STM JOURNALS

Journal of
Polymer & Composites

https://journals.stmjournals.com/jopc

ISSN: 2321-2810 (Online)
ISSN: 2321-8525 (Print)
Volume 14, Special Issue 1, 2026
DOI (Journal): 10.37591/JoPC

Research JoPC

A Decade of Research on Polymer Manufacturing and Industry 4.0 Integration: A Comprehensive Bibliometric Review of Industry

M. Vasavi[1,]*, T. Prem Chander[2], P. Sushmai[3], A. Lakshmi Bai[4]

Abstract

The advent of Industry 4.0 has brought a transformative revolution to the manufacturing sector by integrating advanced polymer technologies with intelligent, interconnected, and data-driven production systems. These developments have significantly reshaped industrial operations by improving efficiency, enhancing production flexibility, and enabling innovative manufacturing practices. Smart polymer processing, supported by automation, artificial intelligence, the Internet of Things (IoT), and real-time data analytics, allows manufacturers to optimize resource utilization, reduce waste, and achieve higher levels of product customization. Over the past two decades, there has been a remarkable increase in scholarly attention toward this interdisciplinary domain, reflecting its growing academic and industrial relevance across materials science, engineering, and digital manufacturing disciplines. The present study offers a comprehensive evaluation of the existing literature on polymer manufacturing within the context of Industry 4.0, covering research publications available up to August 2025. A systematic and structured search strategy resulted in the identification of 1,485 relevant studies, which were subsequently analyzed using advanced bibliometric tools, including R programming and VOS viewer. These analytical techniques enabled the extraction of meaningful insights related to publication trends, collaborative networks, influential authors, leading institutions, and emerging research themes within the domain. The findings reveal a rapid expansion of research activity, highlighting the increasing global interest in smart polymer manufacturing systems. In addition to quantitative bibliometric analysis, the study also examines theoretical advancements and practical implications for industrial implementation. Furthermore, it identifies existing research gaps, discusses methodological limitations, and outlines potential future research directions aimed at enhancing sustainability, scalability, and technological integration in polymer-based manufacturing under the Industry 4.0 paradigm.

Keywords: Bibliometric Analysis, R programming, VOS viewer, Trends, Authors, universities

***Author for Correspondence**
M. Vasavi
E-mail: m.vasavi@cvr.ac.in

[1]Senior Assistant Professor, Department of Computer Science and Engineering, CVR College of Engineering, Hyderabad, Telangana, India
[2]Associate Professor, Department of Computer Science and Engineering, Matrusri Engineering College, Saidabad, Hyderabad, Telangana, India
[3]Assistant Professor, Department of Computer Science and Engineering, Matrusri Engineering College, Saidabad, Hyderabad, Telangana, India
[4]Senior Lecturer, Department of Computer Science and Engineering, Smt. Durgabai Deshmukh Government Women's Technical Training Institute, Hyderabad, Telangana, India

Received Date: February 14, 2026
Accepted Date: March 05, 2026
Published Date: March 25, 2026

Citation: M. Vasavi, T. Prem Chander, P. Sushmai, A. Lakshmi Bai. A Decade of Research on Polymer Manufacturing and Industry 4.0 Integration: A Comprehensive Bibliometric Review of Industry. Journal of Polymer & Composites. 2026; 14 (Special Issue 1): S1897-S1905p.

INTRODUCTION

Industry 4.0 has recently gained popularity; it is seen as the most required choice by academics and industrialists for resolving most of industrial challenges [1]. The phrase "Industry 4.0" first appeared in 2011, and the notion of Industry 4.0 began. The integration of Industry 4.0 and polymer technologies signifies a significant transformation in how industrial systems operate, manage, and create value. Polymer manufacturing employs cutting-edge digital techniques, such as the Internet of Things (IoT), artificial intelligence (AI), big data analytics, cyber-physical systems, and cloud computing to build highly linked and flexible production environments. Industry 4.0, sometimes known as the "fourth industrial revolution," provides the basis for this shift, enabling real-time data exchange, automation, and intelligent decision-making across the value chain. The integration of these technologies not only boosts productivity and efficiency, but it also promotes flexibility, sustainability, and adaptation to changing market demands. Furthermore, polymer manufacturing encourages seamless human-machine collaboration, predictive maintenance, and resource management, ensuring that businesses can compete in a rapidly changing global marketplace. Polymer manufacturing and Industry 4.0 are redefining industrial processes, paving the path for creative, resilient, and sustainable production systems.

REVIEW OF LITERATURE

One of the most significant advances in current industrial practice is the integration of polymer manufacturing within the broader framework of Industry 4.0. Industry 4.0, which was founded by Germany's Industrie 4.0 initiative, is positioned as the fourth industrial revolution, with an emphasis on cyber-physical systems (CPS), the Industrial Internet of Things (IIoT), advanced analytics, and end-to-end digitalization [2]. While polymer manufacturing focuses on data-driven flexibility and intelligence in production processes, its full potential is realized only when it is integrated into the larger Industry 4.0 ecosystem.

Reference Architectures and Standards for Integration

Reference architectures are often regarded as critical tools for guiding integration efforts. RAMI 4.0 provides a three-dimensional framework for mapping assets across the life cycle, hierarchy levels, and information layers [3]. Similarly, the Industrial Internet Reference Architecture (IIRA) encourages cross-domain integration of physical assets, information technologies, and business layers [4]. These frameworks allow enterprises to see integration holistically. The OPC Unified Architecture (OPC UA) has become the de facto standard for machine-to-machine communication, allowing for secure, vendor-neutral, and platform-independent data transfer [5]. The ISO 23247 standard for digital twins (DTs) provides principles for developing interoperable frameworks that may synchronize virtual and physical entities in manufacturing systems.

Digital Twins as Integration Engines

Digital twins (DTs) are commonly regarded as important integration mechanisms in Industry 4.0. DTs, which are virtual representations that are constantly synchronized with their physical counterparts, act as shared information hubs, connecting operational technologies, corporate systems, and analytics platforms [6]. According to the findings, semantic heterogeneity and concerns about data provenance impede practical integration via DTs. Without specified vocabularies and digital threads that connect product and process data across the life cycle, DT integration typically results in bespoke, non-scalable solutions.

Brownfield Integration and Legacy Systems

The issue of incorporating Industry 4.0 technology into brownfield sites has arisen as a popular topic in the literature. Most businesses utilize outdated technology that was not designed for digital communication, thus retrofitting solutions are crucial. Researchers [7] go over approaches including edge gateways for protocol translation, non-intrusive sensors for monitoring, and digital overlays that generate partial digital twins of traditional assets.

Interoperability, Semantics, and Data Governance

Beyond technological connectivity, integration necessitates robust semantic interoperability and governance mechanisms. Protocol-level interoperability (via OPC UA, MQTT, or 5G-enabled communication) addresses transport difficulties, but semantic interoperability is still in the works. Researchers believe that higher-level integration necessitates shared ontologies, standard information models, and contextualized data schemas [8]. Control and data sovereignty are serious inter-enterprise issues. Initiatives, such as Gaia-X and International Data Spaces promote federated data architectures, in which organizations may safely interchange data without losing control [9].

Empirical Outcomes of Integration

Empirical studies typically demonstrate that integration efforts result in significant gains in operational efficiency. Predictive maintenance, enabled by integrated CPS and analytics, reduces downtime and extends equipment life. Integrated digital twins aid in production scheduling and quality control choices, while interoperable architectures provide flexible and adaptive production lines [10]. Despite these gains, research indicates a discrepancy between pilot programs and large-scale rollouts. Many organizations struggle to expand beyond limited demonstrations due to unresolved interoperability, governance, and organizational preparation issues [11].

Research Gap

Many studies focus on technology issues like automation and data analytics, but little attention is paid to the obstacles of interoperability, cybersecurity, labor preparation, and high adoption costs. Furthermore, although major firms are rapidly adopting Industry 4.0 technology, small, and medium-sized businesses face considerable implementation challenges owing to financial, technological, and organizational restrictions [12]. There is also a scarcity of comprehensive frameworks linking technological and intellectual contributions to polymer innovation and commercial solutions in the industrial sector. These difficulties underscore the need for more research on realistic integration models with altimetrics, policy support mechanisms, and cross-disciplinary techniques that may promote widespread and inclusive adoption of polymer manufacturing in a variety of industrial contexts [13].

Research Methodology

To fulfill our study aims, we undertook a systematic review that focuses on the following search string: (TITLE-ABS-KEY (Polymer manufacturing and Industry 4.0 integration)) [14]. The study approach was carefully developed to ensure rigor and reproducibility. The Scopus database, which is widely regarded as one of the most comprehensive sources of peer-reviewed literature, was used to collect data. The keyword search was performed using the phrase "polymer technologies and Industry 4.0 integration." The data extraction was done on August 24, 2025, and covered the publishing period of 2014 to 2025. To ensure uniformity and accuracy, only English-language papers were reviewed [15].

RESULTS AND DISCUSSION

The distribution of documents by subject area, as shown in Figure 1, highlights the dominance of technical and applied fields in research. Engineering has the highest percentage (29%), followed by Computer Science (25%), which combined account for more than half of the overall output, highlighting the importance of technology-driven studies in contemporary research trends. Decision Sciences (6.7%), Business and Management (6.2%), and Mathematics (6.2%) contribute mid-level contributions by giving theoretical, managerial, and analytical support to the primary technical fields. Meanwhile, Materials Science (4.1%), Physics and Astronomy (3.9%), Energy (3.5%), and Chemical Engineering (3.2%) all stress the importance of innovation in long-term scientific development. While accounting for just 2.8%, the social sciences contribute by studying human and societal aspects of development. Furthermore, 9.4% of articles span a wide range of themes, demonstrating the multidisciplinary character of current research, including scientific and social viewpoints.

The trend of documents per year by source shows a steady increase in publications from 2015 to 2020, followed by a sharp growth beginning in 2023, with the peak occurring in 2024. Among the sources, Applied Sciences Switzerland made the most contributions in 2024, with 15 documents, while IFIP Advances in Information and Communication Technology and Lecture Notes in Mechanical Engineering both had a considerable increase over the same time. In contrast, Lecture Notes in Networks and Systems and Procedia CIRP (Figure 2) saw milder variations, peaking in 2020 and again in 2024. However, most sources show a fall in 2025, suggesting that the 2024 jump may have been a one-time research boom rather than a continuing increasing trend. Overall, the results show an increase in research effort in recent years, notably in applied and technical domains, which aligns with the growing worldwide emphasis on innovation and technological development.

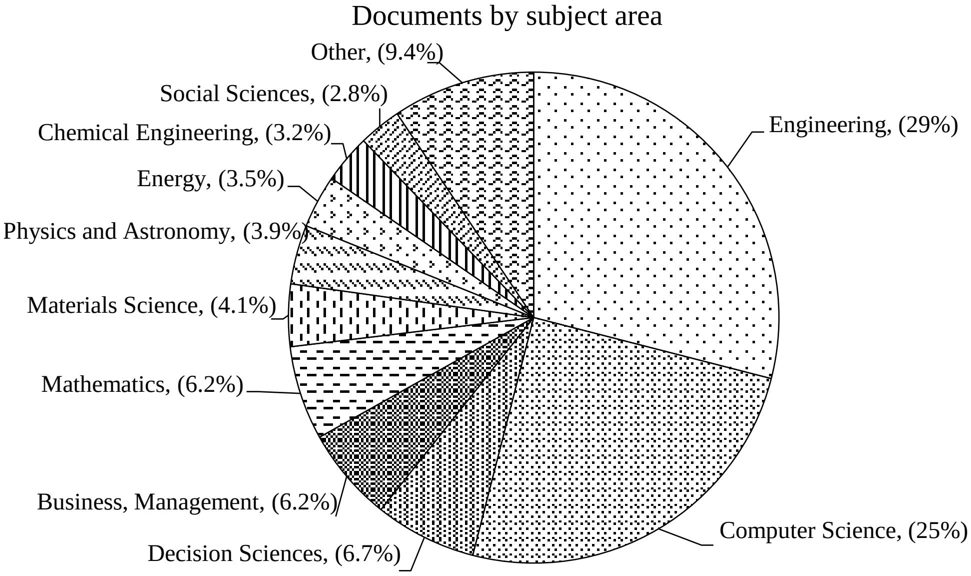

Figure 1. The trend of documents per year by source.
Source: correlation of source to domain interest.

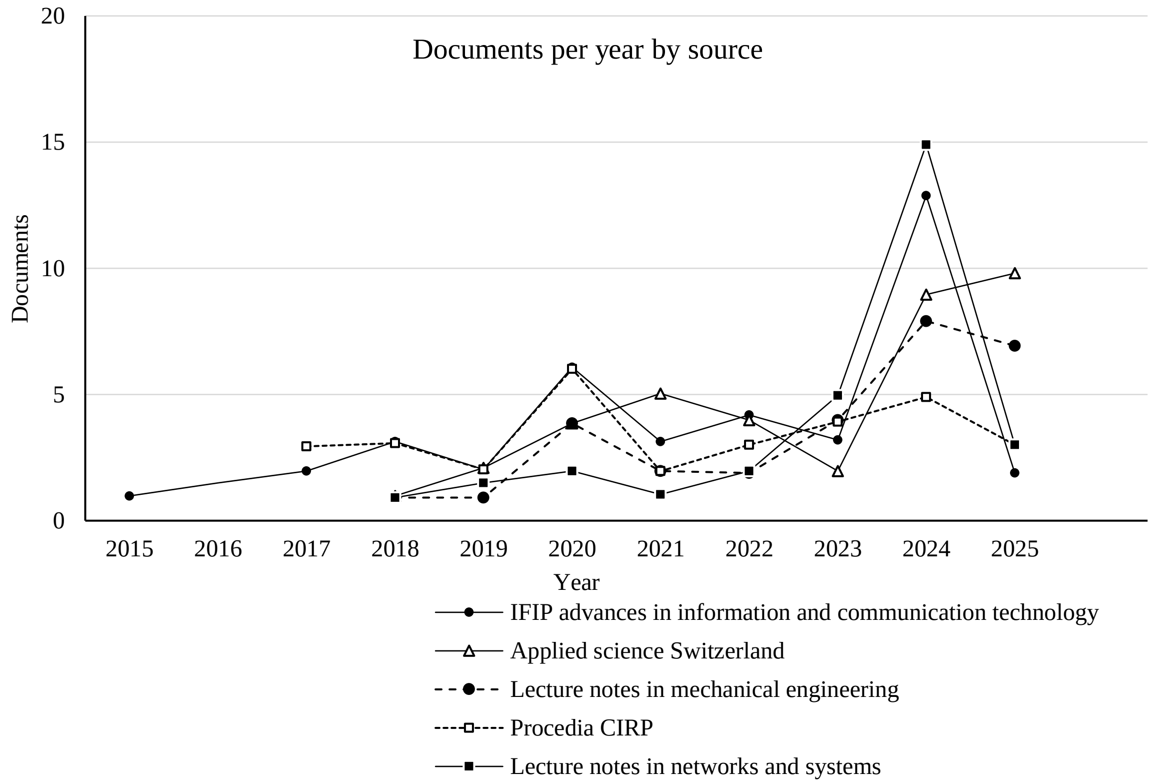

Figure 2. Research efforts.
Source: source is from IFIP advances and data stream.

Journal of Polymer & Composites
Volume 14, Special Issue 1
ISSN: 2321-2810 (Online), ISSN: 2321-8525 (Print)

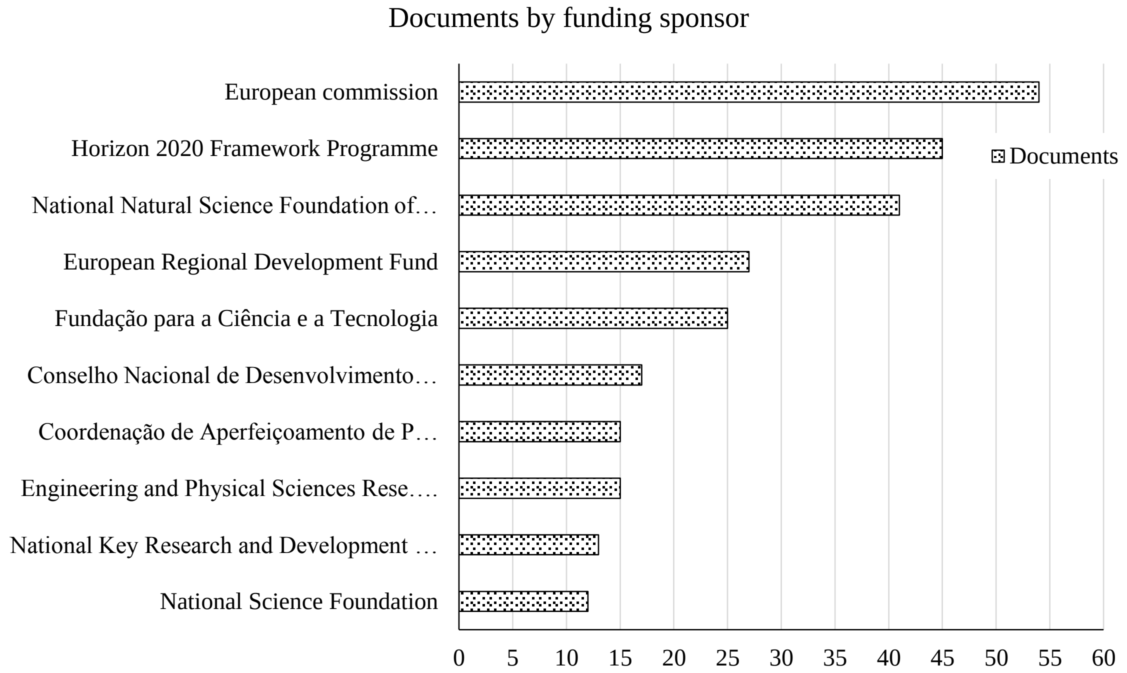

Figure 3. Significant contributions in development program.
Source: collection data stream and technologies

The examination of papers by financial sponsor indicates that the European Commission is the top donor. The Horizon 2020 Framework Programme and China's National Natural Science Foundation came next, supporting around 40 to 45 articles apiece. The European Regional Development Fund and Fundação para a Ciência e a Tecnologia both make considerable contributions, with around 25 articles each. Brazilian institutions, such as CNPq and CAPES, as well as the EPSRC in the United Kingdom, the National Key Research and Development Program in China, and the National Science Foundation in the United States, provide moderate assistance ranging from 15 to 20 papers (Figure 3). These findings highlight the critical role of European and Chinese funding organizations in boosting research outputs, while also reflecting the global nature of scientific advancement, which is assisted by significant contributions from Brazil, the United Kingdom, and the United States.

The distribution of documents by type reveals that Conference papers account for the biggest percentage (40.9%), emphasizing the significance of conferences in presenting new findings and stimulating intellectual exchange. Journal articles are close behind, at 35.0%, highlighting the importance of peer-reviewed publications in establishing credibility and stimulating scholarly discourse. Book chapters (Figure 4) (12.0%) and review papers (8.4%) provide significant contributions, indicating the value of both comprehensive synthesis of prior content and collaborative academic volumes. In contrast, conference reviews (2.1%) and books (1.3%) make just a little contribution, while editorials, short surveys, and retracted articles each contribute 0.1% of total production. This distribution emphasizes the importance of conferences and journal publication as essential information dissemination vehicles, while also recognizing the complementary role of reviews and book-based contributions in affecting the academic environment.

The distribution of papers by nation or territory indicates that India has the most publications, with about 250 documents, followed by the United States with around 160. Germany and Italy also have strong research outputs, each giving more than 120 documents, while China and the United Kingdom are close behind with over 100 documents each. Brazil, France, Spain, and Portugal yield 50-60 documents (Figure 5), showing a moderate yet significant research presence.

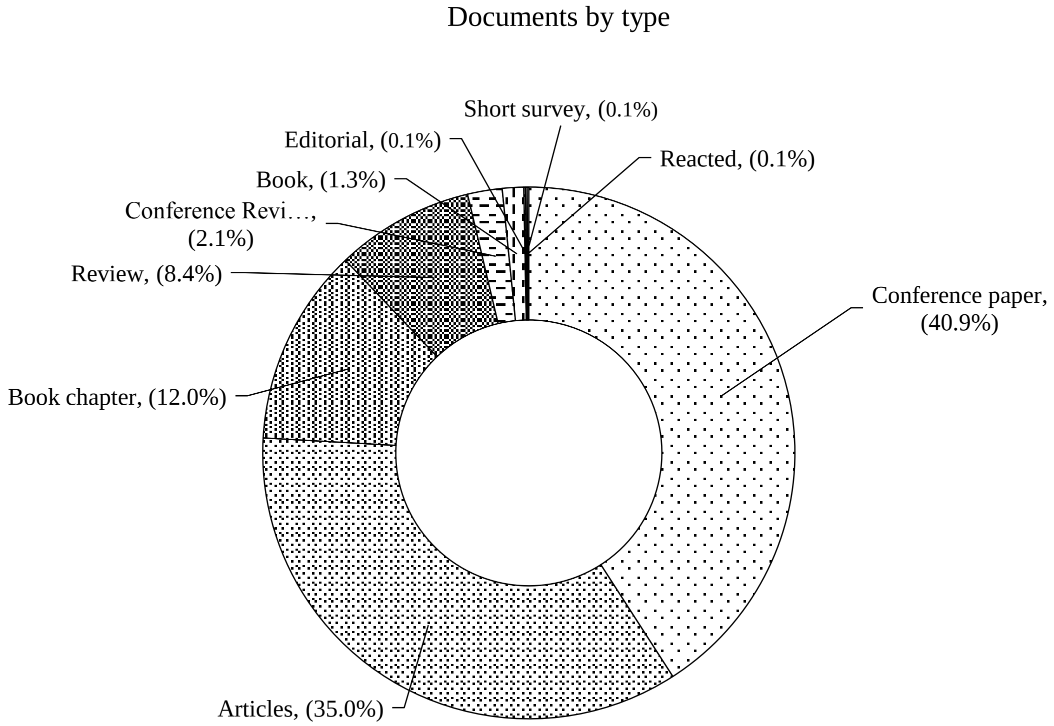

Figure 4. Distribution of documents ratio.
Source: data stream of collection and analysis.

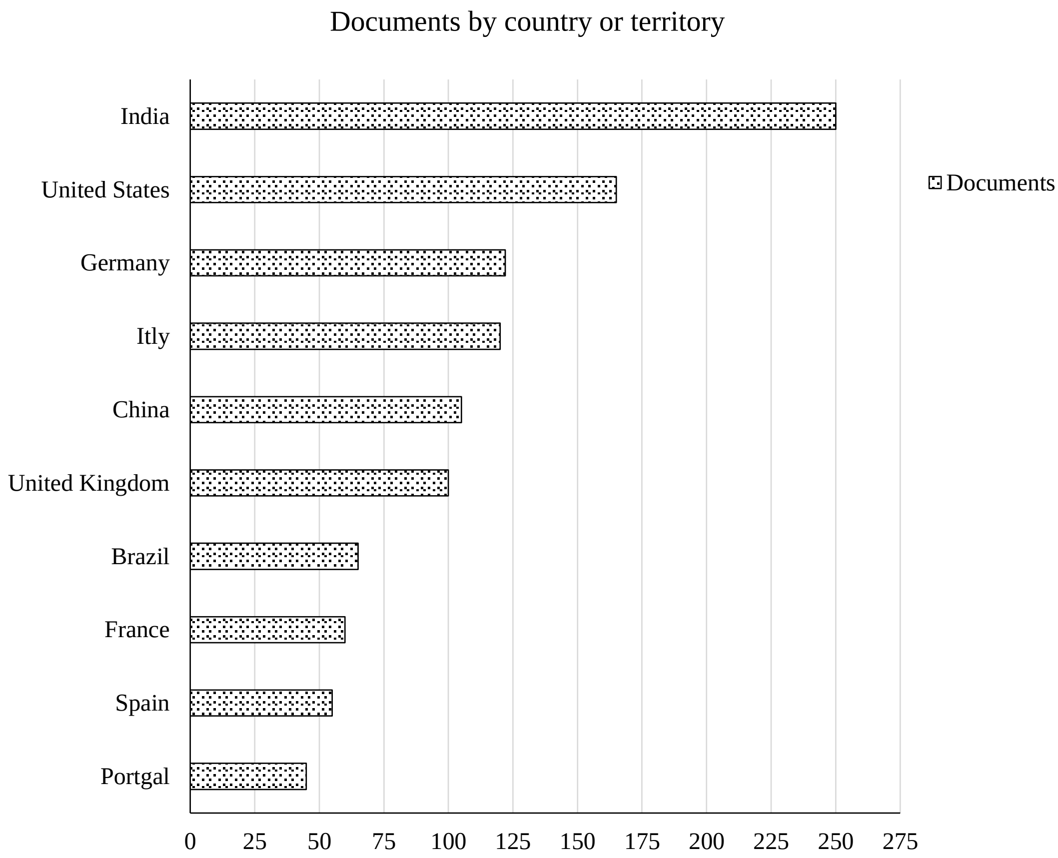

Figure 5. Development and emerging technologies ratio.
Source: analysis and collection meta data

This distribution identifies India and the United States as the key drivers of global research contributions, with significant participation from European countries and China. The findings indicate a geographically diverse research landscape, with both developed and emerging economies playing important roles in growing academic productivity.

DISCUSSION

The bibliometric analysis indicates that Industry 4.0 research is mostly focused on engineering and computer science, which account for the great majority of publications. This theme emphasizes the vital role of technical innovation in defining polymer manufacturing, while contributions from decision sciences, business, and mathematics demonstrate the evolution of multidisciplinary perspectives. Small but important contributions from materials science, energy, and the social sciences indicate the growing emphasis on sustainability and human-centered issues. Publication trends show modest growth until 2020, followed by a significant increase after 2023, with Applied Sciences Switzerland, IFIP Advances in Information and Communication Technology, and Lecture Notes in Mechanical Engineering (Figure 6) emerging as key academic distribution outlets.

Funding patterns show considerable support from European and Chinese organizations, as well as donations from Brazil, the United Kingdom, and the United States, indicating a worldwide research effort. India is first in publication volume, followed by the United States and numerous European countries, indicating both established and growing centers of competence. Prominent writers, like Mourtzis, D. and Szejka, A.L., as well as organizations, such as RWTH Aachen University (Figure 7) and Tecnológico de Monterrey, contribute to the field's collaborative and international character. Overall, the findings represent Industry 4.0 as a fast developing, interdisciplinary subject, highlighting the need for future research to be more inclusive and balanced in terms of technological, managerial, and social viewpoints.

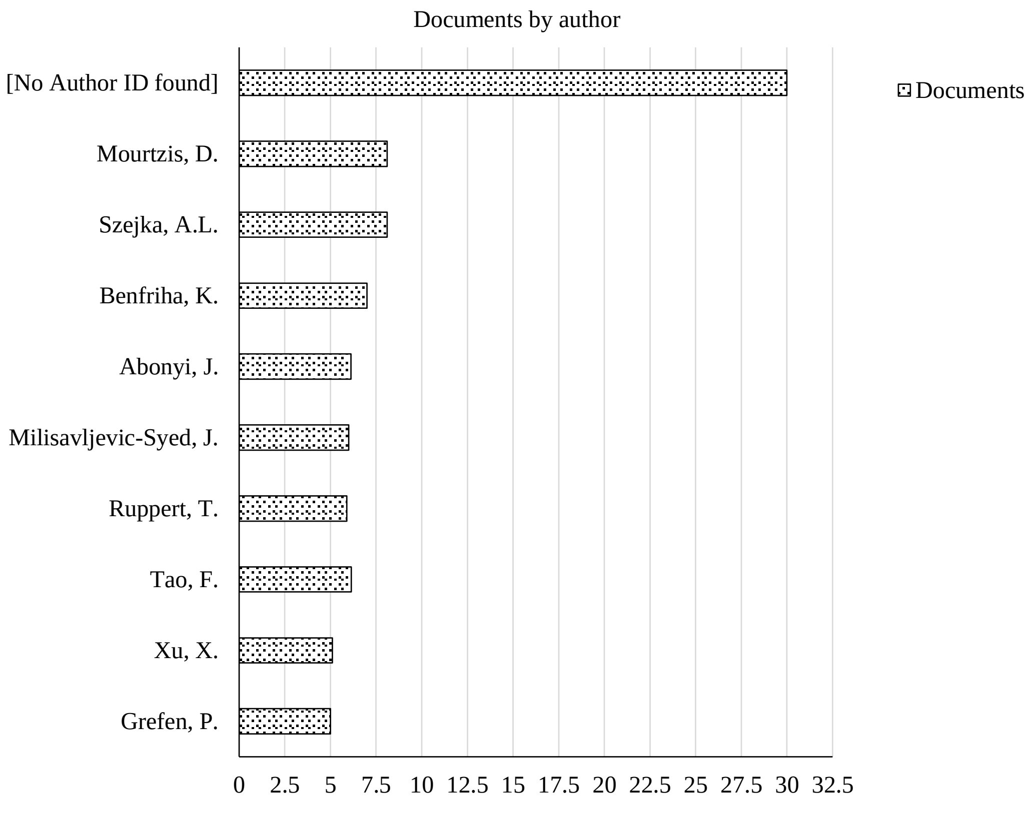

Figure 6. Author interests in research.
Source: research domain acceptance

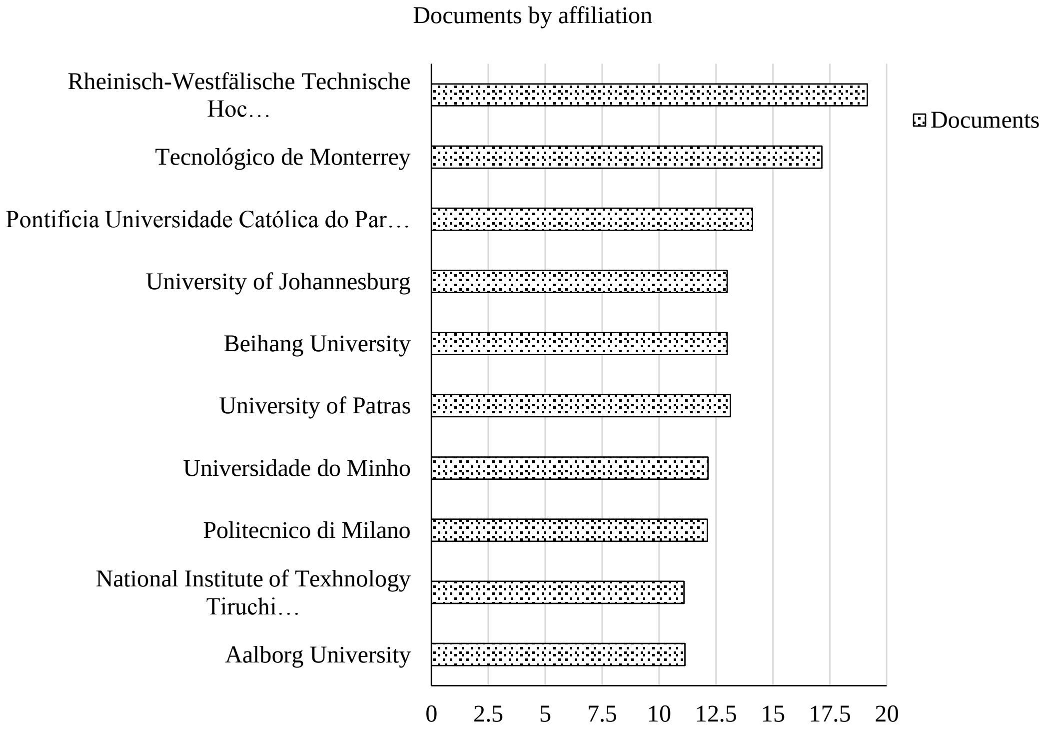

Figure 7. Affiliation of each author of interest.
Source: multi list of data collection and ranking

CONCLUSION, LIMITATIONS, AND FUTURE DIRECTIONS

Although the integration of polymer manufacturing and Industry 4.0 has received substantial research, some limitations remain in the existing body of knowledge. First, much of the present research is conceptual or based on pilot studies, with little large-scale empirical data supporting the long-term success of Industry 4.0 adoption in various industrial contexts. The lack of defined measuring methods also makes it impossible to compare results from different research or set appropriate standards for judging maturity levels. Second, although technology enablers, such as IoT, digital twins, and AI have received extensive coverage, less attention has been paid to the socio-technical problems of integration, such as worker resistance, organizational change management, and cultural hurdles. Third, adoption of Industry 4.0 is very unequal, with small and medium-sized firms (SMEs) experiencing disproportionate obstacles owing to financial restrictions, aging infrastructure, and cybersecurity vulnerabilities.

Finally, sustainability issues are frequently considered as secondary results rather than primary aims, leaving substantial gaps in understanding how digital transformation might connect with environmental and social objectives. Future research should overcome these constraints by taking many approaches. More longitudinal and industry-specific case studies are needed to assess the long-term performance impacts of Industry 4.0 deployment, particularly in terms of productivity, resilience, and sustainability. Furthermore, there is a need to create standardized maturity models and performance indicators that can assist enterprises through the various stages of digital transformation. Researchers should also conduct a more in-depth investigation into the human dimension of polymer manufacturing, with an emphasis on worker upskilling, human-machine collaboration, and change resistance methods. Furthermore, given the unequal adoption of Industry 4.0, future research should target frameworks customized to SMEs, focusing on cost-effective, scalable, and interoperable solutions. Finally, sustainability, and ethical implications should be central to polymer manufacturing research, with a focus on how digitalization may help with circular economy practices, energy efficiency, and responsible data governance. By addressing these issues, future research can contribute to a more comprehensive and inclusive understanding of polymer manufacturing and Industry 4.0 integration.

REFERENCES

1. International Organization for Standardization. (2021). ISO 23247-1: Digital twin framework for manufacturing—Overview and general principles. ISO.Kagermann, H., Wahlster, W., & Helbig, J. (2013). Recommendations for implementing the strategic initiative INDUSTRIE 4.0. acatech.
2. Khan, A., Javaid, N., & Rehman, A. (2023). Digital twin-driven polymer manufacturing: A review of integration challenges and solutions. Journal of Manufacturing Systems, 68(2), 75–89.
3. Lee, J., Bagheri, B., & Kao, H. A. (2015). A cyber-physical systems architecture for Industry 4.0-based manufacturing systems. Manufacturing Letters, 3(1), 18–23.
4. Lin, S. W., Miller, B., Durand, J., & Joshi, A. (2017). The Industrial Internet Reference Architecture. Industrial Internet Consortium.
5. Lu, Y. (2017). Industry 4.0: A survey on technologies, applications, and open research issues. Journal of Industrial Information Integration, 6, 1–10.
6. Moeuf, A., Pellerin, R., Lamouri, S., Tamayo-Giraldo, S., & Barbaray, R. (2020). The industrial management of SMEs in the era of Industry 4.0. International Journal of Production Research, 58(6), 1523–1542.OPC Foundation. (2023). OPC Unified Architecture—Release 15. OPC Foundation.
7. Otto, B., Lohmann, S., & Steinbuß, S. (2021). Data sovereignty in Industry 4.0: Principles and challenges. Business & Information Systems Engineering, 63(5), 407–421.
8. Qi, Q., & Tao, F. (2018). Digital twin and big data towards polymer manufacturing and Industry 4.0: 360° comparison. Journal of Manufacturing Systems, 48, 210–219.Rojas, R., Rauch, E., & Matt, D. T. (2017). Integration of legacy systems in Industry 4.0: A review. Procedia Manufacturing, 11, 1119–1126.
9. Schweichhart, K. (2016). Reference Architectural Model Industrie 4.0 (RAMI 4.0). Plattform Industrie 4.0. Sjödin, D., Parida, V., Leksell, M., & Petrovic, A. (2021). Polymer factory implementation and integration: A socio-technical perspective. Journal of Business Research, 131, 311–320.
10. Wollschlaeger, M., Sauter, T., & Jasperneite, J. (2017). The future of industrial communication: Automation networks in the era of the Internet of Things and Industry 4.0. IEEE Industrial Electronics Magazine, 11(1), 17–27.
11. Palaniappan, M., Palanisamy, S., Murugesan, T., Tadepalli, S., Khan, R., Ataya, S., and Santulli, C. (2024). "Influence of washing with sodium lauryl sulphate (SLS) surfactant on different properties of ramie fibres," BioResources 19(2), 2609-2625.
12. Ramasubbu, R., Kayambu, A., Palanisamy, S., and Ayrilmis, N. (2024). "Mechanical properties of epoxy composites reinforced with Areca catechu fibers containing silicon carbide," BioResources 19(2), 2353-2370.
13. Ayrilmis N, Kanat G, Yildiz Avsar E, Palanisamy S, Ashori A. Utilizing waste manhole covers and fibreboard as reinforcing fillers for thermoplastic composites. Journal of Reinforced Plastics and Composites. 2024;44(17-18):1108-1118. doi:10.1177/07316844241238507
14. Improving performance of composites: Natural and synthetic fibre hybridisation techniques in composite materials – A review, Author links open overlay panelBhuvaneshwaran Mylsamy , Karthik Aruchamy
15. Experimental Analysis and Design Proposal of Banana Fiber Reinforced Polymer Composites and Computer Analysis, Saipogu Lalitha, T. Prem Chander, M. Vasavi**,,** https://doi.org/10.37591/JOPC.v13i06.233979

