Promoting sustainable and human-centric industry 5.0: a thematic analysis of emerging research topics and opportunities

Sivarajah Rajumesh
Department of Marketing, Faculty of Management Studies and Commerce, University of Jaffna, Jaffna, Sri Lanka

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Abstract

Purpose – The study aims to explore the overall growth trend, top publishing countries, co-authorship and author keywords in the field of Industry 5.0.

Design/methodology/approach – This study presents the outcomes of a bibliometric analysis conducted using VOSviewer software. The analysis retrieved data from the Scopus database, including citations, co-authors, keywords, bibliometric coupling and co-occurrence.

Findings – The findings reveal a significant increase in publications and citations related to Industry 5.0 in recent years. China, the USA and India emerge as the leading countries driving research in this field. The co-authorship analysis indicates limited collaboration among authors, with only 48 out of 354 authors being linked through co-authorship. Through co-occurrence analysis, the investigation identifies the most frequently occurring keywords in the research, with "Industry 5.0" and "Industry 4.0" being the most frequently co-occurring keywords. The bibliographic coupling analysis identifies six clusters of research themes.

Research limitations/implications – The study solely relies on data gathered from the Scopus database for analysis on a specific date. Therefore, data from other databases collected at different times may yield different observations and findings.

Practical implications – This study enhances the knowledge of professionals and academia in Industry 5.0, enabling the professionals to efficiently and sustainably manage the sector.

Originality/value – The bibliometric analysis presented in this study provides valuable insights into the contributions made by authors, keywords and co-authors to the field of Industry 5.0. Additionally, the thematic analysis summarized in this study is a novel contribution to the field.

Keywords Industry 5.0, Bibliometric analysis, Sustainability, Human-centric, Artificial intelligence

Paper type Literature review

1. Introduction

Digital technologies offer numerous opportunities to transform industries and gain a competitive advantage by creating new business models (Fraga-Lamas *et al.*, 2021). Over the past 2 decades, there have been significant advancements in both software and hardware, leading to substantial technical growth. The close relationship between artificial intelligence (AI) and information technology (IT) has facilitated the cross-fertilization of ideas and innovation.

Digital transformation, a result of these developments, exhibits two main characteristics: divergence and degradation. Industry 4.0, with the objective of making production "smart" by integrating machines and equipment that can interact throughout their life cycle, serves as

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a fundamental concept. In contrast, Industry 5.0 envisions a fusion of human expertise with powerful, intelligent and precise machines to drive unique innovation. Many technological enthusiasts believe that Industry 5.0 will restore the human connection in the manufacturing industry (Nahavandi, 2019).

The rapid technological advancements in Industry 5.0 have intensified organizational competition across all sectors and industries. In light of this, technical competitiveness is crucial for businesses to differentiate themselves from competitors, predict new market entrants, foster competitiveness and enhance overall performance and sustainability (Alvarez-Aros and Bernal-Torres, 2021). Mass customization plays a pivotal role in Industry 5.0, empowering consumers to select customized and tailored products that align with their preferences and needs (Maddikunta *et al.*, 2022). With the promise of personalized, large-scale production, Industry 5.0 has elevated the concept of personalization and brought it in a completely greater direction, laying the foundation for human–machine interaction and collaboration. Undoubtedly, the collaboration between humans and machines within the manufacturing industry will redefine and reshape their respective roles. Industry 5.0 also brings substantial benefits to the Industrial Internet of Things (IIoT) through a human–machine interface. The Internet of Things (IoT) encompasses a network of interconnected smart devices, machinery and sensors that are connected to the internet (Sarma *et al.*, 2021; Turner *et al.*, 2020).

The global agenda for sustainable development is primarily focused on stimulating the sustained expansion of the global economy through the creation of productive employment opportunities driven by advances in scientific and technical knowledge. Many advanced economies recognize sophisticated technical production as a crucial tool for coping with the new industrial revolution wave. Industry 5.0 (I5.0) aims to generate synergies between technological and human mechanisms, enabling personalized mass customization of goods and services, similar to the rapid technological breakthroughs achieved during the fourth industrial revolution (I4.0) to achieve high performance (Prassida and Asfari, 2021).

The latest wave of industrial revolution, emphasized by human–machine collaboration (Industry 5.0), promotes greater integration between humans and machines. This new manufacturing paradigm necessitates regular data interchange over networks between production equipment and industrial information systems, presenting significant challenges in developing diverse industrial network protocols (Al Faruqi, 2019; Skobelev and Borovik, 2017). With the emergence of breakthrough technologies, the industry is currently undergoing a transformative shift from the integration of digital technology with the material system (Industry 4.0) to a paradigm where human involvement plays a crucial role in both the digital and material systems (Industry 5.0). Human intelligence is essential to enhance the productivity of machine automation coupled with digital technology (Aslam *et al.*, 2020).

In the era of Industry 5.0, sensor systems with intelligence capture a vast volume of information and robots increasingly focus on assisting people through data management and intelligent computation. Individuals will actively interact with cooperative robots to advance the capabilities of machine intelligence (Zhou *et al.*, 2019; Zong *et al.*, 2021). The evolution of Industry 5.0 requires a comprehensive transformation of the human aspects within production systems to achieve socio-technical advancements. All operational processes within the value chain are carried out using intelligent methods (Longo *et al.*, 2020) and underpinned by modern digital technology (Raguseo *et al.*, 2016).

However, there is a need to assess the current state of research on the enabling technologies driving the Industry 5.0 revolution (Xu *et al.*, 2021). Engaging in a scientific literature analysis proves to be an effective method for examining and evaluating scientific publications within a specific field, which can provide insights into research trends and

knowledge gaps. Therefore, this study aims to conduct a literature review using bibliometric methods on Industry 5.0 to identify key research areas, research questions and objectives.

Industry 5.0 represents a significant transformation in the design, implementation and control of manufacturing processes. The integration of AI, big data analytics and IoT is expected to revolutionize manufacturing, making it more efficient, flexible and sustainable. Consequently, there is a growing interest in understanding the research status of pivotal technologies in Industry 5.0 (Maddikunta *et al.*, 2022).

Bibliometric analysis serves as a valuable tool for uncovering research trends, identifying knowledge gaps and recognizing influential publications within a specific field. This approach provides valuable insights for researchers, policymakers and practitioners, enabling them to assess the current state of research on pivotal technologies in Industry 5.0 and guide future research and development initiatives effectively.

To achieve these objectives, the study will address the following research questions:

RQ1. What are the emerging research areas in Industry 5.0?

RQ2. What is the extent of collaboration among scholars from different regions and fields in Industry 5.0 research?

RQ3. How do different countries contribute to Industry 5.0 research?

RQ4. What are the major themes and research topics in Industry 5.0, and how are they evolving over time?

RQ5. What are the future research avenues in Industry 5.0 research?

The main objectives of this study are to:

RO1. Identify and explore the emerging research areas in Industry 5.0.

RO2. Investigate the level of collaboration among scholars from different regions and fields in Industry 5.0 research.

RO3. Analyze the contributions of different countries to Industry 5.0 research.

RO4. Identify the major themes and research topics in the field of Industry 5.0.

RO5. Explore the future research avenues in the area of Industry 5.0 research.

2. Methods

Bibliometric analyses have become increasingly prominent across various fields of study in recent years (Turzo *et al.*, 2022). However, a significant challenge lies in the lack of transparency and reproducibility in many studies, which stems from incomplete disclosure regarding data collection, retention process and analysis protocols. To address this issue, this paper presents a novel, transparent and replicable protocol that researchers can easily implement in their future work.

To evaluate the current research landscape, we adopted a review approach based on a bibliometric analysis conducted by Marzi *et al.* (2021). We employed the visualization of similarities (VOS) technique introduced by van Eck and Waltman (2010) to cluster papers. Subsequently, we conducted a literature review following the methodology proposed by (Tranfield *et al.*, 2003).

To initiate the process, we conducted a literature analysis on Industry 5.0 practices in January 2023. The objective was to acquire an up-to-date understanding of the research topic and compile a comprehensive list of commonly used keywords in the field. Before

commencing the data collection process, we established inclusion criteria following the AMSTAR 2 protocol (Pauletto *et al.*, 2022).

The second step involved formulating the research query. The evaluation of the query devised by Hahn and Lülfs (2014) indicated the necessity for an update to accommodate advancements in the field of Industry 4.0. Consequently, we enhanced the query by incorporating supplementary terms derived from literature reviews focusing on related subjects, as well as the literature exploration conducted in step one, following the approach proposed by Dumay *et al.* (2016).

In the third phase, which occurred in February 2023, we implemented the query in the Scopus Database using the "TITLE-ABS-KEY" operator. This operator enables full-text searches across titles, abstracts and authors' keywords. The query included articles published between 2011 and 2023, document type set as "article", language as English, source type as a journal, and publication stage as final. The initial query obtained a total of 1914 results, including TITLE-ABS-KEY ("Industry 5.0") AND PUBYEAR > 2011 AND PUBYEAR < 2023 AND (LIMIT-TO (DOCTYPE, "ar")) AND (LIMIT-TO (LANGUAGE, "English")) AND (LIMIT-TO (SRCTYPE, "j")) AND (LIMIT-TO (PUBSTAGE, "final")).

We further refined the search query by limiting it to the exact keyword "Industry 5.0". As a result, the final query yielded a total of 122 relevant and significant scientific materials. The refined query included TITLE-ABS-KEY ("Industry 5.0") AND PUBYEAR > 2011 AND PUBYEAR < 2023 AND (LIMIT-TO (DOCTYPE, "ar")) AND (LIMIT-TO (LANGUAGE, "English")) AND (LIMIT-TO (EXACT KEYWORD, "Industry 5.0")) AND (LIMIT-TO (SRCTYPE, "j")) AND (LIMIT-TO (PUBSTAGE, "final")).

The fourth step entailed retrieving papers from the query and subjecting them to a cleaning process. We reviewed a total of 122 papers based on their titles and abstracts. As a result of the cleaning process, 27 articles focusing on topics such as Society 5.0, Employment 5.0 and other unrelated themes were excluded from the sample, leaving 94 papers for further analysis.

In the fifth step, we conducted a bibliometric analysis on the remaining 94 papers. We utilized the VOSviewer 1.6.19 software and employed bibliographic coupling as the aggregation criterion, following the methodology described by van Eck and Waltman (2010).

In step six, we identified clusters based on bibliographic coupling and carefully reviewed the papers within each cluster to identify thematic areas for conducting a literature review.

Step seven involved the implementation of a systematic literature review, following the recommended approach by Tranfield *et al.*, (2003) and adhering to the PRISMA protocol (Wang *et al.*, 2019).

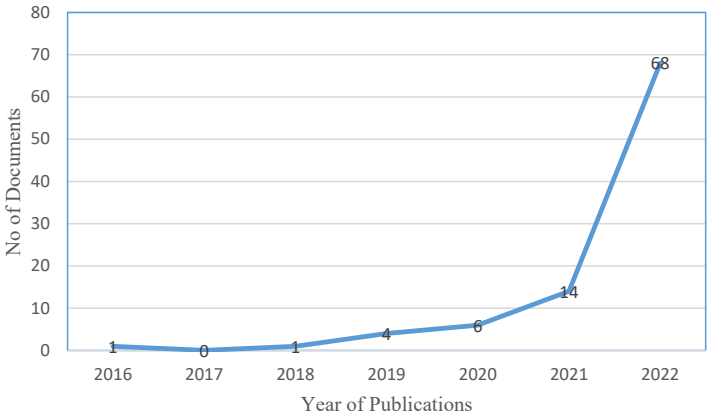
Lastly, in step eight, we provided a synthesis of the most effective managerial practices established during the reviewed period was provided, emphasizing key research directions to explore in the future. By analyzing the findings, we identified significant trends, emerging concepts and gaps in the literature, which can guide researchers in developing their future studies and contribute to the advancement of knowledge in the field of Industry 5.0.

3. Findings from the bibliometric analysis and literature review

This section presents the findings of a bibliometric analysis conducted on publications related to Industry 5.0 during the research period. To examine the influence of journals, VOSviewer, a commonly used bibliographic exploration program for bibliometric analyses (Han *et al.*, 2021), was employed.

3.1 Analysis of the overall growth trend

Figure 1 depicts the annual frequency of papers and citations related to Industry 5.0 from 2016 to 2022, excluding 2017 when no publications were available. Over the years, there has



Source(s): Figure by author

Figure 1.
Publications per year

been substantial growth in the number of publications and citations. Notably, the number of publications on Industry 5.0 experienced a significant increase in 2021 and 2022. The most productive year in terms of publications was 2022, with a total of 68 papers published.

3.2 Top ten publishing countries

Table 1 displays the top ten countries that have made significant contributions to research on Industry 5.0, based on the number of published documents. The data were extracted from the bibliometric analysis using VOSviewer software. China emerged as the leading contributor, accounting for 16% of the total documents analyzed. The USA and India followed closely as the second and third most prolific contributors, with 15 and 14% of the total documents, respectively. Italy also made a significant contribution with 12% of the documents, while the United Kingdom, Poland, Spain, Sweden, Saudi Arabia and Greece rounded out of the top ten countries, each contributing between 5% and 10% of the total documents.

3.3 Co-authorship and authors

Co-authorship analysis helps determine the degree of collaboration between authors in publications. In this study, a total of 354 scholars contributed to publications on the topic of Industry 5.0. Among the connected items, the largest group consisted of 48 pieces, divided into

Countries	No of documents
China	16
The United States	15
India	14
Italy	12
The United Kingdom	10
Poland	8
Spain	8
Sweden	8
Saudi Arabia	7
Greece	5

Source(s): Table by author

Table 1.
Top ten countries publishing in Industry 5.0 research

eight clusters based on their relatedness. There were 165 links and a total link strength of 174 within these clusters. Figure 2 provides a visualization of the co-authorship connections between authors within these clusters. For instance, author Wang I. had 19 co-author links with a total link strength of 24 across four documents in cluster one, along with nine other authors. Similarly, author Li, X. had 19 co-author links with a total link strength of 19 across four documents in cluster five, along with four other authors. Based on the given information, it is evident that there is a limited level of connection and collaboration between authors in the field of Industry 5.0, given that only 48 out of 354 authors were connected with each other through co-authorship. However, it is crucial to consider additional factors, such as research topics, geographical locations and individual research goals that may influence co-authorship patterns.

3.4 Co-occurrence and author keywords

Co-occurrence keyword analysis investigates the interconnectedness of keywords based on their frequency of occurrence within the research database. The analysis creates a network structure that highlights the relationships and link strength between co-occurring terms (Mustak *et al.*, 2021; Wu *et al.*, 2019). The interconnectedness of the keywords is assessed by examining the frequency of their occurrence together in the documents.

In this study, a co-occurrence analysis was conducted on 381 keywords and 17 keywords that appeared together at least three times were identified. The term "co-occurrence analysis" refers to the identification of the frequency with which two or more words appear together in a text corpus. In this case, this method was used to identify keywords that were most commonly used together in the context of the study. The results show that the most frequent co-occurring keywords were "industry 5.0" and "industry 4.0," with 94 and 27 occurrences, respectively, and a total link strength of 98 and 50. This suggests a close relationship and frequent discussion of these two concepts in the context of the study. Other significant co-occurring keywords included "artificial intelligence," "Society 5.0," "Internet of Things," and "sustainability." These terms are also related to the main themes of the study. Table 2 presents the co-occurrence of author keywords and their corresponding total link strength.

3.5 Citations and documents

Table 3 shows the 10 articles related to Industry 5.0 that have received the highest number of citations. The data were obtained from the bibliometric analysis, which identified the most frequently cited articles in other research publications. The article by Nahavandi (2019) received the highest number of citations, with a total of 311 citations to date. Xu *et al.* (2021)

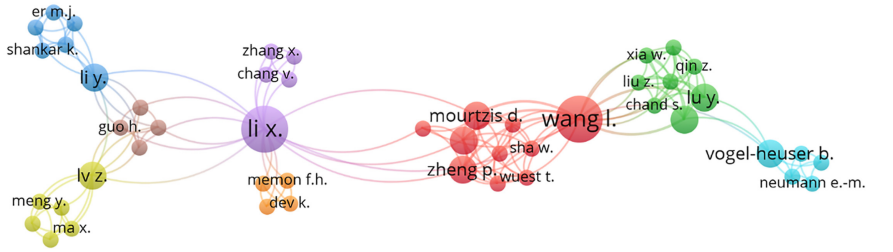


Figure 2.
Co-authorship and authors

Source(s): Figure by author

Keyword	Occurrences	Total link strength
Industry 5.0	94	98
Industry 4.0	27	50
Artificial intelligence	12	23
Society 5.0	9	20
Internet of things	5	15
Sustainability	6	13
Big data	3	9
Digital transformation	5	9
Digitalization	3	8
Edge computing	4	8
Smart manufacturing	3	8
Sustainable development	3	8
Blockchain	4	7
Human-robot collaboration	3	7
Manufacturing	4	7
Human factors	3	6
Machine learning	4	6

Source(s): Table by author

Table 2. Co-occurrence of author keywords

Author(s)	Citations
Nahavandi (2019)	311
Xu *et al.* (2021)	211
Özdemir and Hekim (2018)	200
Longo *et al.* (2020b)	112
Bednar and Welch (2020)	89
Mohd Javaid *et al.* (2020)	69
Javaid and Haleem (2020)	66
Aslam *et al.* (2020)	63
Sachsenmeier (2016)	54
Lu *et al.* (2022)	47

Source(s): Table by author

Table 3. Top ten most cited industry 5.0 related articles

and Özdemir and Hekim (2018) ranked second and third, respectively, with 211 and 200 citations each. The remaining articles in the top ten received citations ranging from 47 to 89 citations, with the most recent article by Lu *et al.* (2022) garnering 47 citations so far. The high number of citations for these articles indicates their significant contributions to the field of Industry 5.0 and their influence in shaping research in this area.

3.6 Bibliographic coupling of documents

Exploring the bibliographic coupling of documents aims to identify research projects that share a similar reference point. The strength of the relationship, for example, can be determined by the number of citations shared between two papers. To avoid redundancy, certain items are not presented. The color of each item represents the cluster, while the lines depict the relationships between different papers (van Eck and Waltman, 2013).

The researchers calculated the overall intensity of these linkages for each paper and identified the documents with the highest connection strengths. To be included in the analysis, a document had to have at least ten citations, which narrowed down the pool to 43

documents, some of which were not linked to any others. Six clusters emerged among the 29 documents that were coupled with other documents' citations. The top 10 documents with the highest link strengths and their corresponding number of citations are presented in Table 4.

The document with the highest link strength is "(Javaid and Haleem, 2020)" with 66 citations and 24 linkages to other papers, followed by "(Saniuk *et al.*, 2022a, b)" with 23 citations and 22 linkages. "Carayannis *et al.* (2022)" and "Javaid and Haleem (2020)" both have high citation counts (24 and 69, respectively) but fewer linkages (20 and 18, respectively). "Madsen and Berg (2021)" and "Carayannis *et al.* (2021a, b)" have lower citation counts (23 and 15, respectively), but relatively high link strengths (17 and 16, respectively). The paper of "Xu *et al.* (2021)" has an exceptionally high citation count (211) but relatively low link strength (13). "Akundi *et al.* (2022)" and "Sindhwani *et al.* (2022)" both have moderate citation counts (31 and 25, respectively) and link strengths (12 for both). Finally, "Carayannis *et al.* (2021a, b)" has a relatively low citation count (24) and link strength (9).

Overall, the study identified the documents with the strongest bibliographic coupling linkages, revealing clusters of related research. These findings provide valuable insights for researchers to better understand the literature in the field of Industry 5.0 and identify important areas for future research.

Figure 3 displays 29 documents organized into six clusters. The clusters vary in size, with the first cluster containing nine items, the second containing eight, the third containing five, the fourth containing three and the fifth and sixth containing two items each. In total, there were 74 links and a total link strength of 148.

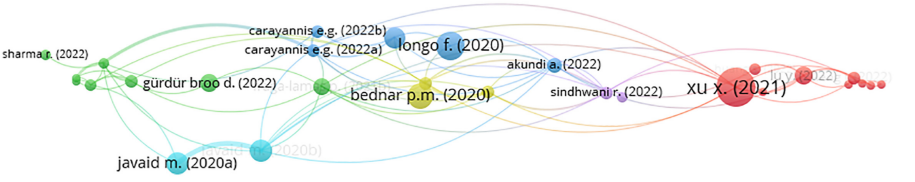
3.7 Thematic analysis of the clusters

Cluster 1: Promoting Industries and Societies that are Sustainable, Human-Centric and Resilient.

Document	Citations	Total link strength
Javaid (2020b)	66	24
Saniuk (2022a, b)	23	22
Carayannis *et al.* (2022a)	24	20
Javaid (2020a)	69	18
Madsen and Berg (2021)	23	17
Carayannis *et al.* (2022c)	15	16
Xu (2021)	211	13
Akundi *et al.* (2022)	31	12
Sindhwani (2022)	25	12
Carayannis *et al.* (2021)	24	9

Source(s): Table by author

Table 4.
Bibliographic coupling of documents



Source(s): Figure by author

Figure 3.
Bibliographic coupling of the documents

This cluster emphasizes the importance of promoting sustainable, human-centric and resilient industries and societies. For instance, Ghobakhloo *et al.* (2022) propose that Industry 5.0 surpasses Industry 4.0 in promoting sustainable development goals, presenting 16 distinct functions.

In contrast, Huang *et al.* (2022) highlight the potential confusion surrounding the coexistence of Industry 5.0 and Society 5.0. To address this, the authors recommend integrating and supplementing these concepts to achieve sustainable development.

Furthermore, Lu *et al.* (2022) suggest that future research should emphasize transparent and trustworthy technologies that create a rewarding work environment based on practical needs. Similarly, Coronado *et al.* (2022) stress the significance of human-centered smart environments for well-being and performance.

Moreover, Kaasinen *et al.* (2022) propose using the joint cognitive systems approach and complementing it with actor-network theory, the concept of operations and ethically aware design. This strategy has the potential to establish a manufacturing system that is both resilient and centered around human needs.

In summary, the studies examined in this thematic analysis provide support for the transition toward an industry that is sustainable, human-centric and resilient within the framework of Industry 5.0.

Cluster 2: The Influence of Digital Transformation on Society and Industry

This cluster focuses on the influence of digital transformation on society and industry, emphasizing the importance of sustainability, human-centric design and innovation in the context of Industry 5.0. For instance, Mihardjo *et al.* (2019) suggest an innovation model called the experience-agility model, which aims to facilitate digital transformation within the context of Industry 5.0. According to the study, organizations can improve their performance in terms of transformation by delivering an engaging customer experience and cultivating agility to drive innovation in their business models.

Furthermore, Grabowska *et al.* (2022) point out the limitations of the Industry 4.0 concept, particularly in terms of humanization and sustainability. They emphasize the necessity of enhancing humanization and sustainability by embracing the principles of Industry 5.0.

Gürdür Broo *et al.* (2022b) examine the transformations necessary in engineering education during the advent of Industry 5.0, the fifth industrial revolution. They propose four strategies that engineering education should embrace to address future challenges brought about by Industry 5.0 trends.

Overall, these studies emphasize the need for a holistic approach to digital transformation that considers both technological and societal factors.

Cluster 3: Integrating advanced technologies for sustainable and ethical innovation: the intersection of human–machine interaction, democracy and ecology

This cluster explores the integration of advanced technologies for sustainable and ethical innovation, covering various perspectives. Akundi *et al.* (2022) focus on the technological aspects of Industry 5.0 and identify major themes, such as supply chain optimization, smart and sustainable manufacturing and human–machine connectivity. Aslam *et al.* (2020) propose an innovation management framework that emphasizes the human-centered and user-oriented approach to innovation, which is relevant within the framework of Industry 5.0 and the internet of Things (IoT).

Carayannis *et al.* (2021a, b) discuss the wider societal impacts of innovation and propose the utilization of Triple, Quadruple and Quintuple Helix Innovation Systems as an approach to enhance the design and functioning of contemporary democratic societies and economies.

The authors assert that the survival of humanity relies on democracy and ecological consciousness. They suggest that the interconnectedness between the Democracy of Climate and the Democracy of Knowledge holds significant implications for strategy, policy and practical implementation, encompassing Industry 5.0 and Society 5.0.

Carayannis *et al.* (2022) introduce the Emerging Unified Theory of Helix Architectures (EUTOHA), which emphasizes the Quintuple Innovation Helix Framework as a unifying tool for optimizing cyber-physical ecosystems that are smart, sustainable, inclusive, resilient and effective, in alignment with the principles of Industry 5.0 and Society 5.0.

Longo *et al.* (2020a) emphasize the ethical and value-oriented considerations involved in future-oriented factory design. They propose the adoption of the Value Sensitive Design (VSD) approach to integrate human values into the design of Cyber-Physical Production Systems (CPPS) and Operator 4.0.

Overall, these articles offer a thorough examination of the topic of integrating advanced technologies for sustainable and ethical innovation. They underscore the significance of human-centered and value-oriented approaches, ecological consciousness, democratic principles and the imperative to optimize smart, sustainable and inclusive cyber-physical ecosystems following Industry 5.0 and Society 5.0.

Cluster 4: The Advent and Impact of Industry 5.0

This cluster focuses on the concept of Industry 5.0 and its impact. It represents a visionary concept that seeks to realize the customization of products and services on a mass scale by integrating technological and social systems (Bednar and Welch, 2020).

Madsen and Berg (2021) aim to chart the field and offer an initial overview of the development and current state of the scientific literature about Industry 5.0. The findings of their analysis demonstrate a notable upward trend in publications concerning Industry 5.0, indicating that it is still considered an emerging field with limited documentation.

The adoption of Industry 5.0 technologies presents fresh challenges in terms of knowledge and skills for industry professionals, particularly engineers responsible for implementing advanced solutions (Saniuk *et al.*, 2022a, b). The attainment of high autonomy and the potential societal advantages offered by cyber-physical systems are anticipated through the incorporation of human factors within the framework of Industry 5.0 (Saniuk *et al.*, 2022a, b).

In conclusion, the advent of Industry 5.0 technologies has noteworthy ramifications for both professionals and researchers in the field. The challenges posed by these technologies need to be addressed by better understanding the critical knowledge and skills required for their implementation.

Cluster 5: Technologies and sustainability

This cluster examines the role of technologies in achieving sustainability within the framework of Industry 5.0. Chen *et al.* (2021) introduce a human-cyber-physical system (HCPS) that combines AI and a human–machine interface for decision-making. The study highlights the use of digital twin technology and identifies key enabling technologies (KETs) to realize the HCPS concept.

Sindhwani *et al.* (2022) direct their attention toward the role of Industry 5.0 in attaining sustainability through the integration of human values and technology. The researchers put forth a multi-criteria framework to analyze the enablers of Industry 5.0. Their findings indicate that personal customization ranked highest in terms of importance, followed by human–machine collaboration, which fosters an intelligent cognitive environment for humans.

In conclusion, both articles demonstrate the importance of utilizing advanced technologies for sustainable development while considering human values and social impact.

Cluster 6: Precision and automation in Industry 5.0 technology

This cluster highlights the importance of precision and automation in Industry 5.0 technology. According to the research conducted by Javid and Haleem (2020) and Javid *et al.* (2020), the precision and swiftness of intelligent digital information and manufacturing technologies are crucial in delivering personalized therapy and treatment to individuals affected by COVID-19, given the availability of comprehensive patient data. This technology also plays a pivotal role in establishing a dynamic healthcare ecosystem with real-time capabilities. Industry 5.0 technology enhances accuracy and expedites industrial automation by leveraging human resources' critical thinking and applying human intelligence to comprehend the needs of operators. Moreover, Industry 5.0 enables digital manufacturing systems to seamlessly communicate with other systems, enabling mass customization and greater value creation.

4. Discussion

This section discusses the insights derived from current cutting-edge research that integrates and unifies advancements in Industry 5.0 technologies, which are crucial for establishing an effective Industry 5.0 ecosystem. This analysis explores six clusters of research on Industry 5.0, revealing significant findings that underscore the importance of promoting sustainable development through Industry 5.0. This includes the principles of designing with a focus on human needs and creating resilient manufacturing systems. Furthermore, it explores the consequences of digital transformation on society and industry, prioritizing sustainability, humanization and innovation. These findings highlight the necessity for a comprehensive approach to digital transformation that takes into account both technological and societal factors. The analysis also addresses the convergence of cutting-edge technologies, sustainability and ethics, underscoring the importance of human–machine interaction, democracy and ecology in promoting sustainable and ethical innovation.

The examination reveals that Industry 5.0 has significant implications for professionals and scholars, particularly for engineers who face challenges in adopting these technologies. The increasing number of publications indicates ongoing evolution and interest in the field. Analyzed articles focusing on "technologies and sustainability" highlight the importance of advanced technologies for sustainable development, while considering human values. Industry 5.0 enhances precision and automation, by utilizing human resources and intelligence, leading to substantial impacts on sustainability, humanization and innovation. Therefore, a comprehensive approach to digital transformation that considers both technology and society is necessary.

Table 5 presents the clusters identified through bibliographic coupling analysis and suggests potential topics and paths for future investigation. The table also includes relevant references to support these findings.

Table 5 provides valuable guidance for future research in the field of bibliometric analysis, such as exploring the applicability of different approaches in diverse domains and contexts and identifying potential challenges and limitations in their implementation. These directions can shape future studies in this field.

5. Conclusion

In summary, the bibliographic analysis indicates that Industry 5.0 is a burgeoning research area that has garnered substantial interest among scholars in recent times. The analysis shows an increasing trend in publications and citations related to Industry 5.0, highlighting the growing interest in this field. The top 10 publishing countries include China, the USA, Germany, Japan and South Korea. Co-authorship and authorship analysis suggests a high level of collaboration among scholars from different regions and fields. The examination of

Topics	Exemplary references	Future research avenues
Cluster 1 Human-Robot Interaction (HRI) for Industry 5.0 Sustainable Development in Industry 5.0 Human-centric design and development of Industry 5.0 manufacturing systems Joint cognitive systems for human–machine collaboration	Coronado *et al.* (2022) Ghobakhloo *et al.* (2022) Kaasinen *et al.* (2022) Leng *et al.* (2022)	• exploring the best ways to design and measure the quality of HRI in manufacturing environments • explore how Industry 5.0 can contribute to sustainable development, including developing a strategic roadmap that explains how Industry 5.0 can deliver its intended sustainability values • Focus on developing design frameworks, tools and methods that support human-centric design and development of Industry 5.0 manufacturing systems • Investigate the effectiveness of joint cognitive systems in supporting human–machine collaboration and explore the design of effective joint cognitive systems
Cluster 2 Knowledge-based innovation and decision-making processes in Industry 5.0 Next-generation Edge-AI G-IoT (Green-IoT) systems Industry 5.0 and its Implications for Humanization, Sustainability and Innovation	Carayannis *et al.* (2021) Fraga-Lamas *et al.* (2021) Sharma and Arya (2022)	• Focus on developing effective practices for knowledge-based innovation and decision-making processes in Industry 5.0 • Explore how Green IoT (G-IoT) and Edge AI can be effectively integrated to design and develop the next generation of Edge-AI G-IoT systems • Explore the potential impact of Industry 5.0 on the workforce and how it can be managed to ensure human-centric design and sustainability
Cluster 3 Democratization and Ecological Sensitivity in the Innovation System Value-Oriented and Ethical Technology Engineering for Industry 5.0	Carayannis *et al.* (2022) Longo *et al.* (2020)	• Explore how democratic principles and ecological considerations can be integrated into the innovation system to create a smart, sustainable, inclusive, resilient and efficacious Industry 5.0 ecosystem • Focus on the development of ethical and value-oriented technology engineering approaches that can guide the design and development of Industry 5.0 systems and how these approaches can be practically applied in the manufacturing industry

(*continued*)

Table 5.
Main topics discussed and future research avenues

Topics	Exemplary references	Future research avenues
Cluster 4 Socio-Technical Perspectives on Smart Working Exploratory analysis in Industry 5.0 Knowledge and Skills Development in the Context of Fifth Industrial Revolution Technologies	Bednar and Welch (2020) Madsen and Berg (2021) Saniuk *et al.* (2022)	• Focus on understanding the impact of smart systems on different stakeholders, such as employees, customers and the environment and how to design and implement these systems to promote sustainability and well-being • Focus on understanding the evolution of the industry 5.0 concept, identifying its key drivers and barriers to adoption and exploring its implications for different industries and societies • Focus on understanding the challenges and opportunities associated with these technologies, identifying the most effective ways to train and develop the necessary skills, and exploring the implications for the workforce and society as a whole
Cluster 5 Integration of Human Values with Technology Human-Centered AI	Chen *et al.* (2021) Sindhwani *et al.* (2022)	• develop specific methods and strategies for achieving this integration in practice • Explore the potential of human-centered AI in other industries and applications and develop guidelines and best practices for its implementation
Cluster 6 Critical components of Industry 5.0 toward successful adoption in the manufacturing field	Javaid and Haleem (2020)	• Investigate the implementation of Industry 5.0 critical components in the manufacturing industry and their impact on productivity and efficiency

Source(s): Table by author

Table 5.

co-occurrence and author keywords offers valuable insights into the primary themes and research subjects within the realm of Industry 5.0, encompassing topics such as sustainable development, digital transformation, human-centric design and innovation. The bibliographic coupling analysis and thematic clustering suggest that integrating advanced technologies for sustainable and ethical innovation is a crucial research area. In summary, the analysis underscores the potential of Industry 5.0 in advancing sustainable development and emphasizes the importance of adopting a comprehensive approach that encompasses technological, societal and ethical considerations. The findings of this study offer valuable insights that can inform future research and development endeavors within the domain of Industry 5.0.

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Corresponding author
Sivarajah Rajumesh can be contacted at: rajumesh@univ.jfn.ac.lk