable practices in the manufacturing sector. Aiming towards sustainable practices, the concepts of circular economy and technological innovation offer promising avenues for achieving sustainability goals. In this context, the aim is to examine the evolving research landscape concerning the integration of circular economy principles and technological innovation toward sustainability in the manufacturing sector. To achieve this objective, bibliometrics were conducted using R-Studio. A dataset of scholarly publications from Scopus and Web of Science was used for bibliometrics and analyzed. To analyze the key bibliographic data such as publication titles, authors, publication years, journal/conference names, keywords, abstracts, citation counts, etc., were extracted from the Scopus and Web of Science databases. This study, with the help of R-Studio/Biblioshiny, summarizes the data in the form of main information of the data, most relevant sources, sources production over time, word cloud, and co-occurrence network in the form of tables and figures as well. The findings of the study reveal a growing interest in integrating circular economy and sustainability with 360 documents from both databases. The key themes identified in this study are Sustainable Development, Performance, Management, Sustainability, and Framework. The main limitation of the study is that it focuses only on two databases and suggests future research with a more analytical and broader dataset. This study is most relevant for research scholars by helping them identify key research areas to explore and for organizations and governments as well by suggesting which areas to focus on more.

Keywords: Circular economy, technology innovation, sustainability, manufacturing sector, bibliometric analysis.

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INTRODUCTION

Background information

The global manufacturing sector has experienced remarkable growth and development in recent decades, driving economic progress, technological innovation, and societal advancement. However, this expanded progress also brings huge costs to our environment, with widespread environmental degradation, resource depletion, and social inequality. It is clearly evident that many sustainability programs are organized all around the world for a better future for us and the next generations. According to today's environmental conditions, there is a strong need to make the manufacturing process more sustainable around the globe.

By keeping environmental degradation, resource scarcity, and social inequity in mind, it is necessary to change the understanding and methods of industrial production to attain the sustainable development goal for society. The conventional methods of production and consumption, i.e. extraction of raw materials, manufacturing processes, and waste disposal, are now increasingly recognized as unsustainable over the long period. So there is a need to emphasize more on circular and sustainable practices, resource efficiency, waste reduction, and environmental management to tackle the limitations of old manufacturing methods.

The term Circular Economy has gained widespread attention in recent decades and has its roots in various schools of thought and culture, including "Cradle to Cradle" and "Biomimicry." The idea of a circular economy has become increasingly popular and supported by government officials, especially in China and the European Union. This approach, with the help of sustainable production practices, tries to minimize environmental impact and create a closed-loop system for maximum utilization of resources. By shifting from a linear model of production and consumption to a circular one, CE seeks to achieve sustainable economic growth while preserving natural resources and reducing ecological footprints (EU Commission, 2014; Murray et al., 2015). This innovative economic model aims to be restorative and regenerative by design, with key objectives focused on eliminating waste, replenishing natural capital, and generating economic value through the effective utilization, rather than consumption, of resources (Torres-Giner, 2023). The Circular Economy has emerged as a promising framework for achieving sustainability in the manufacturing sector. At its core, a circular economy seeks to mimic the regenerative processes found in nature, where waste is minimized, and resources are reused, recycled, and restored in a closed-loop system. By rethinking product design, material flows, and supply chain management, the circular economy offers a pathway toward a more sustainable and resilient manufacturing ecosystem.

The interdependent connection between industry and the environment significantly influences the performance of industrial enterprises. As environmental concerns escalate, the impact on industrial operations becomes increasingly pronounced, exerting mounting pressure on business performance

(Lieder & Rashid, 2016). Moreover, technological innovation has been instrumental in propelling the shift towards sustainable manufacturing methods. Progress in materials science, digitalization, automation, and renewable energy has opened up fresh avenues for enhancing efficiency, curbing waste, and reducing environmental carbon footprints. Technologies such as additive manufacturing (3D printing), Internet of Things (IoT) sensors, and artificial intelligence (AI) are revolutionizing production processes, enabling greater flexibility, customization, and resource optimization.

CE preserves the environment by reducing the consumption of natural resources (Centobelli et al., 2020), eliminating waste, preventing the depletion of resources, and relying on material loops (Prieto-Sandoval et al., 2018). The amalgamation of Circular Economy principles with technological innovation presents substantial opportunities to elevate sustainability within the manufacturing sector. By leveraging technology-driven solutions such as smart manufacturing, predictive maintenance, and the integration of renewable energy, businesses can streamline resource usage, boost operational efficiency, and reduce their carbon footprint. Furthermore, the commitment to sustainability in manufacturing isn't just about environmental responsibility; it's also an economic imperative. With rising consumer and regulatory expectations for ethically sourced, environmentally conscious, and socially responsible products, manufacturers prioritizing sustainability are poised to enhance their competitive advantage in the global market.

Research Question

What are the key trends in research on the circular economy and technology innovation in the manufacturing sector?

Motivator or importance of the study

The manufacturing sector significantly impacts the environment through resource consumption and waste generation. As such, there is an increasing need to explore sustainable practices that can mitigate these effects.

The rapid advancement of technology presents new opportunities for enhancing sustainability within the manufacturing sector. Innovations such as digitalization, automation, and green technologies are pivotal in developing sustainable manufacturing processes.

A bibliometric analysis can reveal the research landscape's evolution, including identifying key trends, influential publications, and emerging research gaps.

LITERATURE REVIEW

Circular Economy and Sustainability

A comprehensive catalogue of 15 business sustainability movements encompasses various strategies and approaches designed to promote environmental responsibility and economic viability. These movements include recycling, waste minimization, cleaner production, zero-emission, zero-growth economy, green economy, triple bottom line, life-cycle assessment, sustainable consumption, corporate social responsibility,

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blue economy, share value creation, industrial ecology, and Circular Economy (CE) (Tóth, 2019). The Circular Economy (CE) is an economic paradigm that shifts away from the traditional 'end-of-life' concept, instead prioritizing the reduction, reuse, recycling, and recovery of materials throughout the entirety of production, distribution, and consumption processes (Kirchherr et al., 2017). Sustainability emerged as an overarching concept covering CE, with "Recycle" being the most frequently addressed imperative, followed by "Remanufacture," "Recover," "Reduce," and "Repair." While CE publications in the maritime industry have increased since 2018, there is limited evidence of CE principles emerging in seaports (Razmjooei et al., 2024). In the realm of circular economy approaches, scholars and industry experts have developed various R-imperatives or R-frameworks to guide implementation. These frameworks include the 3Rs (Ghisellini et al., 2016; Kirchherr et al., 2017), 4Rs, and 6Rs (Sihvonen & Ritola, 2015), as well as more comprehensive models like the 9Rs (Potting et al., 2017) and the 10Rs (Reike et al., 2018). The circular economy interacts with various environmental protection concepts, including sustainable development (Millar et al., 2019), climate change mitigation (Chizaryfard et al., 2020), green growth, zero waste, and the minimization of environmental impact (Zink & Geyer, 2017; Korhonen et al., 2018). It has a significant impact on sectors such as infrastructure (Kucukvar et al., 2021; Ki et al., 2021a), industry (Koop et al., 2021), mining (Smol et al., 2020; Upadhyay et al., 2021), recycling (Ki et al., 2021b), and renewable energy (Farooq et al., 2021). Moreover, the circular economy requires a societal shift toward new ways of thinking and Interventions (Skene, 2022). However, some scholars suggest that instead of merely reducing production and consumption, the circular economy might sometimes lead to an increase in these activities. This phenomenon is referred to as the circular economy rebound (Zink & Geyer, 2017; Makov & Font Vivanco, 2018).

Manufacturing Sector and Sustainability

(De Angelis (2018) employs the natural resource-based view and agency theory to explore circularity approaches and the integration of digitalization technologies in Sustainable Manufacturing (SM) operations and processes. According to the natural resource-based view, three critical capabilities—pollution prevention, product monitoring, and sustainable development—are identified as key drivers for achieving competitive advantage. Agency theory suggests that circular business models can enhance recycling and asset reuse through effective monitoring and incentives. Furthermore, digital technologies like the Internet of Things (IoT) are instrumental in asset tracking, significantly improving efficiency (Lahti et al., 2018).

The term "sustainability" was initially coined in 1980 within the World Conservation Strategy. However, it wasn't until the release of Our Common Future (WCED, 1987) that sustainability gained widespread acknowledgment, particularly in tandem with the perspective of development, giving rise to the term “sustainable development.” Victor (1991) defines sustainable development as attaining the highest extent of progress feasible without exhausting a nation’s capital assets, primarily consisting of its natural resource base. Attaining a sustainable ecological footprint per capita, especially in nations with very high human development, is feasible through a 40% reduction in the ecological footprint, a goal attainable with existing knowledge and technologies (WWF, 2012; IEA, 2012). Increasing the proportion of renewable energy in the energy mix to at least 27% by 2030 is deemed both achievable and realistic. The rapid growth in renewable energy deployment, along with the ample technical potential and opportunities for further integration, suggests that this threshold is within reach (IPCC, 2011). However, achieving this target will require supportive policies and measures to stimulate the transition to renewable energy sources (Holden et al., 2014). Sustainable development seeks to surpass traditional concepts of economic advancement and societal welfare by adopting a more comprehensive approach. It involves tackling a diverse array of interlinked issues, including energy, urbanization, poverty reduction, hunger, and the advancement of environmentally sound economic growth (Bonnedahl et al., 2022; Filho et al., 2023). The pivotal roles of green finance and corporate governance in China’s sustainable development objectives are underscored, with green monetary policy exhibiting superior efficacy when compared to green fiscal policy (Zhao & Xing, 2024).

Technology Innovation and Sustainability

Hicks (1932) was the pioneer in introducing the concept of technology effects, suggesting that fluctuations in product prices drive firms to prioritize innovation. Innovation is a key driver of socio-economic development, and it is primarily technological advancements that yield profitability (Dai, M., 2012). Command-controlled regulations have the most positive impact, while market-incentivized regulations offer flexibility and greater potential for promoting green development. Though green technology innovation improves sustainability, the impact of green product innovation is minimal, indicating an area for improvement (Wang, M., 2022). It is essential to differentiate between the types of green technology innovation, such as green product innovation and process innovation (Clark, K., 1998). While changes in production processes can foster new product innovations, technological advancements do not always result in product innovation (Shao, S., et.al., 2022).

Research Gap

InSufficient focus on sector-specific challenges and opportunities for implementing CE and technological innovations in the manufacturing sector. Lack of quantitative metrics and comprehensive bibliometric analysis linking CE and technological innovation with measurable sustainability outcomes in manufacturing. Underexploration of the role of emerging technologies (such as AI, IoT, blockchain, etc.) in enabling CE practices and sustainable manufacturing.cturing.

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RESEARCH METHODOLOGY

Objective

To examine the evolving landscape of research concerning the integration of circular economy principles and technological innovation towards sustainability in the manufacturing sector.

Research Design

This study utilized bibliometric analysis to examine the progression of Circular Economy (CE) research within the context of sustainability in the manufacturing industry. Specifically, it investigated the interconnection between CE and sustainability, tracked the development of CE within studies on Sustainable Manufacturing (SM), and outlined the present status of CE R-imperatives within manufacturing industry research. By employing bibliometric analysis as a quantitative method, the study efficiently identified collaboration patterns, research clusters, and areas of knowledge deficiency. Furthermore, it elucidated the intellectual framework of the investigated domain along with its evolving trends (Donthu et al., 2021). For bibliometric analysis, data is abstracted from Scopus and Web of Science using "circular economy, technology innovation, sustainability, and manufacturing sector" as keywords. The important observation is that, by using these keywords collectively, no result is shown. The result is abstracted using two keywords one by one in inverted commas, which is shown in Table 1.

Table: 1 summarizes the number of documents found on Scopus and Web of Science for various keyword combinations. The keywords are Circular Economy, Technology Innovation, Manufacturing Sector, and Sustainability. A significant amount of research is found on the intersection of Circular Economy and Sustainability, with 241 documents in Scopus and 119 in Web of Science. In contrast, only 12 documents in Scopus and 4 in Web of Science explore the connection between Technology Innovation and Sustainability. The combination of Manufacturing Sector and Sustainability is scarcely researched, with just 2 documents in Scopus. For the intersection of Technology Innovation and Circular Economy, there are 2 documents in Scopus and 1 in Web of Science. The lack of data for the combinations of Circular Economy and Manufacturing Sector, and Technology Innovation and Manufacturing Sector, indicates potential gaps in the research for these specific areas. Overall, the table highlights

Table 1:

Keywords	No. of documents from Scopus	No. of documents from Web of Science
Circular economy and manufacturing sector	-	-
Circular economy and sustainability	241	119
Technology innovation and manufacturing sector	-	-
Technology innovation and sustainability	12	4
Manufacturing sector and sustainability	2	-
Technology innovation and circular economy	2	1

a stronger research emphasis on sustainability within the circular economy framework, while other intersections involving technology and specific sectors remain less explored.

RESULTS

After extracting the data, the total number of documents from Scopus and Web of Science is 255 and 124 respectively and analyzed with the help of R Studio and biblioshiny. The information abstracted from these two databases includes main information, most relevant sources, sources production over time, word cloud, and co-occurrence network. These results will help in determining the future directions for research and trying to fill the gap. The analyzed results are shown below:

Main Information

Table: 2 Source: Biblioshiny

Description	Results
MAIN INFORMATION ABOUT DATA	
Timespan	2017:2024
Sources (Journals, Books, etc)	79
Documents	124
Annual Growth Rate %	31.13
Document Average Age	2.16
Average citations per doc	51.18
References	10821
DOCUMENT CONTENTS	
Keywords Plus (ID)	591
Author's Keywords (DE)	485
AUTHORS	
Authors	553
Authors of single-authored docs	7
AUTHORS COLLABORATION	
Single-authored docs	7
Co-Authors per Doc	4.59
International co-authorships %	37.1
DOCUMENT TYPES	
article	80
article; early access	2
article; proceedings paper	1
book review	1
editorial material	8
review	31
review; early access	1

Description	Results
Timespan	2007:2024
Sources (Journals, Books, etc)	183
Documents	255
Annual Growth Rate %	23.86
Document Average Age	2.38
Average citations per doc	34.78
References	0
DOCUMENT CONTENTS	
Keywords Plus (ID)	1673
Author's Keywords (DE)	874
AUTHORS	
Authors	996
Authors of single-authored docs	22
AUTHORS COLLABORATION	
Single-authored docs	24
Co-Authors per Doc	4.1
International co-authorships %	30.59
DOCUMENT TYPES	

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Description	Results
MAIN INFORMATION ABOUT DATA	
article	121
article article	1
article conference paper	1
book	7
book chapter	33
conference paper	32
conference review	2
editorial	6
erratum	10
note	2
retracted	1
review	39

Table: 2 interprets all the main information, that a researcher or analyst wants to know to carry research and for analysis; like number of documents, type of document, document content, average growth rate, authors, author collaboration, time span etc.; this information is abstracted from both the databases and this is shown in a single table to make the reader easy to compare as well both the databases.

Most relevant sources

Web of Science Scopus

Table 3: Source: Biblioshiny

Sources	Articles
SUSTAINABILITY	16
JOURNAL OF CLEANER PRODUCTION	11
ENVIRONMENT DEVELOPMENT AND SUSTAINABILITY	5
BUSINESS STRATEGY AND THE ENVIRONMENT	4
APPLIED SCIENCES-BASEL	3
MANAGEMENT DECISION	3
SCIENCE OF THE TOTAL ENVIRONMENT	3
ANTIOXIDANTS	2
DRYING TECHNOLOGY	2
ENERGIES	2

Sources	Articles
CIRCULAR ECONOMY AND SUSTAINABILITY	18
SUSTAINABILITY (SWITZERLAND)	12
JOURNAL OF CLEANER PRODUCTION	10
ENVIRONMENT, DEVELOPMENT AND SUSTAINABILITY	5
BUSINESS STRATEGY AND THE ENVIRONMENT	4
SCIENCE OF THE TOTAL ENVIRONMENT	4
APPLIED SCIENCES (SWITZERLAND)	3
FRONTIERS IN SUSTAINABILITY	3
IFIP ADVANCES IN INFORMATION AND COMMUNICATION TECHNOLOGY	3
JOURNAL OF ENVIRONMENTAL MANAGEMENT	3

Table: 3 summaries the information regarding the most relevant sources of both the databases and this is shown in descending order to make it easily understandable; which journal is contributing highest in their field and make it easy for researchers and scholars to easily set targets for publications and to find most relevant journal for their research.

Most relevant sources

Web of Science Scopus

Source: Biblioshiny (figure:1)

From Figure: 1, it is interpreted that four journals are common in this field these are: Journal of Cleaner Production, Business Strategy and Environment, Environment, Development and Sustainability and Management Decision. The most relevant source is from the Web of Science with 16 documents i.e. Sustainability and from Scopus its Circular Economy and Sustainability with 18 documents.

Sources Production over time

Table:4 Source: Biblioshiny

Year	SUSTAIN-ABILITY	JOURNAL OF CLEANER PRODUC-TION	ENVIRONMENT DEVELOPMENT AND SUSTAIN-ABILITY	BUSINESS STRATEGY AND THE ENVIRON-MENT	APPLIED SCIENC-ES-BASEL	MANAGE-MENT DECI-SION	SCIENCE OF THE TOTAL ENVIRON-MENT
2017	0	1	0	0	0	0	0
2018	0	1	1	1	0	0	0
2019	1	5	1	1	0	1	1
2020	1	6	1	1	0	1	1
2021	6	10	1	2	1	1	1
2022	10	10	1	2	2	2	2
2023	13	11	1	4	3	3	3
2024	16	11	5	4	3	3	3

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Table 4 shows the frequency or number of documents generated by the most relevant or active sources in its field per year of Web of Science. This indicates that the frequency of documents published per year is increasing, but few of them have a constant frequency compared to last year and may increase as the year is not finished yet because the data is abstracted in the middle of the year. This suggests that work on these keywords began in 2017.

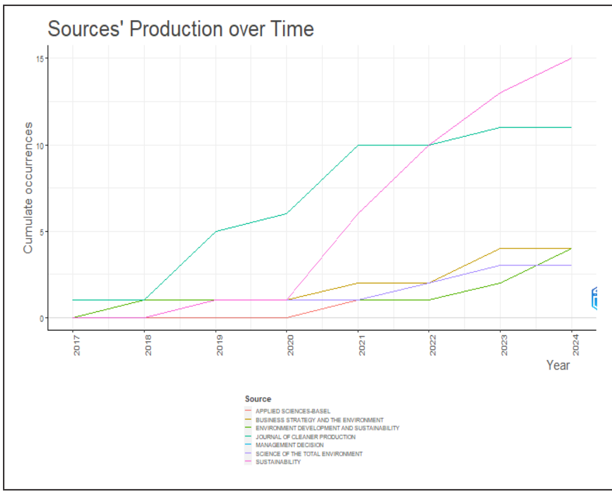
Sources Production over time

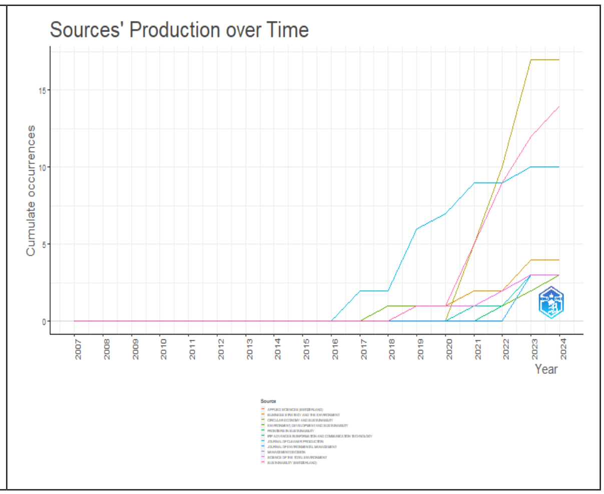
Table: 5 shows the data abstracted from Scopus and the publication started in the year 2017. The frequency of the published documents is increasing per year. And few journals started working in this field in later stages like in 2021 or 2019; these journals are Circular Economy and Sustainability and Sustainability (Switzerland) respectively. Circular Economy and Sustainability started its publication in the year 2021, and publishing documents at a very high and increasing rate.

Table 5: Source: Biblioshiny

Year	CIRCULAR ECONOMY AND SUSTAINABILITY	SUSTAINABILITY (SWITZERLAND)	JOURNAL OF CLEANER PRODUCTION	ENVIRONMENT, DEVELOPMENT AND SUSTAINABILITY	BUSINESS STRATEGY AND THE ENVIRONMENT	SCIENCE OF THE TOTAL ENVIRONMENT
2017	0	0	2	0	0	0
2018	0	0	2	1	1	0
2019	0	1	6	1	1	1
2020	0	1	7	1	1	1
2021	5	5	9	1	2	1
2022	10	8	9	1	2	2
2023	17	11	10	1	4	3
2024	18	14	10	5	4	4

Source production over time
Web of Science Scopus





Source: Biblioshiny (figure: 2)

Figure: 2, shows that sustainability and circular economy and sustainability both journals have the highest production and increase continuously over time. After 2020 both the journals show a sudden increase in publication. The Journal of Cleaner Production has been working in these areas since 2017 and increasing its publication yearly.

Word cloud

Web of Science Scopus

Source: Biblioshiny (figure: 3)

Figure: 3 interprets that the larger words are frequently used by the researchers and the most significant words in both the databases, as the size decreases frequency also decreases. Word cloud is the visual representation of the text based on the frequency of the text. Sustainable development, circular economy, sustainability and recycling are the most commonly used keywords in Scopus documents and performance, management, framework, management are frequent words used in the Web of Science.

Frequency of words in the word cloud

Web of Science Scopus

Table 6: Source: Biblioshiny

Terms	Frequency
performance	21
management	15
framework	12
innovation	10
design	8
sustainability	8
systems	8
efficiency	7
life-cycle assessment	7
model	7
recovery	7
waste	7
water	7
challenges	6
barriers	5
behavior	5
business models	5
indicators	5
supply chain	5
system	5
sustainable development	**89**
circular economy	**64**

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recycling	**32**
sustainability	**32**
waste management	**16**
life cycle	**14**
environmental impact	**13**
biomass	**12**
article	**11**
agriculture	**10**
carbon	**10**
economic and social effects	**10**
tensile strength	**10**
wastewater treatment	**10**
decision making	**9**
greenhouse gases	**9**
cellulose	**7**
climate change	**7**
economics	**7**
innovation	**7**

Table 6 shows the top 20 keywords of a word cloud, indicating the frequency of the keywords in the word cloud. The higher the frequency, the greater the prominence of the word in the word cloud. This table suggests which keywords are commonly used by researchers in their studies and which words they can use to find and fill research gaps. Additionally, this information interprets that the frequency of the keywords suggests which database is working more in which field, and accordingly, it is helpful for future research references in their field or areas of interest.

Co-occurrence network

IIn the co-occurrence table, the "Node" column lists the different terms or concepts within the network. These represent the entities whose relationships are being analyzed. The "Cluster" column indicates the grouping or community to which each node belongs. Nodes in the same cluster are more closely related to each other than to nodes in other clusters. Betweenness centrality measures the extent to which a node lies on the shortest paths between other nodes. A high betweenness score suggests that the node acts as a bridge or connector within the network, facilitating communication between different parts. Closeness centrality indicates how quickly a node can reach all other nodes in the network. It is calculated as the inverse of the average length of the shortest paths to all other nodes. A higher closeness value suggests that a node is more centrally located. PageRank evaluates the importance of a node based on the number and quality of links pointing to it.t. A higher PageRank value suggests greater influence or importance within the network.

Web of Science

Table 7 indicates that there are five clusters in total, with cluster 3 having the maximum number of nodes and cluster 5 having the lowest number of nodes. In cluster 1, "Life-cycle assessment" has the highest betweenness and PageRank within this cluster, suggesting it is a key term in this group. In cluster 2, "Framework" stands out with high betweenness, closeness, and PageRank, indicating its central importance in this cluster. In cluster 3, "innovation" has the highest betweenness and PageRank, signifying its influential role. In cluster 4, "Performance" has the highest scores across all three metrics, making it a highly central and influential node. In cluster 5, there are only two nodes, "model" and "system," both showing maximum closeness centrality (a value of 1), indicating they are crucial connectors in the network, even though they have low betweenness and PageRank scores.

Table 7: Source: Biblioshiny

Node	Cluster	Betweenness	Closeness	PageRank
life-cycle assessment	1	25.595122	0.01515152	0.03696818
waste	1	5.43190109	0.01639344	0.0226765
municipal solid-waste	1	0	0.01111111	0.01321288
framework	2	57.0979127	0.02380952	0.07422448
sustainability	2	14.7011481	0.01960784	0.03823287
systems	2	25.3769956	0.02083333	0.0508158
efficiency	2	2.42360599	0.02	0.04280985
business models	2	3.76167958	0.01960784	0.03067621
indicators	2	0.76496674	0.01960784	0.0364551
opportunities	2	0	0.01515152	0.01166622
management	3	51.9547313	0.02380952	0.09613762
innovation	3	67.179441	0.02325581	0.09496008
design	3	3.67684332	0.01851852	0.03506996
recovery	3	0	0.01818182	0.01767633
challenges	3	0	0.01538462	0.01803458
barriers	3	0	0.01923077	0.02413361
impact	3	0	0.01851852	0.01808051
capabilities	3	0	0.01612903	0.01786754
perspectives	3	0	0.01492537	0.01181443
big data	3	0	0.01492537	0.01181443
performance	4	151.035653	0.02777778	0.15480897
water	4	0	0.01666667	0.01475626
technologies	4	0	0.01818182	0.02080937
pyrolysis	4	0	0.01666667	0.01162322
supply chain management	4	0	0.01666667	0.01162322
acceptance	4	0	0.01666667	0.01162322
model	5	0	1	0.03571429
system	5	0	1	0.03571429

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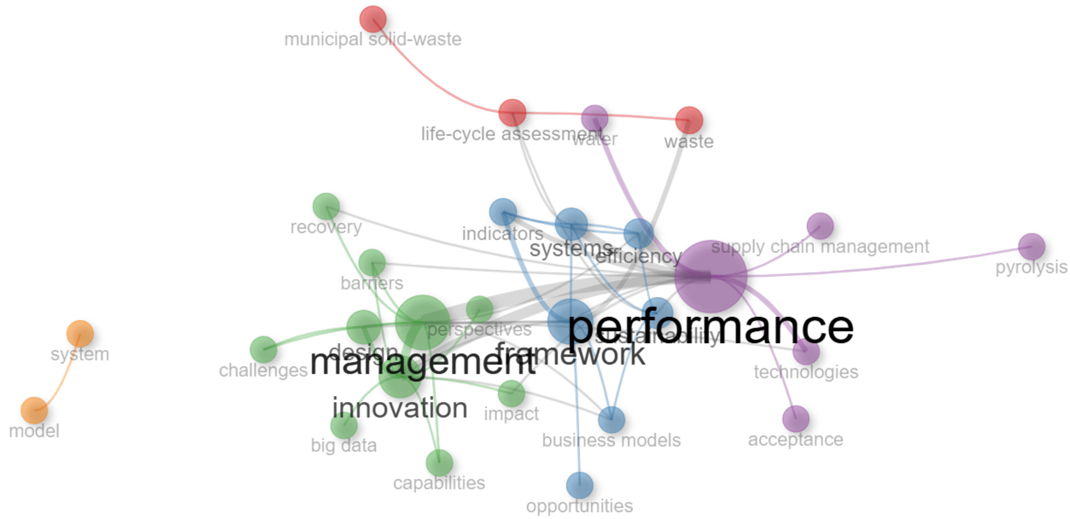

This figure shows the result of data from the Web of Science

Source: biblioshiny (figure: 4)

Figure 4 interprets that the largest nodes in the center of the network likely represent the most important or frequently occurring terms. For example, "Performance" appears prominently suggesting it is a key term in the dataset. Different colored clusters indicate thematic groupings. For example, there might be a cluster focused on management concepts, another on frameworks, and others on more specialized topics. The edges connecting nodes between different clusters show the relationships or co-occurrences of terms across different themes.

Scopus

Table 8 interprets that cluster 2 has the highest number of nodes and cluster 5 has the lowest number of nodes. In cluster 1, "Sustainability" has the highest betweenness, closeness, and PageRank in the cluster, indicating it is a critical connector and influential node. In cluster 2, "sustainable development" has very high betweenness, closeness, and PageRank scores, highlighting its central and influential roles. This cluster contains many terms related to environmental and economic considerations. In cluster 3, "Metabolism" has notable betweenness, indicating it acts as an important connector within its cluster. In cluster 4, nodes generally have lower centrality metrics, suggesting they may be more specialized or peripheral in the overall network. In cluster 5, "Valorization" stands out with relatively high betweenness and PageRank, indicating its relevance in connecting different concepts related to this cluster.

Table 8: Source: Biblioshiny

Node	Cluster	Betweenness	Closeness	PageRank
recycling	1	11.8203846	0.01298701	0.04271981
sustainability	1	77.923422	0.01408451	0.06704341
waste management	1	7.48396869	0.01204819	0.02534515
biomass	1	24.1160581	0.01298701	0.03337537
article	1	2.90167232	0.01204819	0.02951368
agriculture	1	0.02941176	0.01111111	0.0112646
carbon	1	1.25747747	0.01190476	0.01950165
tensile strength	1	0.46693122	0.01123596	0.01300549
wastewater treatment	1	0.09836066	0.01149425	0.01301955
greenhouse gases	1	2.28902389	0.01190476	0.02255159
economics	1	0.27901316	0.01149425	0.01655104
innovation	1	0	0.01086957	0.00974076
phosphorus	1	0	0.01075269	0.00738641
adsorption	1	0.28888889	0.01111111	0.01023601
china	1	0	0.01052632	0.00610764
economic analysis	1	0	0.01098901	0.00794852
environmental economics	1	0	0.01123596	0.01263523
environmental sustainability	1	1.19714022	0.01176471	0.01777475
municipal solid waste	1	0	0.01086957	0.00795263
sustainable development	2	598.049077	0.01960784	0.19016668
circular economy	2	257.940011	0.01754386	0.13362272
life cycle	2	1.57679041	0.01190476	0.02608334
environmental impact	2	0.665085	0.01149425	0.02108598
economic and social effects	2	0.16752545	0.01136364	0.01895594
decision making	2	0	0.01098901	0.01394755
climate change	2	0.05309735	0.01098901	0.01287113
product design	2	0	0.01098901	0.01284714
supply chains	2	0.38529746	0.01136364	0.01516682
alkalinity	2	0	0.00970874	0.00489968
environmental management	2	0	0.01111111	0.00972863
lignin	2	0.33936316	0.01098901	0.01050158
literature reviews	2	0	0.01075269	0.01027974
systematic literature review	2	0	0.01086957	0.01104522
business models	2	0	0.01075269	0.00789483

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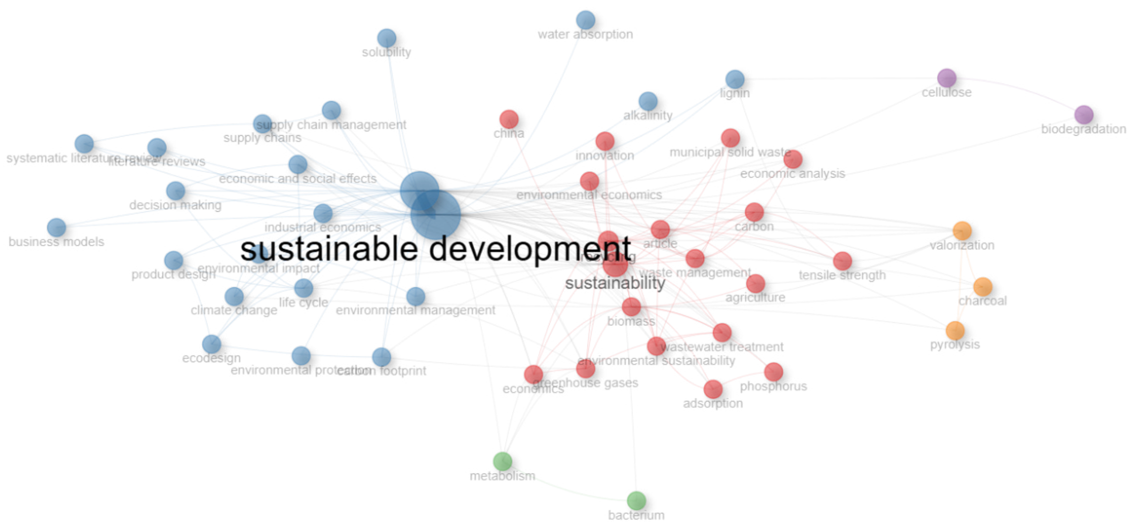
Node	Cluster	Betweenness	Closeness	PageRank
carbon footprint	2	0.13059515	0.01123596	0.01113908
ecodesign	2	0.17118746	0.01111111	0.01370658
environmental protection	2	0	0.01030928	0.00552859
industrial economics	2	0	0.01075269	0.00849573
solubility	2	0	0.01075269	0.00550991
supply chain management	2	0	0.01111111	0.00924663
water absorption	2	0	0.01030928	0.0043268
bacterium	3	0.08	0.00869565	0.00616235
metabolism	3	3.58972719	0.01111111	0.01088305
cellulose	4	0.33333333	0.01052632	0.00953612
biodegradation	4	0	0.01041667	0.00664271
charcoal	5	0.46609878	0.01052632	0.01021451
pyrolysis	5	0	0.01020408	0.00881132
valorization	5	3.90105859	0.01176471	0.01702636



This figure shows the result of data from Scopus

Source: biblioshinhy (figure: 5)

Figure 5 interprets the largest nodes in the center of the network, likely representing the most important or frequently occurring terms. For example, "sustainable development" appears prominently, suggesting it is a key term in the dataset. Different colored clusters indicate thematic groupings. For example, there might be a cluster focused on circular economy concepts, another on sustainability, and others on more specialized topics. The edges connecting nodes between different clusters show the relationships or co-occurrences of terms across different themes.

DISCUSSION

The research focuses on analyzing the evolution of circular economy studies within the context of sustainability, particularly in the manufacturing sector. It emphasizes the importance of comprehending the interplay among circular economy, technological innovation, and sustainability to promote durable practices within the manufacturing industry. This analysis reveals an interesting fact about the occurrence of certain keywords across both databases. “Circular economy and sustainability” are the most researched topics, while other combinations like technology innovation and the manufacturing sector showed fewer results. This suggests further research on the intersection of circular economy, technology innovation, and manufacturing sustainability to fill the gap and also help in attaining SDGs like SDG 9 and SDG 11. The findings of this bibliometric analysis provide valuable information for researchers interested in circular economy, technology innovation, and sustainability in the manufacturing sector. This suggests an opportunity for further exploration and development of integrated frameworks that utilize technological advancements to enhance circular economy practices. The analysis of both datasets indicates that major themes such as sustainable development, circular economy, performance, management, and framework lead the research areas. However, this study addresses a notable gap specifically, the integration of technological innovation with circular economy principles in the manufacturing sector. This gap acts as a valuable research area for scholars trying to develop comprehensive frameworks integrating advanced technologies to achieve sustainability goals.

Green Technological innovations such as the Internet of Things (IoT), artificial intelligence (AI), and additive manufacturing (3D printing) play a major role in the transformation of lean manufacturing to the circular economy. Keywords like sustainability, waste management, sustainable development, circular economy, efficiency, recycle, recovery, etc., are the most influential according to this analysis. Furthermore, studying these keywords also helps policymakers and organizations to achieve their sustainability goals and work for the environment and society as well. It’s the responsibility of every organization to work for the three P’s (People, Planet, Profit), and this can be possible with the integration of technology innovation and circular economy in the manufacturing sector. Nowadays, consumers are also focusing on the environment and trying to purchase eco-friendly products, so those manufacturers that prioritize sustainability can enhance their competitive advantage and work for the three P’s. These practices help improve brand image, customer loyalty, and compliance with regulations, which can lead to increased market share and profitability. This study emphasizes the importance of integrating circular economy principles with technological innovation to promote sustainability in the manufacturing sector.

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Implications

The findings offer actionable insights for managers and policymakers in the manufacturing sector. From strategic planning and innovation management to supply chain optimization and corporate social responsibility initiatives, managers can leverage the insights to drive organizational change and foster sustainable practices. Implementing a circular economy and sustainable manufacturing practices results in significant cost savings through efficient resource utilization, waste reduction, and energy conservation, improving profitability and contributing to environmental preservation and social well-being. Rethinking supply chain management to incorporate circular principles improves supply chain resilience and reduces dependency on finite resources. Companies can develop closed-loop systems that enhance material flow and reduce the environmental impact. The findings of this study are helpful for research scholars as well. With this, they can find the gap and the most influential keyword in their area of interest in the study, i.e., related to sustainability.

Limitations and Future Research Direction

The main limitation of this study is that it focuses only on the two databases, i.e. Scopus and Web of Science. While extracting the data from databases, no screening was done because the number of publications was low. Further research can be done in this area using more analytical tools, and an empirical study should also be conducted in the manufacturing sector by taking "circular economy and technology innovation" into consideration.

CONCLUSION

The study illuminates the dynamic landscape of the circular economy, technology innovation, and sustainability research within the manufacturing sector. It highlights the increasing attention and scholarly interest in these interconnected fields, reflecting a growing recognition of their importance for achieving sustainable development goals. The analysis identifies emerging trends and research priorities, such as the embedding of circular economy principles into manufacturing processes, the role of technology innovation in driving sustainability, and the importance of collaborative approaches to address complex sustainability challenges. Despite the progress made in understanding the circular economy and technology innovation in the context of sustainability, the analysis also reveals certain knowledge gaps and areas requiring further exploration. This includes the need for more research on specific intersections, such as the integration of digital technologies in circular economy practices or the impact of regulatory frameworks on sustainable manufacturing. The analysis highlights the importance of interdisciplinary collaboration and knowledge sharing in advancing research and practice in the circular economy, technological innovation, and sustainability. By fostering partnerships between academia, industry, and government agencies, stakeholders can collectively address sustainability challenges and accelerate the transition towards a circular and sustainable manufacturing sector. This bibliometric analysis shows that technology innovation and the manufacturing sector both lack research work towards sustainability and, according to today's requirements, it's important to work towards sustainability for any country and organization, as well as for a better future and the healthy lives of our young ones.

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