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Mapping the Research Landscape of Industry 5.0 from a Machine Learning and Big Data Analytics Perspective: A Bibliometric Approach

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Abstract: Over the past years, machine learning and big data analysis have emerged, starting as a scientific and fictional domain, very interesting but difficult to test, and becoming one of the most powerful tools that is part of Industry 5.0 and has a significant impact on sustainable, resilient manufacturing. This has garnered increasing attention within scholarly circles due to its applicability in various domains. The scope of the article is to perform an exhaustive bibliometric analysis of existing papers that belong to machine learning and big data, pointing out the capability from a scientific point of view, explaining the usability of applications, and identifying which is the actual in a continually changing domain. In this context, the present paper aims to discuss the research landscape associated with the use of machine learning and big data analysis in Industry 5.0 in terms of themes, authors, citations, preferred journals, research networks, and collaborations. The initial part of the analysis focuses on the latest trends and how researchers lend a helping hand to change preconceptions about machine learning. The annual growth rate is 123.69%, which is considerable for such a short period, and it requires a comprehensive analysis to check the boom of articles in this domain. Further, the exploration investigates affiliated academic institutions, influential publications, journals, key contributors, and most delineative authors. To accomplish this, a dataset has been created containing researchers' papers extracted from the ISI Web of Science database using keywords associated with machine learning and big data, starting in 2016 and ending in 2023. The paper incorporates graphs, which describe the most relevant authors, academic institutions, annual publications, country collaborations, and the most used words. The paper ends with a review of the globally most cited documents, describing the importance of machine learning and big data in Industry 5.0.

Keywords: Industry 5.0; machine learning; big data analytics; bibliometric analysis; Bibliometrix

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1. Introduction

Nowadays, the manufacturing industry is facing constant evolution due to both digitization and artificial intelligence-based solutions. The task for manufacturers to increase productivity is becoming more and more difficult due to robots that are gaining significant influence. These shortcomings have given rise to the industrial revolution known as Industry 5.0, which is based on collaboration between humans and robots [1].

Industry 5.0 represents a fifth revolution in the industrial domain, offering various possibilities to adapt manufacturing processes and creating a connection between humans and machines using Artificial Intelligence (AI) [2]. Implementation of robots became crucial, facilitating manufacturing processes, increasing productivity, keeping humans in the domain, and providing new opportunities for working with newer technologies [3].

The aim of Industry 5.0 is to create a connection between humans and robots, helping each other while working. Robots become able to understand humans, with the help of AI, and the very expectations and goals they set for themselves [4].

Numerous benefits were discovered when Industry 5.0 was released, enabling development in Information and Communication Technology (ICT), including the Internet of Things (IoT), edge computing (EC), big data analytics, automation, and AI. Edge computing offers a variety of AI services, making services more stable, storing and processing information in real time, and ensuring safety [5,6]. EC is an open platform, incorporating networking tools, computing, applications, storage, data optimization, real-time business, application intelligence, security, and privacy, and being applied to numerous domains such as production, transportation, and energy [7]. EC utilizes complex technology for servers, running machine learning algorithms to analyze data in real time [8]. It is crucial to create a reliable code because several threats could appear and change the results, and in this moment, employees should handle this important step [8].

IoT facilitates daily activities, ensuring continuous smart city optimization, and COVID-19 had a significant impact on human interactions, facilitating the implementation of IoT tools. Salama and Al-Turjman [9] IoT can be used to collect energy in hubs, creating self-sustainable and ecological sources of energy, which implies the installation of numerous wireless sensor networks. The data are transferred between IoT devices in an online cloud, offering instant availability of information and providing a smart city with more sustainable solutions. Ramos et al. [10] analyzed the data from fishing and non-fishing boats, creating influence diagrams and providing information to fisheries on fishing patterns. Several models have been tested before identifying the optimum one, having a utility of 18.64% for catches, which stands as a tangible event, and 31.96% for satisfaction, an intangible event. Oprea and Bâra [11] explained how IoT can be implemented for photovoltaic (PV) panels, reducing costs, reducing grid dependency, and replacing other heating sources. An adaptive optimization and control module has been developed that forecasts the PV output, scheduling and controlling in real-time the prosumers' appliances. The real-time control is accomplished with a set of IoT devices and protocols: Message Wueue Telemetry Transport (MQTT), smart plugs for controllable appliances, or Raspberry Pi. The self-sustainable ratio increased by 12%, or 13%, thanks to the discovered module. Furthermore, the implementation of IoT in energy communities has been further extended by the authors in [12,13].

Coelho et al. [14] explored Industry 5.0 and IoT using a bibliometric analysis, discovering a strong correlation between IoT, big data, CPS, augmented reality, and intelligent robots. One of the most cited documents from their database is "A Novel Intelligent Medical Decision Support Model Based on Soft Computing and IoT", with 12 citations.

Big data analytics and smart grids are two important factors in the operation of systems. Edge computing is often used in IoT systems, especially those that cannot be serviced efficiently. Even so, applications produce large amounts of data, which end up being modified to run on edge or cloud platforms [15]. In other words, managing IoT data poses numerous challenges, commencing with the sheer volume of data generated. These challenges extend to dealing with the diverse nature of data originating from different sensors and devices, ensuring seamless management across cloud and edge environments, facilitating real-time processing across all stages of data science, and providing timely feedback to devices [16].

Madhavan et al. [17] used the bibliometrix package in the R programming language to realize a comprehensive analysis of their database, which contains 221 papers extracted from Scopus. IoT was one of the main topics in manufacturing processes and supply chain integration, with well-developed and relevant research between 2015 and 2018. During the pandemic period (between 2019 and 2022), the IoT became a central theme for more and more people.

Industry 1.0 introduced mass production at the beginning of the 19th century, lasting for almost one century until Industry 2.0 was developed, creating production lines and piece-rate work. Industry 3.0 was described for the first time as an industrial computer during the Second World War in 1941. Industry 4.0 uses IoT-defined supply chains and autonomous production lines [18]. Starting with Industry 4.0, the complexity of technology increased exponentially, resulting in some impediments, such as privacy, safety, security threats, and data breaches [19]. Industry 5.0 has developed a performant interaction between humans, robots, and AI.

In the beginning of Industry 5.0, robots were built completely differently. In 1951, the first robot was created, which dealt with radioactive materials, trying to protect humans from dangerous activities [20]. Another critical evolution was when the first industrial robot was created, reducing manufacturing costs but lacking flexibility in tasks [21].

The usage of biomanufacturing, which elaborates a set of processes that produce biological products at a commercial scale [22], and in combination with Industry 5.0, it became a more and more interesting domain, growing rapidly and having a global market around 1023.92 billion dollars in 2021, with a hike of 13.9% compound annual growth rate in 2030 [23].

There are also some limitations and risks related to Industry 5.0, which could affect the manufacturing process. Cybersecurity attacks are the main risks of Industry 5.0, blocking robots, software, and hardware systems, which could eventually block the whole activity of a company, resulting in significant losses. EC has the potential to transition from Industry 4.0 to Industry 5.0. Industry 5.0 develops more skilled jobs compared with Industry 4.0, focusing on mass customization, a special case of activity design resulting in a product or service from a predefined number of components with some constraints [24]. If the product needs different specifications, it can be easily changed using configuration applications, which are integrated into computers and robots [25]. The functions used by AI and ML should have trusted execution for security, integrating data set filters for training and testing, and protecting the information and applications [26]. Industry 5.0 has the potential to automatically analyze data at a certain point in time, updating the values and calculating outputs. Another critical element is the existence of proactive security mechanisms that protect transferred data among IoT devices [27].

In this context, the aim of the paper is to present in a comprehensive way the evolution of the Industry 5.0 domain and how important ML and big data have become.

There are also some secondary objectives to be achieved with the research:

- Which are the most impactful journals for papers in the area of Industry 5.0 ML and big data?
- Which are the most representative universities in the analyzed field?
- Which are the most cited articles in the Industry 5.0 domain?
- Who are the most notable authors based on the number of papers and citations?
- How has the evolution of scientific production progressed?
- What are the most commonly used groups of words by the authors?
- Which countries collaborated on creating scientific articles over time on Industry 5.0?

In order to answer the formulated questions, the remainder of the paper is structured as follows. Section 1 is the introductory part, explaining the domain and a historical part, and Section 2 describes the process of data extraction. Section 3 provides the exploratory analysis of the extracted dataset, with an accent on authors, sources, cited papers, and collaboration networks. Section 4 is dedicated to a review of the top 10 most cited papers, accompanied by a word and a mixed analysis. Section 5 discusses the limitations of the research, while conclusions end the paper.

2. Dataset Extraction

Similar methodological approaches to Industry 5.0, together with ML and AI, have been conducted by other authors, trying to understand from a bibliometric perspective how the domain evolved, which are the most important authors, affiliations, articles, and journals [28,29]. The main steps of the research were illustrated in Figure 1. This was divided into three different parts: the first one focuses on dataset extraction, the second on exploratory analysis of datasets, and the third on literature review and mixed analysis.

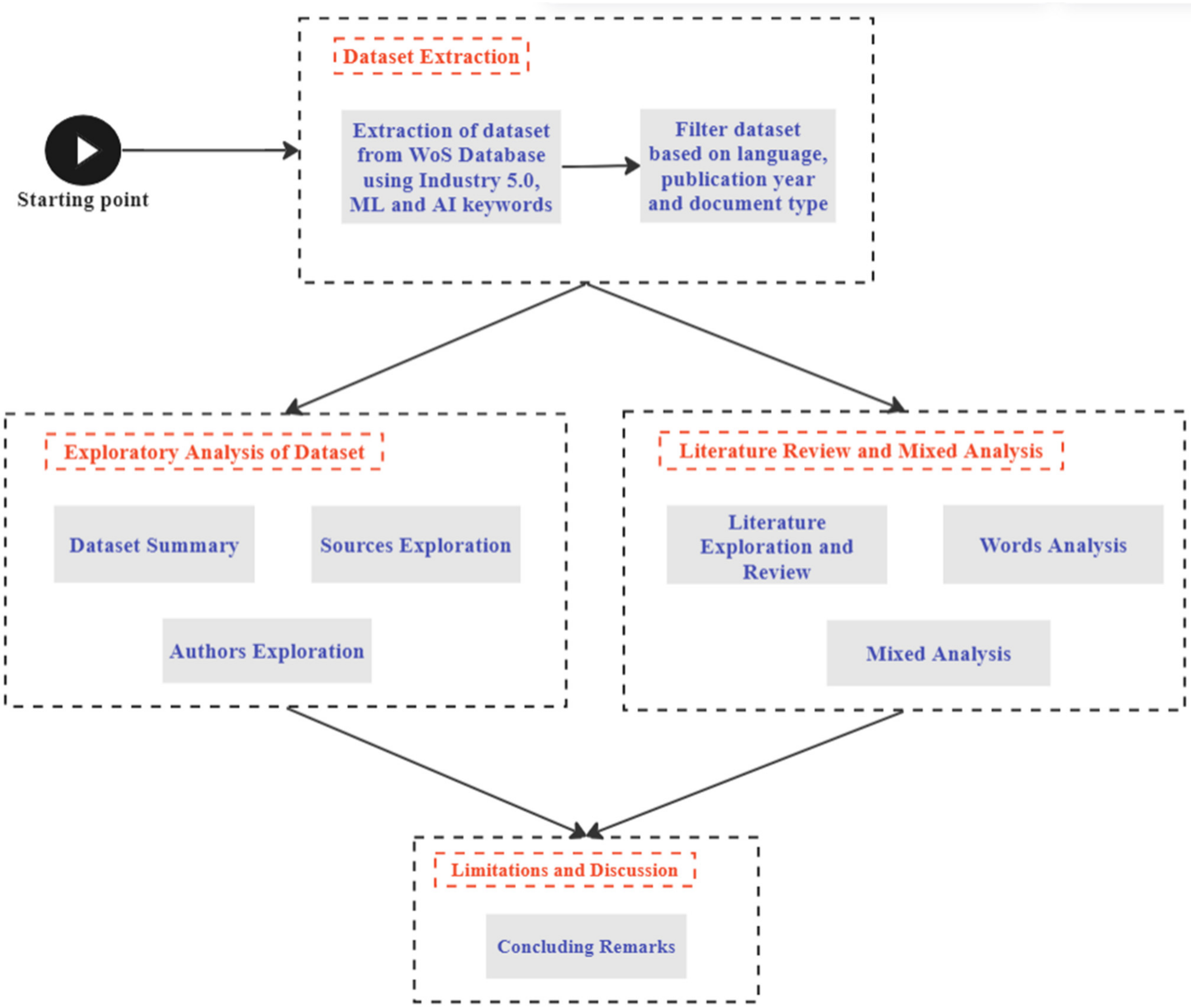


Figure 1. Bibliometric analysis main steps.

In order to better illustrate the achievement of the secondary objectives mentioned above, Table 1 shows what was included in the exploratory analysis of the dataset, literature review, and mixed analysis.

Table 1. Main elements discussed in the exploratory analysis of the dataset, literature review, and mixed analysis.

Section	Elements
Exploratory Analysis of the Dataset	Timespan
	Sources
	Documents
	Average years from publication
	Average citations per document
	Average citations per year per document
	Keywords plus

Table 1. *Cont.*

Section	Elements
Exploratory Analysis of the Dataset	Author's keywords
	References
	Authors
	Author appearances
	Authors of single-authored documents
	Authors of multi-authored documents
	Single-authored documents
	Documents per author
	Authors per document
	Co-authors per document
	Collaboration index
	Annual scientific production and average citations per year
	Top 10 most relevant journals
	Bradford's law on source clustering
	Journals' impact based on the h-index
	Journals' growth (cumulative) based on the number of papers
	Top 10 authors based on the number of documents
	Top 10 authors' production over time
	Top 10 most relevant affiliations
	Top 10 most relevant corresponding authors' countries
	Scientific production based on country
	Top 10 countries with the most citations
	Country collaboration map
	Top 50 author collaboration network
Literature Review and Mixed Analysis	Top 10 most globally cited documents
	Brief summary of the content of the top 10 most globally cited documents
	Top 10 most frequent words in keywords plus
	Top 10 most frequent words in authors' keywords
	Top 10 most frequent words in subject categories
	Top 50 words based on keywords plus (A) and authors' keywords (B)
	Top 10 most frequent bigrams in abstracts and titles
	Top 10 most frequent trigrams in abstracts and titles
	Thematic map for titles
	Thematic map for keywords plus
	Thematic map for abstracts
	Factorial Analysis
	Three-fields plot: countries (left), authors (middle), journals (right)
	Three-fields plot: affiliations (left), authors (middle), keywords (right)

Previous analyses have elaborated on multiple databases, but Bakir et al. [30] explained why the Clarivate Analytics Web of Science Core Collection database (referred to as WoS in this paper) is the most suitable one for a bibliometric analysis, including a variety of areas and journals indexed, the majority of which are very well known within the scientific community [31]. WoS inclusivity is smaller compared with other databases, but it is the most used in scientific literature [32].

Numerous databases can be analyzed from a bibliometric perspective, for instance, Scopus, Google Scholar, Cochrane Library, IEEE, and others, but in this case, papers were extracted from Clarivate Analytics' Web of Science Core Collection database.

The research took into account all ten indexes provided by WoS [33,34]:

- Conference Proceedings Citation Index—Social Sciences and Humanities (CPCI-SSH)—1990–present;
- Conference Proceedings Citation Index—Science (CPCI-S)—1990–present;
- Emerging Sources Citations Index (ESCI) 2005–present;
- Science Citation Index Expanded (SCIE)—1900–present;
- Arts and Humanities Citation Index (A&HCI)—1975–present;
- Social Sciences Citation Index (SSCI)—1975–present;
- Index Chemicus (IC)—2010–present;
- Book Citation Index—Social Sciences and Humanities (BKCI-SSH)—2010–present;
- Book Citation Index—Science (BKCI-S)—2010–present;
- Current Chemical Reactions (CCR-Expanded)—2010–present.

Several filters have been applied while selecting the database, as presented in Table 2. The first filter was referring to the titles, which should contain the word "Industry 5.0", resulting in 276 papers. In the next step, abstracts were filtered, searching for "Industry 5.0" words, revealing 572 articles. The third filter was for keywords, keeping into account if "Industry 5.0" was found, returning 201 papers. A logic OR has been applied on the fourth step, searching for the "Industry 5.0" word in titles, abstracts, and/or keywords, revealing 661 articles. In the fifth step, we searched for words related to machine learning (ML) and big data analytics for titles such as "machine learning", "supervised learning", "artificial intelligence", "unsupervised learning", "deep learning", "artificial neural network", "artificial neural networks", and "big data analytics", resulting in 267,908 articles.

In the next step, the filters described previously were applied to abstracts, resulting in a total of 603,935 documents. The seventh filter was for keywords, searching for ML and big data analytics filters, resulting in 381,635 papers. Similar to the fourth step, on the eighth step, an OR logic has been applied for ML and big data analytics filters, resulting in a total of 775,358 articles. In order to keep only papers that refer to Industry 5.0, ML, and the big data industry, on step number nine, an AND logic has been applied for the fourth and eighth steps, indicating 187 articles. A series of exclusion criteria have been applied, and on step number ten, articles were filtered based on language, keeping only papers published in English, which did not affect the number of papers, as explained by Liu [35].

The exclusion criteria number eleven focused on document type; other criteria have been applied, keeping into account only papers that were marked as "article" in the WoS database, resulting in 132 documents. It is worth mentioning that, for WoS, a paper falls into this category only if it is original and new, including technical notes, research papers, case reports that have been presented at a conference or published, short communications, or proceedings papers [36]. As in our paper, this criterion was also used by Haleem and Fatma in their paper [37].

The last filter was a year criterion, removing papers published in 2024, reducing the sample size from 132 to 129 papers.

The data were analyzed using Bibliometrix, which is an R package known for its use in bibliometric analysis and graphical representations [38]. A full description of the steps is presented in Table 2.

Table 2. Data selection steps.

Exploration Steps	Questions on the Web of Science	Description	Query	Query Number	Count
1	Title	Contains the specific keywords related to Industry 5.0	TI = (industry_5.0)	#1	276
2	Abstract	Contains the specific keywords related to Industry 5.0	AB = (industry_5.0)	#2	572
3	Keywords	Contains the specific keywords related to Industry 5.0	AK = (industry_5.0)	#3	201
4	Title/Abstract/Keywords	Contains the specific keywords related to Industry 5.0	#1 OR #2 OR #3	#4	661
5	Title	Contains the specific keywords related to machine learning and big data analytics	((((((((TI = (machine_learning)) OR TI = (supervised_learning)) OR TI = (artificial_intelligence)) OR TI = (unsupervised_learning)) OR TI = (deep_learning)) OR TI = (artificial_neural_network)) OR TI = (artificial_neural_networks)) OR TI = (big_data_analytics))	#5	267,908
6	Abstract	Contains the specific keywords related to machine learning and big data analytics	((((((((AB = (machine_learning)) OR AB = (supervised_learning)) OR AB = (artificial_intelligence)) OR AB = (unsupervised_learning)) OR AB = (deep_learning)) OR AB = (artificial_neural_network)) OR AB = (artificial_neural_networks)) OR AB = (big_data_analytics))	#6	603,935
7	Keywords	Contains the specific keywords related to machine learning and big data analytics	((((((((AK = (machine_learning)) OR AK = (supervised_learning)) OR AK = (artificial_intelligence)) OR AK = (unsupervised_learning)) OR AK = (deep_learning)) OR AK = (artificial_neural_network)) OR AK = (artificial_neural_networks)) OR AK = (big_data_analytics))	#7	381,535
8	Title/Abstract/Keywords	Contains the specific keywords related to machine learning and big data analytics	#5 OR #6 OR #7	#8	775,358
9	Title/Abstract/Keywords	Contains the specific keywords related to Industry 5.0 and the specific keywords related to machine learning and big data analytics	#4 AND #8	#9	187
10	Language	Contains only the papers in English	(#9) AND LA = (English)	#10	187
11	Document Type	Limit to Article	(#10) AND DT = (Article)	#11	132
12	Year published	Exclude 2024	(#11) NOT PY = (2024)	#12	129

3. Exploratory Analysis of the Dataset

In this section, a detailed description of the data is provided. The purpose is to extract the main information about authors, articles, publication evolution, most important sources, affiliations, and how many references have been used. Furthermore, in the next section, we introduced a factor analysis in order to be able to observe which keywords of the analyzed articles were used and to reduce the dimensionality of the data.

3.1. Dataset Summary

Tables 3 and 4 describe, from different perspectives, the extracted data in the Industry 5.0 domain. Table 3 presents the key elements of the data. The analyzed time span begins in 2016 and ends in 2023, including 129 documents and 80 unique sources, with an average citation per year per document of 14.49. There are 241 unique keywords plus 575 authors' keywords used in the analyzed papers, for a total of 8394 references. The data are described in Table 3.

Table 3. Main information about the data.

Indicator	Value
Timespan	2016–2023
Sources	80
Documents	129
Average years from publication	1.64
Average citations per document	14.49
Average citations per year per document	4.23
Keywords plus	241
Authors' keywords	575
References	8394

Table 4. Authors' information.

Indicator	Value
Authors	531
Author appearances	582
Authors of single-authored documents	13
Authors of multi-authored documents	518
Single-authored documents	14
Documents per author	0.243
Authors per document	4.12
Co-authors per document	4.51
Collaboration index	4.5

Table 4 encompasses author data, indicating the total number of 531 authors extracted from the dataset. Only 13 documents have a single author, a small proportion compared with 518 documents with multiple authors, which shows the difficulty of creating articles on a new subject. Since the formula for calculating co-authors per document includes sole authors, even if they published multiple documents, the value of co-authors per document is only 4.51. The number of single-authored documents is also small; fourteen were published between 2016 and 2023.

The evolution of article publications and average citations per year is presented in Table 5. The domain was recently discovered by the authors; the first document published was in 2016, with only 5.7 citations per year. In the following 2 years, no article has been published. Starting with 2019, a new journey begins for Industry 5.0, ML, and big data analytics, publishing one paper with an average of 57.5 citations per year, which is a significant number, proving the rapid growth of interest in this domain. The annual growth rate is 123.69%, a very big value, confirming the interest from researchers and journals. In the following years, the number of publications increased, with 4 in 2020, 9 in 2021, 41 in 2022, and 73 in 2023. Due to the newness of the documents, the number of citations is lower, resulting in a smaller citation average; the peak was 57.5 in 2019, 9.9 in 2020, 8.1 in 2021, 5.9 in 2022, and 1.7 in 2023. Costas et al. [39] and Tahamtan et al. [40] show the impact of articles that have below-average citations per year in a field, highlighting the fact that these articles benefit from an increase in the number of papers when compared with the scholars in the middle and top citation density.

Table 5. Annual scientific production and average citations per year.

Year of Publication	Number of Published Papers	Average Citations per Year
2016	1	5.7
2017	0	0
2018	0	0
2019	1	57.5
2020	4	9.9
2021	9	8.1
2022	41	5.9
2023	73	1.7

3.2. Sources Exploration

Sources offer a perspective on the importance of journals, showing where most articles are published in the analyzed domain. The impact of an article is influenced not only by the authenticity and quality of the analysis but also by where it is published.

In Figure 2, we describe the most relevant 10 journals where Industry 5.0, ML, and big data papers are published. The most impactful journal is *IEEE Transactions on Industrial Informatics*, with 10 articles published, representing one of the most known journals and having a variety of documents related to technologies used in Industry 5.0 [41]. The journal with the second most published articles is *Sustainability*, with nine papers, followed by *Sensors*, with eight documents. The rest of the journals have an impact of less than five articles. The full list of journals is presented in Figure 2.

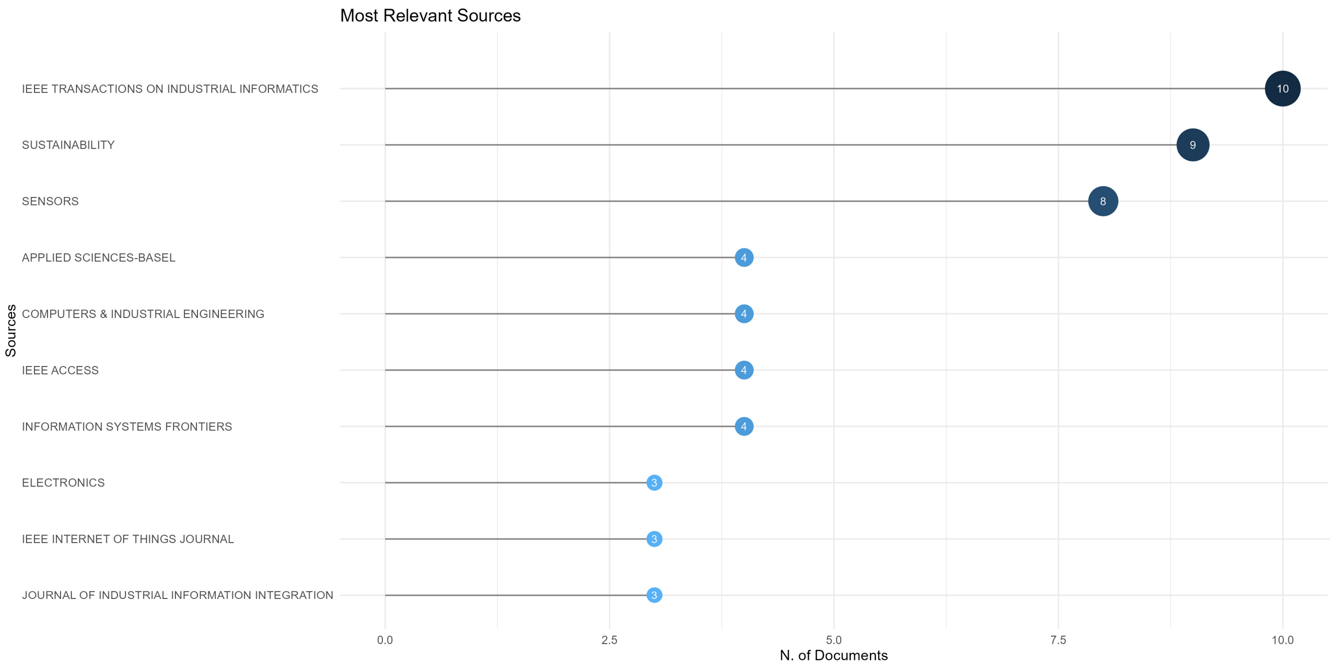


Figure 2. Top 10 most relevant journals.

Figure 3 presents Bradford's Law graph, which separates the most cited journals in the Industry 5.0 domain from other journals with smaller impacts. Bradford's Law arranges the journals in three different categories based on the number of published articles, and if the proportion of papers in each category is one-third of the total number of articles extracted, then Bradford' Law logic groups in a proportional way with 1:n:n^2 [42]. There are only seven journals described as relevant according to this criterion: *IEEE Transactions on Industrial Engineering*, *Sustainability*, *Sensors*, *Applied Sciences-Basel*, *Computers & Industrial Engineering*, *IEEE Access*, and *Information Systems Frontiers*. Similar results were observed in the Madhavan et al. [17] paper, where Sustainability was the second most relevant journal, with 18 documents, and Applied Sciences was fourth, with 7 papers.

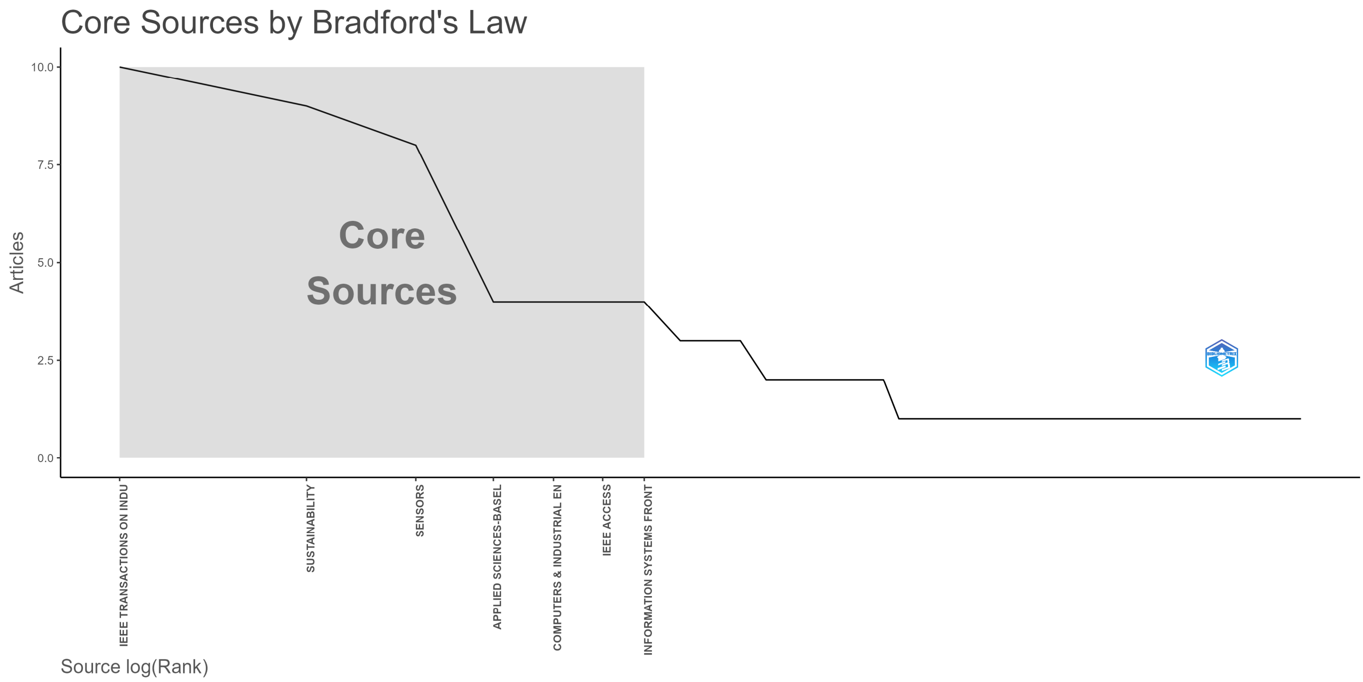


Figure 3. Bradford's law on source clustering.

Figure 4 elaborates, from a bibliometric perspective, on the impact of sources with an h-index over 2. The h-index stands as an index for journal significance, explaining the correlation between publication volume and citations. The most preeminent journal is *IEEE Transactions on Industrial Informatics*, with an h-index of 7, followed by *Sustainability* with 5, and *Sensors* with 4. *Computers & Industrial Engineering* and *IEEE Internet of Things Journal* have an h-index of 3, and the rest of the journals that are in the top 10 have an h-index of 2.

Figure 5 defines the top seven sources of production over time. *IEEE Transactions on Industrial Informatics* has the most articles published at the end of 2023 on Industry 5.0, ML, and big data analytics domains: 10 papers. A significant increase started with 2022. In 2021, there was only one article published; in 2022, the number increased to five; and in 2023, the number doubled. The second source with the most published articles in the analyzed domain is *Sustainability*, with nine papers having a similar pattern to the previous source. The third is *Sensors*, with eight articles, and the rest of the four have less than five documents. The full list is presented in Figure 5. Please note that in Figure 5 for the period 2021–2023, two journals, namely *Computers & Industrial Engineering* and *Information Systems Frontiers* have had the same number of publications, namely 1, 2 and 4 and thus their evolution overlaps—as a result, in Figure 5 for the 2021–2023 period only the evolution of the number of papers for the *Information Systems Frontiers* can be observed (in blue).

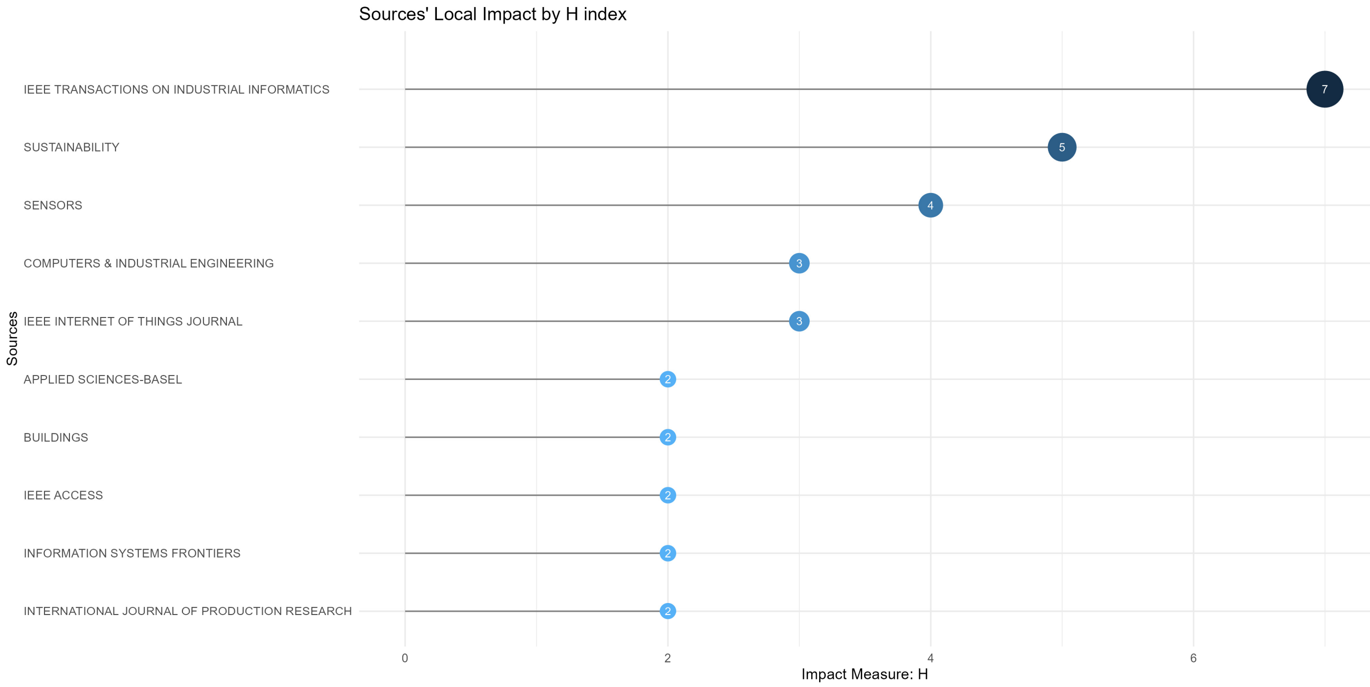


Figure 4. Journals' impacts based on the h-index.

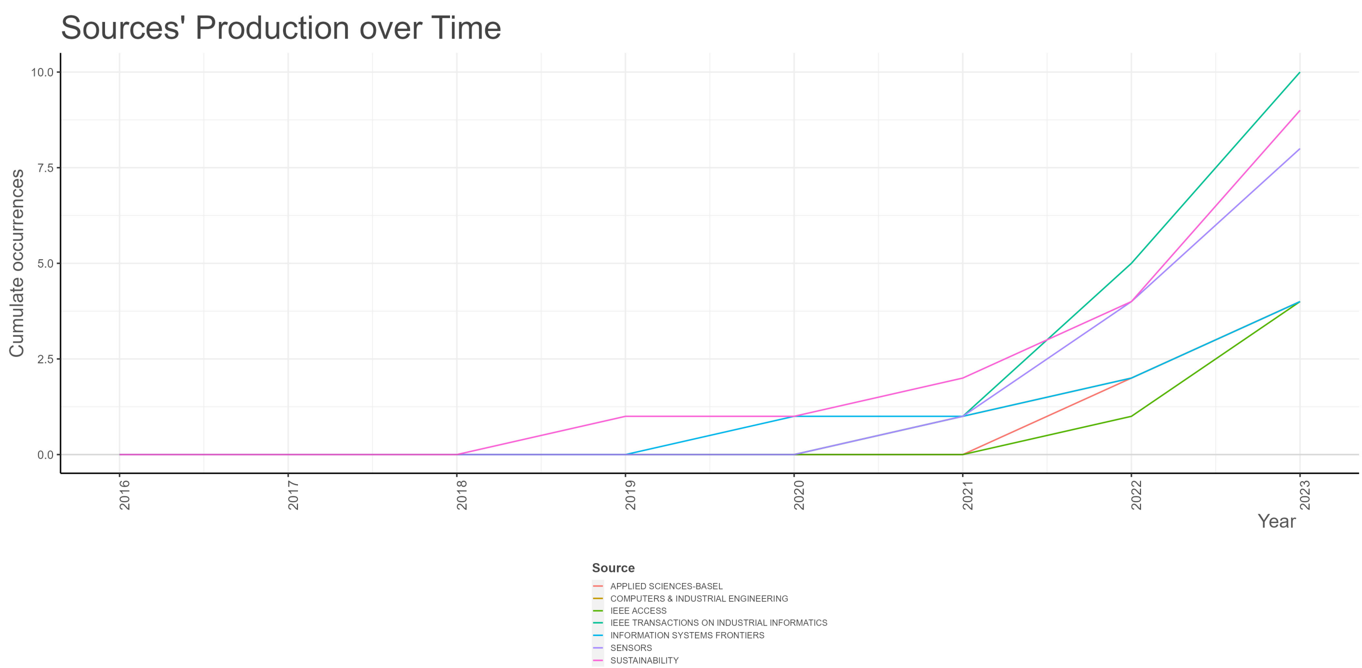


Figure 5. Journals' growth (cumulative) based on the number of papers.

3.3. Authors' Explanation

A crucial step in bibliographic research is the authors' exploration, identifying the most relevant researchers, the number of articles, the impact of the papers, annual production, and the collaboration between them, which are the most important affiliations and countries for Industry 5.0, ML, and big data analytics domains.

Table 6 presents in a detailed manner the top 10 authors, the number of articles published in the analyzed time span, and the articles fractionalized [43].

Table 6. Top 10 authors based on the number of documents.

Author Name	Number of Articles	Articles Fractionalized
Fortuna B	3	0.25
Kenda K	3	0.25
Kumar S	3	0.92
Mladenic D	3	0.25
Novalija I	3	0.25
Zajec P	3	0.25
Abbas S	2	0.23
Abuhasel KA	2	2.00
Alkahtani NE	2	0.37
Alonso R	2	0.11

The author with the most significant contribution to an article publication is Abuhasel KA, with an index score of 2, having published two papers in the field. The rest of the authors have an article fractionalized index of less than 1, with Kumar S having the closest value to 1, 0.92, having three articles published. The full list of the authors is presented in Table 6.

Figure 6 evaluates the production of the top 10 authors between 2021 and 2023. There are two authors who published one article per year: Fortuna B. and Kenda K. With the red lines, we can identify if an author has published articles during the period analyzed and make a comparison between the top 10 authors. If we look at Kumar S., it can be observed that the author published papers only between 2022 and 2023, unlike other authors, such as Fortuna B., who has a continuous line for the 3 years (2021–2023). The middle dots in Figure 6 represent the authors' production for the year 2022. The most impactful article by Fortuna B. has been published recently, in 2023, with a total citation of 15 and an average citation of 7.5 per year. The average citation formula also considers the current year, even if it was not included in the analysis. For Kenda K., the most relevant article is the same as for Fortuna B., because they published together with Mladenic D., Zajec P., and Novalija I. the article titled "Human-Centric Artificial Intelligence Architecture for Industry 5.0 Applications". Kumar S. published two articles in 2022 and one in 2023. Among the published papers, the article "Recop: Fine-Grained Opinions and Sentiments-Based Recommender System for Industry 5.0" from 2023 reached the highest number of citations, namely 10 citations, and an average of 5 citations per year. The remainder of the authors is presented in Figure 6.

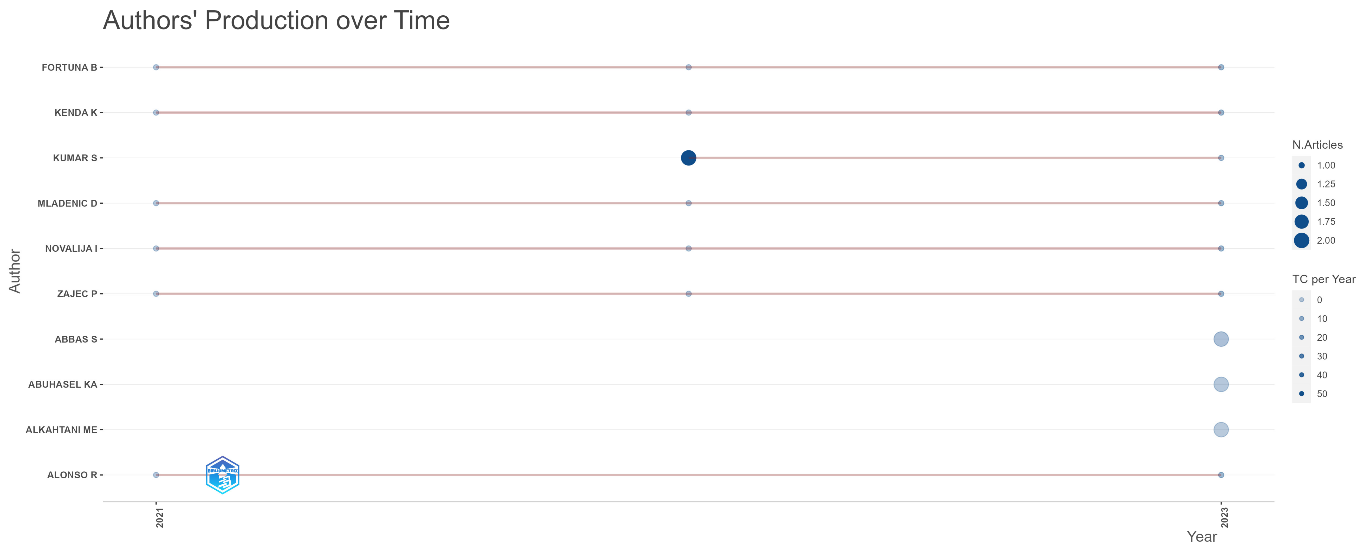


Figure 6. Top 10 authors' production over time.

Figure 7 presents the most important affiliations that created articles in the Industry 5.0 domain combined with ML and big data analytics. The most influential affiliation is the Chinese Academy of Sciences, which published seven papers, followed by the Egyptian Knowledge Bank (EKB) with five documents. In third place is the University of Petroleum and Energy Studies (UPES) from India, with four articles. The rest of the affiliations listed in Figure 7 have three articles published. Similar papers have been analyzed, and Xu et al. [44] found that the Chinese Academy of Sciences is the most relevant university, with 52 papers published related to climate change and software implementations, such as IoT, in order to reduce global warming and identify energy storage systems.

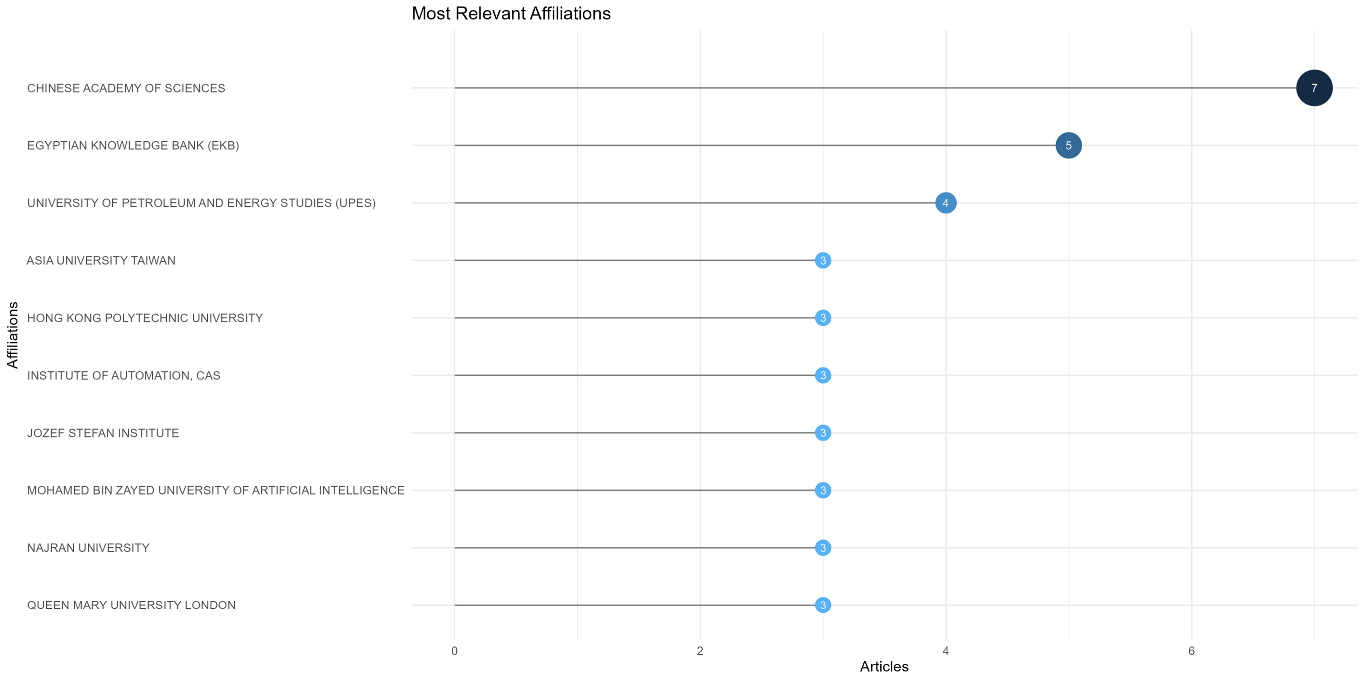


Figure 7. Top 10 most relevant affiliations.

An important aspect of bibliometric analysis is represented by the authors' countries, providing information about the international interest in a domain and where specialists can be found. In Industry 5.0, ML, and big data analytics domains, the most influential country is China, with 17 articles; 8 or 47.06% of total papers are single-country publications (SCP), and 9 or 52.94% of total articles are multiple-country publications (MCP). Comparing with the rest of the countries in the top 10, China has the most SCP articles, showing how important it is for them as an industrialized country that has already implemented data envelopment analysis (DEA), making ecological activities more efficient [45]. The documents published by the Chinese authors represent 13.2% of the total articles. In second place is the United Kingdom (UK), with 16 articles, very close to China, having the most MCP articles (11, or 68.75% of total articles published by the UK), and only 5 were SCP, indicating the need for international authors to extract information on Industry 5.0 and to create valuable articles. The UK has 12.4% of the total articles. The third is Italy, with 10 articles, with a big difference between the top two and number three, having the highest percentage of SCP papers (70% or 7 papers out of 10), and only 3 were MCP. Italy has 7.8% of the total articles. The full list of the top ten countries is described in Table 7. Considering other papers from the scientific literature, it was observed that similar results have been observed. For instance, Ikudayisi et al. [46] analyzed the benefits of Industry 5.0 in architecture, engineering, and construction, and one of the most used integrated practices is modular integrated construction (MiC), which was implemented in China, the UK, Hong Kong, and Canada, confirming the interest of those countries in researching and implementing Industry 5.0 tools.

Table 7. Top 10 most relevant corresponding authors' countries.

Country	Articles	SCP	SCP_Percentage	MCP	MCP_Percentage	Percentage
China	17	8	47.06%	9	52.94%	13.2%
UK	16	5	31.25%	11	68.75%	12.4%
Italy	10	7	70%	3	30%	7.8%
India	9	6	66.67%	3	33.33%	7%
USA	7	3	42.86%	4	57.14%	5.4%
Australia	6	2	33.33%	4	66.67%	4.7%
Korea	5	3	60%	2	40%	3.9%
Slovenia	5	3	60%	2	40%	3.9%
Slovakia	4	4	100%	0	0%	3.1%
Pakistan	3	0	0	3	100%	2.3%

In Tables 8 and 9, the top 10 countries in terms of scientific productions and citations are listed along with their contribution to the domain. Similar results were obtained by Barata and Kayser [47] who created a country map for Industry 5.0 journal publications, and the most important countries were China, India, the United Kingdom, the United States of America, Italy, Spain, and Australia, developing articles on various domains such as "Engineering", "Computer Science", "Business, Management and Accounting", or "Social Sciences".

Table 8. Scientific production based on country.

Region	Frequency	Percentage
China	64	14.71%
India	43	9.89%
United Kingdom	39	8.97%
Italy	27	6.21%
United States of America	18	4.14%
Pakistan	17	3.91%
Saudi Arabia	17	3.91%
Australia	15	3.45%
Greece	15	3.45%
Slovenia	14	3.22%

Table 9. Top 10 countries with the most citations.

Region	Number of Citations	Average Article Citations
Australia	457	76.2
USA	340	48.6
China	296	17.4
UK	162	10.1
India	147	16.3
Spain	67	33.5
Pakistan	65	21.7
Italy	52	5.2
United Arab Emirates	49	16.3
Slovenia	29	5.8

Previously, the multiple-country publications were analyzed in Table 7, extracting valuable information about countries productivity, and a country collaboration map was created on Figure 8, where countries' colors differ according to scientific productivity. The more intense the color, the higher the number of articles published.

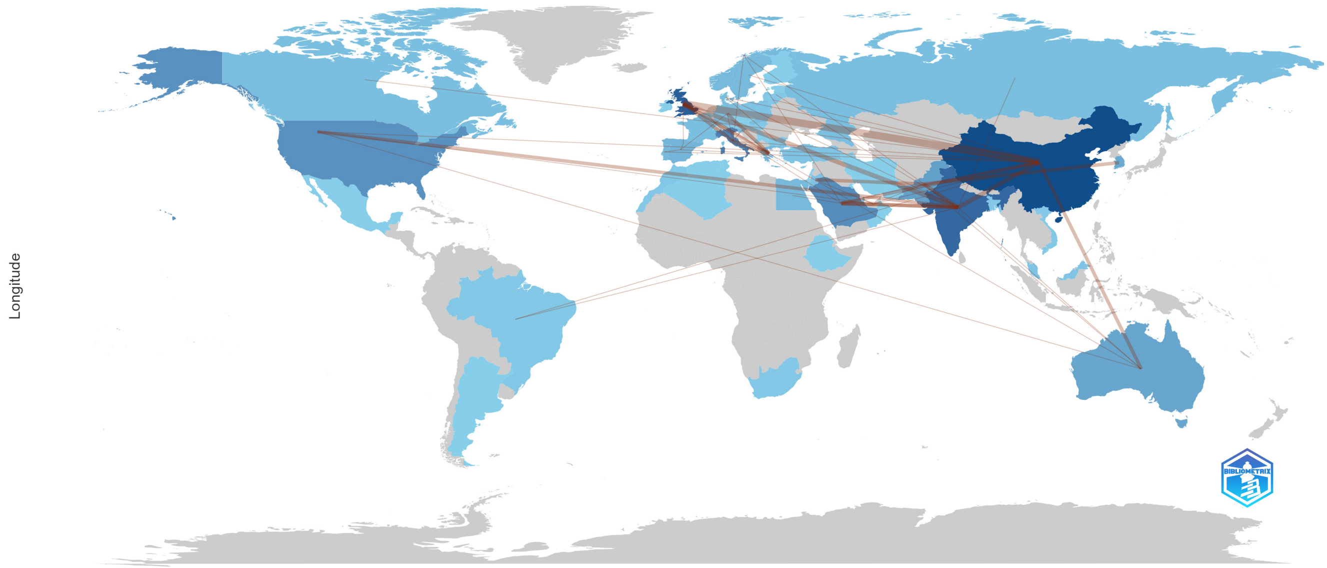


Figure 8. Country collaboration map.

The most fruitful collaboration was between China and the UK, which had eight articles together. A good collaboration between those two countries was predictable since both are in the top three countries with the most publications, followed by China and India, India and the UK, Italy and Greece, Saudi Arabia, and the United Arab Emirates, each with four articles published. The rest of the collaborations ended up with three or fewer articles published, which is not very relevant. Taking into consideration documents from scientific literature, Madhavan et al. discovered a significant correlation between the United Kingdom and Italy, with 14 documents published each, and the United States of America, with 12 documents released. China has an important impact, having collaborations with the United Kingdom and India.

A crucial analysis is the collaboration network between authors, and in Figure 9, an insightful description was realized. There are five different groups; the most influential is the red one, which contains 17 authors and had a fruitful collaboration, discovering new methods and techniques to improve manufacturing. In the red group, the importance of the authors is represented by the size of the circles and the number of lines that enter and leave each circle. Zajec P., Kenda K., and Mladenic D. are some of the most popular authors. They analyzed various subjects, such as the importance of humans in the evolution of manufacturing and architecture for trusted and secured systems, using Industry 5.0 and AI [48–50]. The second group is the green one, including four authors, with less impact compared to the red group. They explored the pharmaceutics domain, looking for process optimization of 3D printing using ML and improving the quality control of 3D printing with the ML vision tool [51,52]. The blue group formed by four authors has a similar impact compared with the previous group, but much less than the first one. They mainly approached the medicine domain, looking for ML tools to predict lung cancer disease [53,54]. The last two groups contain two authors for each group, with a very small impact: discovering technologies and operations in Industry 4.0, proposing a framework for logistic management, and material characterization using Industry 5.0 [55–58]. The full list of authors is listed in Figure 9.

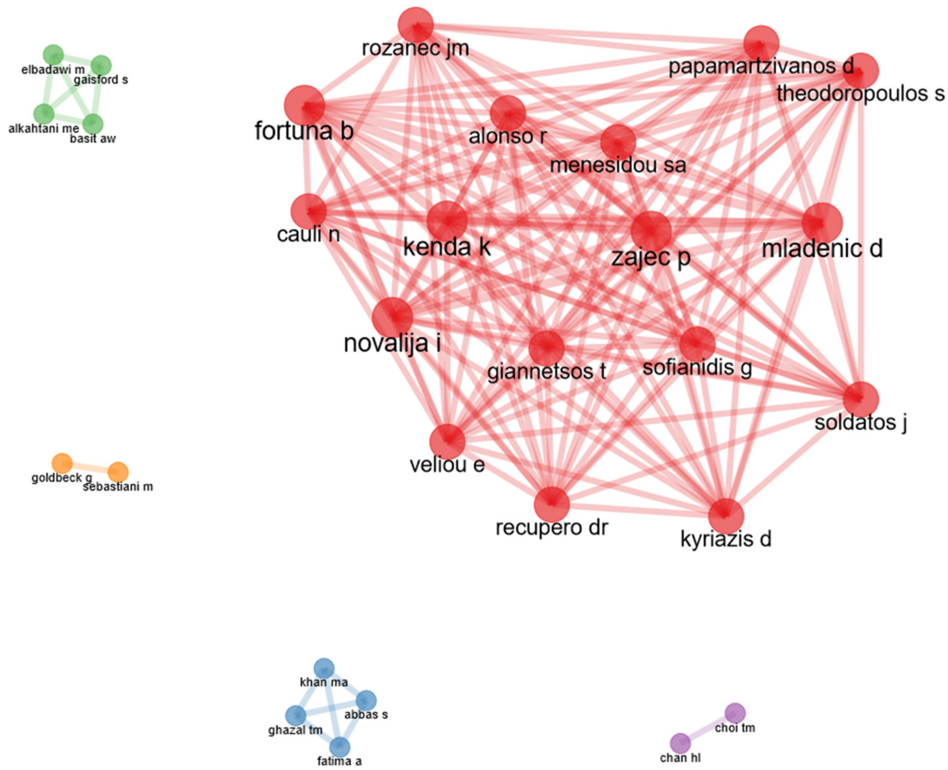


Figure 9. Top 50 authors' collaboration networks.

4. Literature Review and Mixed Analysis

In the following, a literature exploration is provided from the perspective of a review of the top 10 most cited papers, followed by a mixed analysis.

4.1. Literature Exploration and Review

The top 10 most cited papers are discussed in the following section with the purpose of offering more insight into the interests of the research community in the area of using ML and big data analytics in the field of Industry 5.0.

4.1.1. Top 10 Most Cited Papers—Overview

Table 10 includes the most global cited documents on Industry 5.0, ML, and big data analytics, the number of authors, region, total citations, total citations per year, and normalized total citations (NTC). NTC refers to citations to all authors of the paper, assuming an equal effort from all authors while taking into account the average citations per document for each paper published in the same year [59–61]. Extracting the main information from all ten papers, we can see the focus of each author, how the articles evolved, and what the main topics are.

Nahavandi [1], affiliated with Deakin University, Australia, published in 2019 the most cited paper, describing the contemporary world as fast-growing and changing perspectives into digital technologies, AI, and robots. The need for Industry 5.0 was presented in the paper in connection with the manufacturing domain, impacting the global economy, introducing robots that can work together with humans, solving the strong necessity of increasing productivity, and reverting the concept of robots and humans from enemies to collaborators. Since the pollution level has increased to dangerous levels, the focus of industry has moved to reducing environmental impacts [1]. Industry 5.0 tries to reduce pollution by combining human brainpower with intelligent systems, resulting in significant value-added production, increasing the efficiency of software, robots, and processes, and reducing costs and waste. Robots are just programmable machines that need human input to work. The Fifth Industrial Revolution, or Industry 5.0, will come when three major elements—intelligent devices, intelligent automation (autonomous robots will interact as smart agents), and intelligent systems—will be co-working with humans [1]. The paper has, at the end of 2023, a total number of citations of 345, with an average of 57.50 citations per year, and a normalized total citation (NTC) of 1.

Choi et al. [56] elaborate a comparison between Industry 4.0 and Industry 5.0. According to the authors, the fourth industrial revolution promoted automation, data analytics, and making operations management more efficient by using the latest technologies such as 5G, IoT, and 3D printing. The purpose of Industry 5.0 is to improve workers' social lives. The benefits brought by Industry 4.0 to businesses have the potential to reach around USD 3.7 trillion in 2025, since more and more governments are interested in investing in the latest technologies. The US government paid 1 billion dollars for research and development projects using Industry 4.0 in 2020. Industry 5.0 tries to create a balance between machines and workers and to help the social life of humans, human rights, and legal protection [56]. The evolution from Industry 3.0 to Industry 4.0 completely changed the overview of working, implementing the concept of "intelligence" in daily tasks. More than 10% of the companies are using AI in their operations, helping workers with pattern identification and automatic and smart procurement. In logistics, AI helped with decision-making in complex situations with numerous restrictions, which was very difficult and stressful for humans to handle. In conclusion, both Industry 4.0 and Industry 5.0 changed the work environment [56]. Four different authors participated in the research, the majority of them from China. The paper had 137 citations at the end of 2023, with an average of 45.67 citations per year, and the NTC was 7.71, much higher compared to the previous paper analyzed.

Pillai et al. [62] present the possibility of combining Industry 5.0 and the medicine domain during the COVID-19 pandemic, improving hygiene and cleanliness, creating Hospitality 5.0, optimizing operational efficiency, and finding the optimum synergy between humans and machines. Since COVID-19 affected people's lives and activities, the hospitality domain was conditioned by human vacations and mobility, which were forbidden in the majority of countries. According to the authors, as a plan to recover clients from tourism, the hotels should readapt to the latest criteria of cleanliness, safety, and hygiene [62]. Hospitality 5.0 introduces technologies that ensure hygiene and safety by creating contactless services, personalizing the offered services for each client, giving the possibility for hotel employees to monitor consumption, being notified by clients when bottles need replacing, and reducing human interaction as much as possible. Introducing technology in tourism is conducted for cost and electricity efficiency, increases the productivity of employees, and reduces license fees for equipment.

Javed et al. [63] elaborate a description of future smart cities, how information and communications will change, and provide accessible resources for people. In the paper, the future technologies were identified, describing deep learning, ML, IoT, big data, 6G, Industry 5.0, and flying cars. The technological revolution was a great success wherever it was implemented. Having a smart city requires incorporating management and governance, which have a direct impact on human life (human-computer interaction (HCI)). Many cities have moved to smart city technology implementation, such as London, New York, Barcelona, Singapore, Tokyo, Paris, Dubai, Copenhagen, and Hong Kong [63]. A city transformation also requires investment in design, which could have a positive economic, social, and environmental impact. Smart cities are founded on seven fundamental pillars: smart life, smart economy, smart governance, smart power, smart communication, smart environment, and smart transportation. Designing a city from scratch using smart technologies is the best idea, significantly raising the quality of life for people.

Bednar and Welch [21] described technological evolution, which helped industrial and commercial domains by implementing AI, virtual reality, and integrated manufacturing systems. According to the authors, some researchers correlate Industry 4.0 with smart working since that was the moment when factories started to use robots to achieve a bonus of performance and productivity. However, Industry 5.0 is trying to improve the work environment by providing a harmonious collaboration between technology and social systems and delivering dedicated products and services. The focus of manufacturers moved from mass customization to mass personalization, forcing companies to build more personal products and experiences for clients by adapting collaborative business models, creating an interaction between suppliers, manufacturers, and clients [21]. Industry 5.0 creates a group of humans and computers to create value-added products, reducing the efforts of human capacities for creativity and decision-making. The integration of the latest technologies takes time and raises concerns because Industry 5.0 should not only represent a cost reduction and better products but also offer the possibility for people to reach their full potential in creating personalized services and goods.

Javaid and Haleem [64] describe Industry 5.0 as an evolution that provided better interaction between humans and tools, improved efficiency and effectiveness, offered the possibility of personalizing, and resolved problems. The authors believe that technology offers new possibilities for development in the manufacturing domain, replacing human repetitive tasks with robots. AI increased the accuracy and speed of industrial automation, facilitating digital systems to be connected and to receive information in real-time. Moreover, the authors highlighted that Industry 5.0 uses robots with a human brain, automating processes, creating personalized products, and increasing the accuracy and quality of the goods and services. Each industry revolution contributed to evolution, improving working conditions. Industry 1.0 started in 1765, creating machines powered by steam or water to reduce human efforts [64]. The second industrial revolution began in 1870 by describing the mass production method to produce identical products in large numbers, improving production speed, and reducing costs. Industry 3.0 appeared in 1950, when automation was for the first time implemented on manufacturing systems, connecting computers, robots, and humans' tasks. The fourth industrial revolution was implemented starting in 2020, creating digital systems for manufacturing using the newest technologies. Industry 5.0 is only a concept that will begin in a few years, providing mass production for the personalized needs of clients using the most powerful technologies.

Fraga-Lamas et al. [65] explain the benefits of IoT on the circular economy, creating a sustainable environment by digitalizing water distribution and preventive maintenance processes. According to the authors, in this moment, IoT and edge computing are not contributing to a more sustainable world because, in the economic industries where they are used, raw materials are frequently used, and electricity consumption is higher when more software is used, even if their potential is huge. The green IoT (G-IoT) was analyzed by researchers as having the potential to reduce the carbon footprint. By 2030, the IoT and IIoT can provide around USD 14 trillion to the global economy, but it is mandatory to implement solutions for a sustainable and efficient life cycle for the circular economy. G-IoT represents an energy-efficient method implemented by IoT technology, reducing the greenhouse effect of IoT. The greenhouse effect appears when solar radiation from the sun passes through the atmosphere, and the majority of it is distributed everywhere by clouds and gas molecules, warming the Earth's surface [66]. Edge-AI is another tool that could reduce pollution and, combined with G-IoT, can connect devices, offering smart services in real-time, generating personalized information, and making the supply chain much simpler, transparent, and visible. The decision-making process is significantly improved, with technology offering various solutions. CO_2 emissions increased based on the number of devices that use Edge-AI and G-IoT, but in future, it could dramatically reduce emissions, providing more green energy.

Akundi et al. [3] detail the fourth industrial revolution, which introduced automated processes for operational production, growing productivity and efficiency. A historical description of each industrial revolution has been provided in the analyzed article. The purpose of Industry 5.0 is to personalize manufacturing and empower humans in various processes. Text mining algorithms have been used to explore the perspectives of Industry 5.0, examine the literature and determine which are the best future directions of research. Around 196 documents have been extracted from various journals, such as IEEE, MDPI, and Science Direct, between 2016 and 2022, using the R programming language, pointing out the most frequently used tools [67]. The terms big data, supply chain, ML, and digital transformation had the most appearances, which was expected since Industry 5.0 uses AI to replace repetitive tasks or to control real-time data stored in databases. The research also indicated a strong connection between humans and machines, resulting in smart and sustainable manufacturing. Agent-based is applied to explore and predict the effects of the interaction of humans and robots on smart manufacturing [67].

Sigov et al. [68] describe the evolution of Industry 4.0, which was introduced for the first time in 2011 as a German strategic to revolutionize the manufacturing system, and it was released officially in 2013. The analysis evaluated the 10 years of evolution between 2011 and 2021, presenting the frameworks and what changes have been made. The new generation of Industry 4.0 is also called Industry 5.0. Industry 4.0 introduced a new set of tools, such as cyber-physical systems. The IoT will interact with the next generation of Industry 4.0 tools: AI, 5G, and quantum computing [68]. The success of Industry 4.0 depends on the transition to the latest technologies in order to stay competitive in the manufacturing area, extend the production line, and introduce personalized goods and services for customers. AI has the power to revolutionize the industry, but it must be understood by the users; otherwise, it will not generate the expected outcome, increasing flexibility and dynamicity.

Table 10. Top 10 most globally cited documents.

No.	Paper (First Author, Year, Journal, Reference)	Number of Authors	Region	Total Citations (TC)	Total Citations per Year (TCY)	Normalized TC (NTC)
1	Nahavandi, Saeid, 2019, *Applied System Inovation* [1]	1	Australia	345	57.50	1.00
2	Choi, Tsan-Ming, 2022, *Production and Operations Management* [56]	4	China	137	45.67	7.71
3	Pillai Souji Gopalakrishna, 2021, *International Journal of Hospitality Management* [62]	4	USA	113	28.25	3.48
4	Javed, Abdul Rehman, 2022, *Cities* [63]	7	Australia	104	34.67	5.85
5	Bednar, Peter M., 2019, *Information Systems Frontier* [21]	2	UK	98	19.60	1.98
6	Javaid, Mohd, 2929, *Journal of Industrial Integration and Management* [64]	2	India	70	14.00	1.41
7	Fraga-Lamas, Paula, 2021, *Sensors* [65]	3	Spain, Portugal	67	16.75	2.07
8	Akundi, Aditya, 2022, *Applied System Innovation* [3]	6	USA	58	19.33	3.26
9	Sigov, Alexander, 2022, *Information Systems Frontier*, [68]	4	Russia	58	19.33	3.26
10	Sachsenmeier Peter, 2016, *Engineering* [69]	1	UK	51	5.67	1.0

Sachsenmeier [69] evaluates the inventions of nature, also known as the bionics industry, how they have been changed, and how new technologies can discover or even create new products. The chemical industry is trying to use sustainable resources, create synthetic biofuels, and harvest solar energy. Bioengineering combines engineering, life sciences, and mathematics, offering new solutions for researchers in biology and medicine [70]. It represents the next step of the evolution in biology and chemistry, being compared with digitalization regarding the possible impact of human life. The concept of Industry 4.0 enabled the processes to be digitalized, but the changes that have been made for synthetic biology are part of Industry 5.0. Synthetic biology combines mathematics, biology, and computer science, enabling the possibility of creating synthetic organisms that emerge from a pathogen's point of view in humans [71]. Industry 5.0 promotes a stronger relationship between humans and nature, including various automated tasks. Industry 4.0 was a milestone, generating new jobs, changing society, and making people more worried regarding the evolution of jobs. Industry 4.0 introduced the basic government-supplied income for people, while the robots will work. In this moment, the basic income is discussed as being introduced only in richer societies.

4.1.2. Top 10 Most Cited Papers—Review

Table 11 summarizes the information from most global cited documents, indicating the title, data, and purpose of each article.

Table 11. Brief summary of the content of the top 10 most globally cited documents.

No.	Paper (First Author, Year, Journal, Reference)	Title	Data	Purpose
1	Nahavandi, Saeid, 2019, *Sustainability* [1]	Industry 5.0—A Human-Centric Solution	Real-time data received from users (theoretical approach of Industry 5.0)	To present the benefits of technology using Industry 5.0 and robots, which increase the productivity of humans, while not removing them from the manufacturing industry. Also describes the key features and concerns related to Industry 5.0
2	Choi, Tsan-Ming, 2022, *SageJournals* [56]	Disruptive Technologies and Operations Management in the Industry 4.0 Era and Beyond	Real-time data received from users (theoretical approach of Industry 5.0)	To compare Industry 4.0 and Industry 5.0 and to explain the benefits of each industrial revolution
3	Pillai Souji Gopalakrishna, 2021, [62]	COVID-19 and hospitality 5.0: Redefining hospitality operations	Authors did not use data; they explained the concepts in a theoretic manner	To create an extension of Industry 5.0, create Hospitality 5.0 for the tourism domain, which suffered from the COVID-19 pandemic, using the latest technologies in order to reduce human interaction to a minimum
4	Javed, Abdul Rehman, 2022, *Elsevier* [63]	Future smart cities: requirements, emerging technologies, applications, challenges, and future aspects	Authors did not use data; they explained the concepts in a theoretic manner	To explain the concept of smart cities, what technologies should be used, what is the impact of technologies on the social and economic lives of people, and which cities are focusing on smart technologies
5	Bednar, Peter M., 2019, *Springer* [21]	Socio-Technical Perspectives on Smart Working: Creating Meaningful and Sustainable Systems	Authors did not use data; they explained the concepts in a theoretic manner	To present the focus of manufacturers, how technologies have improved production and the environment, and what is the real scope of Industry 5.0 implementation

Table 11. *Cont.*

No.	Paper (First Author, Year, Journal, Reference)	Title	Data	Purpose
6	Javaid, Mohd, 2929, *Journal of Industrial Integration and Management* [64]	Critical Components of Industry 5.0 Towards a Successful Adoption in the Field of Manufacturing	Authors did not use data; they explained the concepts in a theoretic manner	To point out the evolution of each industrial revolution, which are the particularities of each one, which are the main benefits of using Industry 5.0 when it is released
7	Fraga-Lamas, Paula, 2021, *Sustainability* [65]	Green IoT and Edge AI as Key Technological Enablers for a Sustainable Digital Transition towards a Smart Circular Economy: An Industry 5.0 Use Case	Data collected and analyzed using IoT	To explain how IoT can help the circular economy and develop a more sustainable world by digitalizing processes and to present practical use-cases where Industry 5.0 has been used
8	Akundi, Aditya, 2022, *Sustainability* [3]	State of Industry 5.0—Analysis and Identification of Current Research Trends	One hundred ninety-six documents from IEEE, Science Direct, and MDPI	To present the benefits of each industrial revolution, how Industry 4.0 and Industry 5.0 can change human and machine interactions. A literature review has been performed for 196 documents
9	Sigov, Alexander, 2022, *Springer*, [68]	Emerging Enabling Technologies for Industry 4.0 and Beyond	Authors did not use data; they explained the concepts in a theoretic manner	To describe the benefits of Industry 4.0, when it was implemented for the first time, what technologies have been used, where it was applied successfully, and why the evolution of Industry 4.0 is necessary
10	Sachsenmeier Peter, 2016, *Elsevier* [69]	Industry 5.0—The Relevance and Implications of Bionics and Synthetic Biology	Authors did not use data; they explained the concepts in a theoretic manner	To explain how the bionics domain is used in Industry 4.0, what Industry 5.0 is, how it can be implemented in order to obtain more sustainable fuels, and how industrial revolutions changed society

4.2. Word Analysis

The most used words describe a pattern of authors, indicating what are the main topics and what are the most important elements for Industry 5.0, ML, and big data analytics, based on Keywords Plus author keywords and subject categories.

At the beginning of our analysis, we specified the application of certain filters, according to which the works we kept were chosen. This paper, designed to be able to observe Industry 5.0 from the perspective of machine learning and big data analysis, expected that most of the words, whether single words or groups of words, that were found to have a high frequency would be part of this field of work.

4.2.1. Most Frequent Words in Keywords Plus

Table 12 elaborates a description of the top ten most frequent Keywords Plus extracted from sources. The most used word is “Internet”, with 17 occurrences, which is not a surprise because it is a crucial element of Industry 5.0; everything is now connected to the Internet. The second word is “Systems”, having 13 appearances, another key element of the domain, including complex systems that are working together using the Internet. The third is “Framework”, with 12 occurrences, which can also be assimilated to “Systems” if we are considering the software frameworks as systems. “IoT” is the fourth word, referring to the Internet of Things, which was presented previously, with 11 appearances and a strong correlation with “Artificial-Intelligence”, “Challenges”, and “Future”, each with 10 occurrences. IoT uses AI, which is considered a “future technology”, in order to solve more and more complex challenges [72]. “Management” has 9 appearances, and “Big Data” and “Technology” have 8 occurrences each, all three describing important components of Industry 5.0.

Table 12. Top 10 most frequent words in Keywords Plus.

Words	Occurrences
Internet	17
Systems	13
Framework	12
IoT	11
Artificial intelligence	10
Challenges	10
Future	10
Management	9
Big Data	8
Technology	8

4.2.2. Most Frequent Words in Authors' Keywords

Table 13 describes the top ten words used in the authors' keywords, a key step in finding patterns. The most used word is "Industry 5", referring to the domain of Industry 5.0, which is the topic of the analysis and has 40 occurrences. In second place is artificial intelligence, another topic of discussion, with 37 appearances. The third word refers to the same domain as the first one, "Industry 5.0", which has 32 occurrences. We can sum the first and third appearances since they are describing the same element, resulting in 72 occurrences. In fourth place is "Industry 4", the previous industrial revolution, with 17 appearances, followed by machine learning, a useful and very common technology used in Industry 5.0, with 16 appearances. The rest of the list has less than 16 appearances and is not very influential. Table 13 presents the full list.

Table 13. Top 10 most frequent words in authors' keywords.

Words	Occurrences
Industry 5	40
Artificial intelligence	37
Industry 5.0	32
Industry 4	17
Machine learning	16
Internet of Things	12
Security	12
Deep learning	9
Smart manufacturing	9
Industries	8

4.2.3. Most Frequent Words in Subject Categories

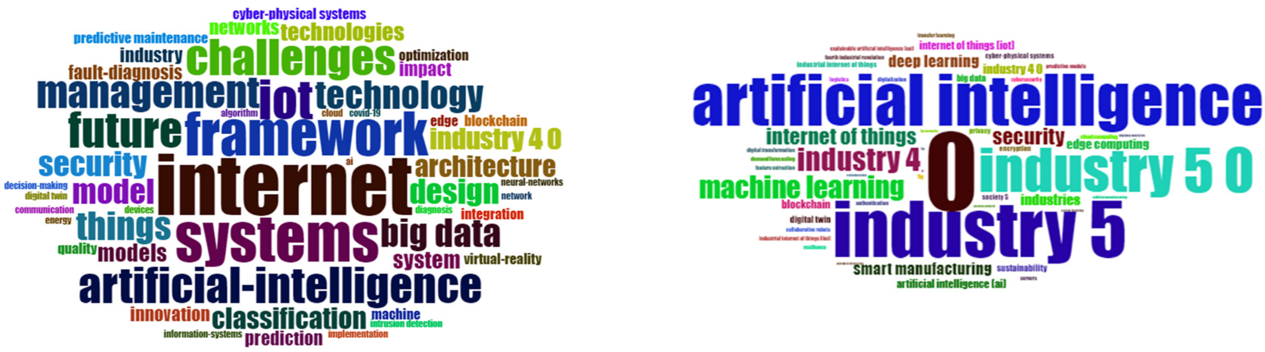
Table 14 presents the most frequent subject categories used by the authors. The most frequent subject is "Engineering electrical & electronic", a domain where Industry 5.0 significantly improved productivity, having 28 appearances. The second and third subjects are "Computer science information systems" and "Engineering industrial" with 26 occurrences each and related to industry activities. "Computer science interdisciplinary applications", which are applicable also to Industry 5.0, appeared 18 times. "Telecommunications" is a domain where Industry 5.0, ML, big data analytics, and robots can improve activities, reducing costs and increasing performance. "Automation & control systems" are often used in decision-making, supply chain management, and manufacturing. The last words are presented in Table 14.

Table 14. Top 10 most frequent words in subject categories.

Words	Occurrences
Engineering electrical and electronic	28
Computer science information systems	26
Engineering industrial	26
Computer science interdisciplinary applications	18
Telecommunications	15
Automation and control systems	13
Instruments and instrumentation	12
Chemistry analytical	11
Environmental sciences	10
Physics applied	10

4.2.4. WordClouds for Keywords Plus and Authors' Keywords

Using the Biblioshiny package [38], WordClouds have been created, including the most used words in all examined papers, extracting only keywords plus or authors' keywords. On the left side of Figure 10 is the WordCloud list of the top 50 most used keywords plus, and on the right side are the most frequently used authors' keywords. The size of the text indicates the frequency of each word.



(**A**) Top 50 words based on keywords plus. (**B**) Top 50 words based on authors' keywords

Figure 10. Top 50 words based on keywords plus (**A**) and authors' keywords (**B**).

"Internet" is the most repeated word, with 17 appearances, followed by "systems" with 13 occurrences, "framework" with 12 occurrences, "IoT" with 11 appearances, "artificial-intelligence", "challenges", and "future" with 10 appearances each. The last three words in the top 10 are "management", appearing nine times, "big data", and "technology", with eight occurrences each. The rest of the words have less importance. All words are describing Industry 5.0 processes or technologies, describing what tools should be implemented and used, what the threats are, and how to avoid them using the latest software and hardware tools.

In the authors' keywords, the most frequently used word is "0", since sometimes industry 5.0 is written in different ways, such as "Industry 5 0", and Biblioshiny is taken as a separate word. "0" appeared 56 times, followed by "Industry 5" with 40 appearances. Third is "artificial intelligence" with 37 occurrences, followed by "Industry 5.0" and "Industry 4" with 32 and 17 appearances. The last five words are "machine learning" appearing 16 times, "internet of things" with 12 appearances, "security" with 12 occurrences, "deep learning" appearing 9 times, and "smart manufacturing" with 9 appearances, showing less interest compared with the first half of the top 10. Similar to keywords plus, the focus was to indicate the topic analyzed, "Industry 5.0", and the tools such as AI, ML, and deep learning.

4.2.5. Bigrams and Trigrams in Abstracts and Titles

The group of two words, or bigrams, and the group of three words, or trigrams, were extracted from articles and counted to identify how authors explain what they discovered in their papers as simply as possible or what tools they used. Table 15 illustrates the most commonly used bigrams in abstracts and titles. The most common group of two words used is "Artificial Intelligence" with 81 occurrences, which is not a surprise since it is related to ML and big data analytics, which were part of the analysis. AI is a very used technology, making robots autonomous and helping humans make decisions. In second place, with almost half of the appearances, 45, is "Machine Learning", a more and more interesting domain, not just for companies but also for people, offering various possibilities of simplifying activities or extracting information that was not processed using only human brainpower. "Industrial revolution" and "Intelligence AI" each made 30 appearances, describing an important milestone, the revolution that occurred while implementing Industry 5.0, and one of the main tools used, AI. "Deep learning" appeared 24 times, "digital twin" 20 times, "manufacturing system" and "supply chain" 15 times each, "digital twins" 14 times, and "edge computing" 12 times. All bigrams describe tools that help manufacturers improve productivity, reduce costs, and reduce waste.

Table 15. Top 10 most frequent bigrams in abstracts and titles.

Bigrams in Abstracts	Occurrences	Bigrams in Titles	Occurrences
Artificial intelligence	81	Artificial intelligence	9
Machine learning	45	Machine learning	6
Industrial revolution	30	Digital twin	5
Intelligence AI	30	Edge computing	5
Deep learning	24	Supply chain	4
Digital twin	20	Deep learning	3
Manufacturing system	15	Federated learning	3
Supply chain	15	Human-robot collaboration	3
Digital twins	14	Industry application	3
Edge computing	12	Learning model	3

Looking at bigrams in titles, we observed a smaller frequency; the most used bigram is "artificial intelligence" with nine appearances, followed by "machine learning" with six occurrences, "digital twin", and "edge computing" with five appearances each. "Supply chain" appeared four times; "deep learning", "federated learning", "human-robot collaboration", "industry application", "industry application", and "learning model" appeared three times. The frequency of each bigram is provided in Table 15, while the frequency of the trigrams are depicted in Table 16.

Table 16. Top 10 most frequent trigrams in abstracts and titles.

Trigrams in Abstracts	Occurrences	Trigrams in Titles	Occurrences
Artificial intelligence AI	30	Deep learning model	2
Machine learning (ML)	11	Future research directions	2
Industrial revolution industry	10	Hybrid deep learning	2
Smart healthcare industry	8	Supply chain management	2
Fourth industrial revolution	7	Web-based attack detection	2
Deep learning (DL)	5	Access control scheme	1
Deep extreme machine	4	Adaptive bead modeling	1
Explainable artificial intelligence	4	Adaptive human-robot collaboration	1
Extreme machine learning	4	Adaptive optimization algorithms	1
Federated deep extreme	4	Additive manufacturing machine	1

4.2.6. Thematic Map for Titles

Thematic mapping takes into consideration the most used words from a category, such as titles, keywords, or abstracts, and discovers the connections between them to obtain various themes [73]. There are two features that explain the themes of density and centrality, represented on the vertical and horizontal axes. Density measures the ability of nodes to create groups, and centrality is the correlation between different topics [73].

Applying to our dataset the biblioshiny package [38] from the R programming language, Figure 11 shows the thematic map for titles, divided into four quadrants (Niche Themes, Motor Themes, Emerging or Declining Themes, and Basic Themes).

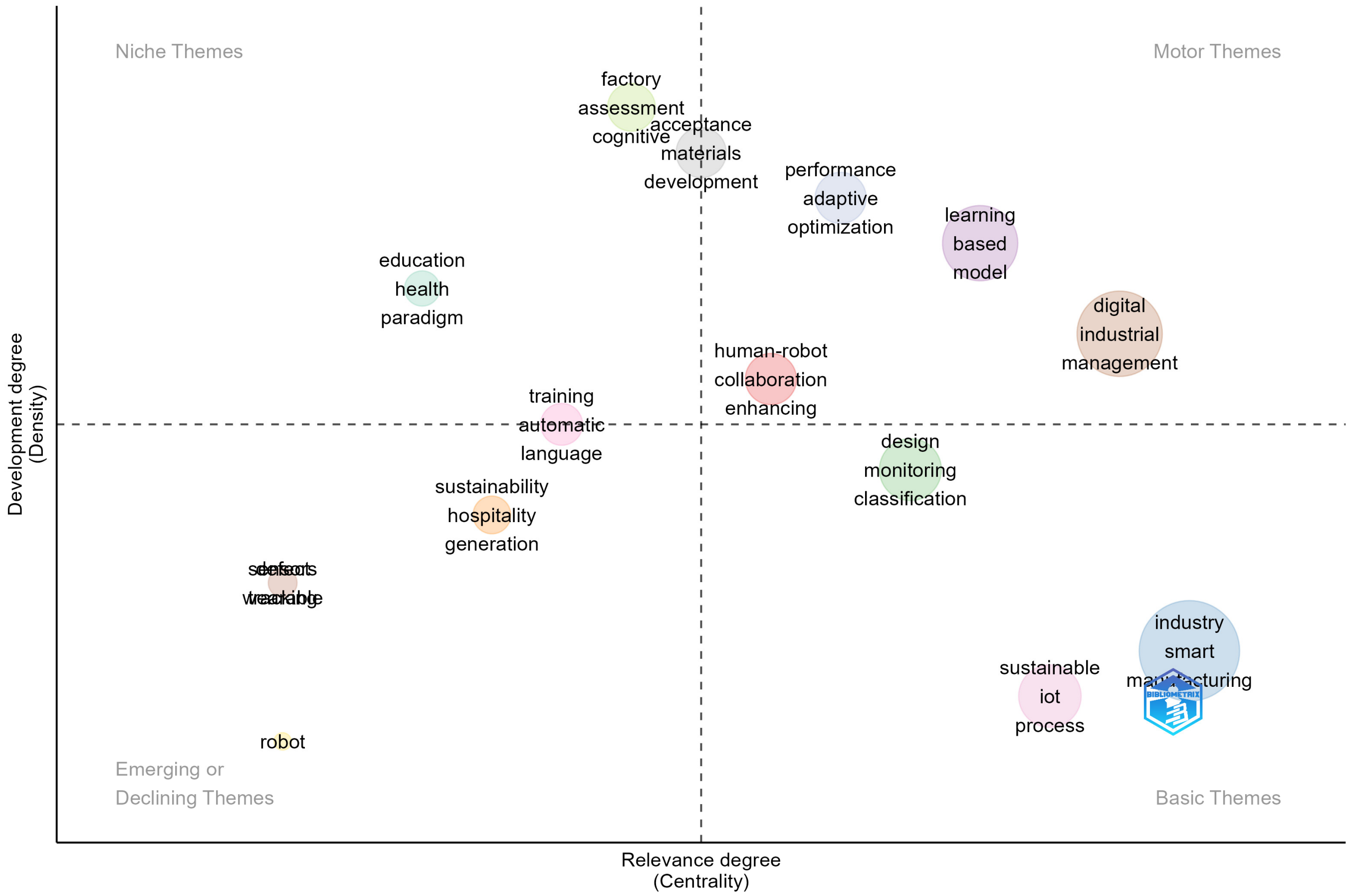


Figure 11. Thematic map for titles.

In the first quadrant, called Niche Themes, different topics are presented, such as "education health paradigm", "factory assessment cognitive", and other topics are between quadrants ("acceptance materials development", "training automatic language"). Based on the node size, those topics are not very relevant for Industry 5.0 but are used, depending on the domain. In the second quadrant, called Motor Themes, are two nodes bigger than the others recently described: "learning", "based", "model", and "digital industrial management", which makes sense to be more important since the focus of the research is to discover the connection between the newest technologies and industries. The third quadrant, Emerging or Declining Themes, has non-important topics, from the author's point of view, "sustainability hospitality and generation", while the last quadrant, Basic Themes, has the most relevant theme, "industry smart manufacturing", which stands as the purpose of Industry 5.0, to change the work environment by integrating the newest technologies. Figure 11 presents the full description of each node included in the thematic map.

4.2.7. Thematic Map for Keywords Plus

Figure 12 contains the thematic map associated with the keywords plus, which has fewer and less relevant topics discovered compared with the previous map. The most relevant theme is in the second quadrant, called Motor Themes, and describing the "internal systems framework", describing the need to use smart tools to improve productivity and products. Other topics include tools such as "artificial intelligence", "intrusion detection", and "classification system fault-diagnosis". The nodes are presented in Figure 12.

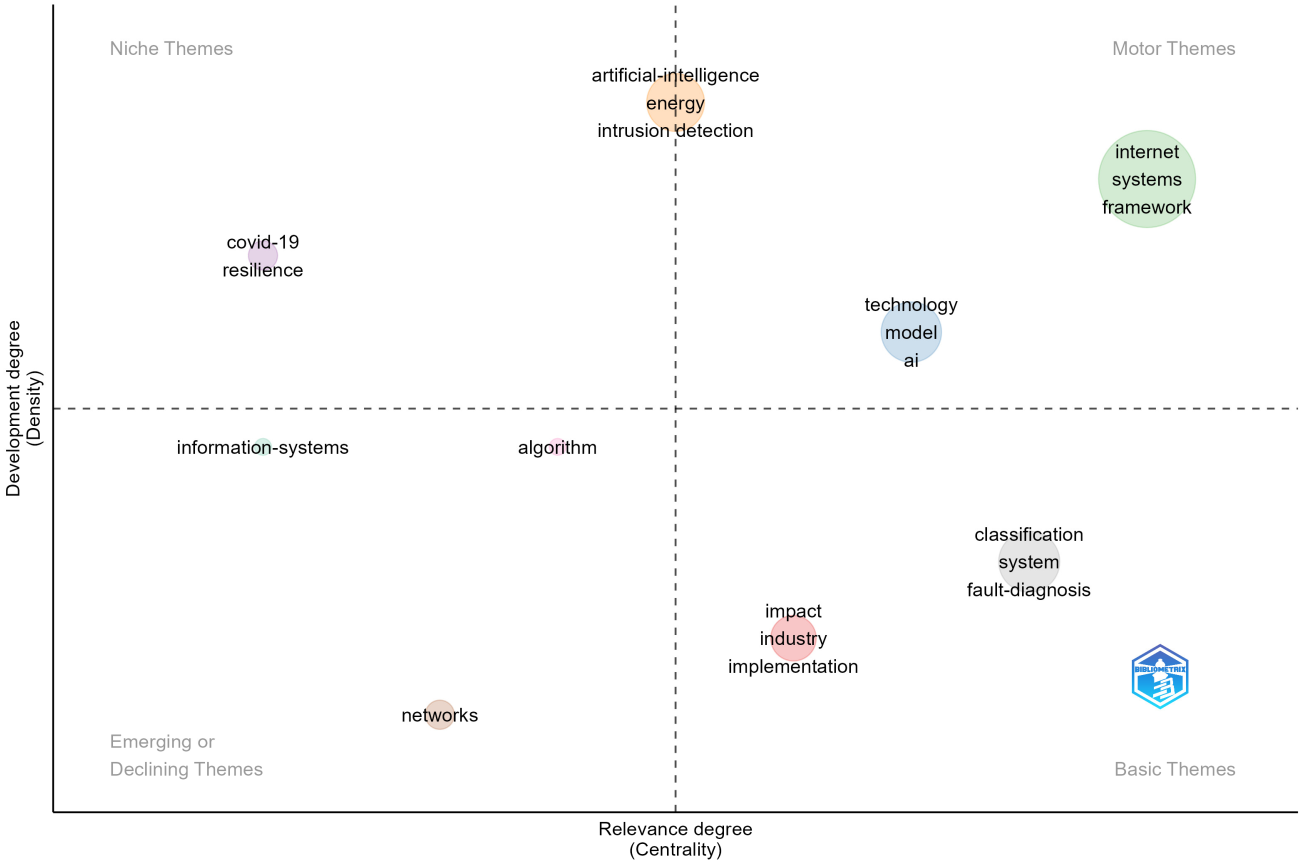


Figure 12. Thematic map for keywords plus.

4.2.8. Thematic Map for Abstracts

Figure 13 includes an abstract thematic map, which has three topics, but only two of them are relevant: "intelligence artificial industrial" and "industry data research". The first theme is positioned between two types of themes, "Niche Themes" and "Motor Themes", referring to industrial technologies. The second theme is in the "Basic Themes" category, presenting the new technologies that are possible to be discovered for industry based on the data collected. Figure 13 offers a complete description of the thematic map.

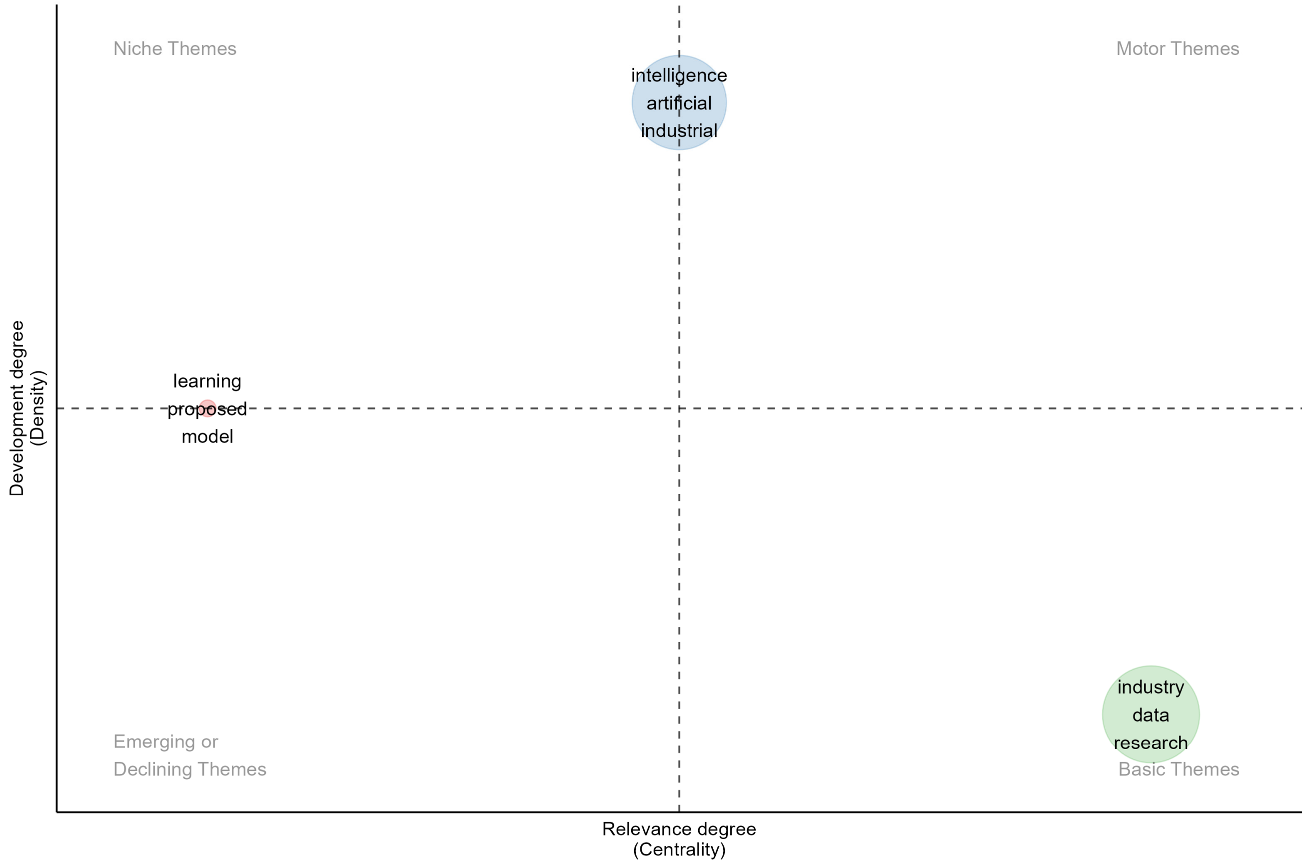


Figure 13. Thematic map for abstracts.

4.2.9. Factorial Analysis

Using Multiple Correspondence Analysis (MCA), factorial analysis reduces the dimensionality of data by grouping it into low-dimensional areas. MCA is an extension of correspondence analysis, which offers the possibility of verifying the patterns of existing relationships on variables [38,74].

Figure 14 shows the results of the MCA factorial analysis, with vertical and horizontal dimensions. Both dimensions have values, which represent the variance expressed by each dimension. The first dimension explains 53.99% of the variance, while the second dimension explains 24.22% of the variance. We chose to keep only two dimensions in the analysis because they account for over 75% of the variability, representing the top 23 most common terms at the author's keyword level.

The result of MCA represents two groups, the blue (privacy and security in the context of AI in Industry 5.0) and red (modeling and computing in the context of AI in Industry 5.0) categories. The blue group has words such as "industry.5", "smart.manufacturing", "industry.5.0", "industry.4", "machine.learning" or "internet.of.things", while the red group, which is much smaller than the first one, contains various words, and some of them are: "industrial.internet.of.things", "artificial.intelligence..ai", "privacy", "security", "industries" and "big.data".

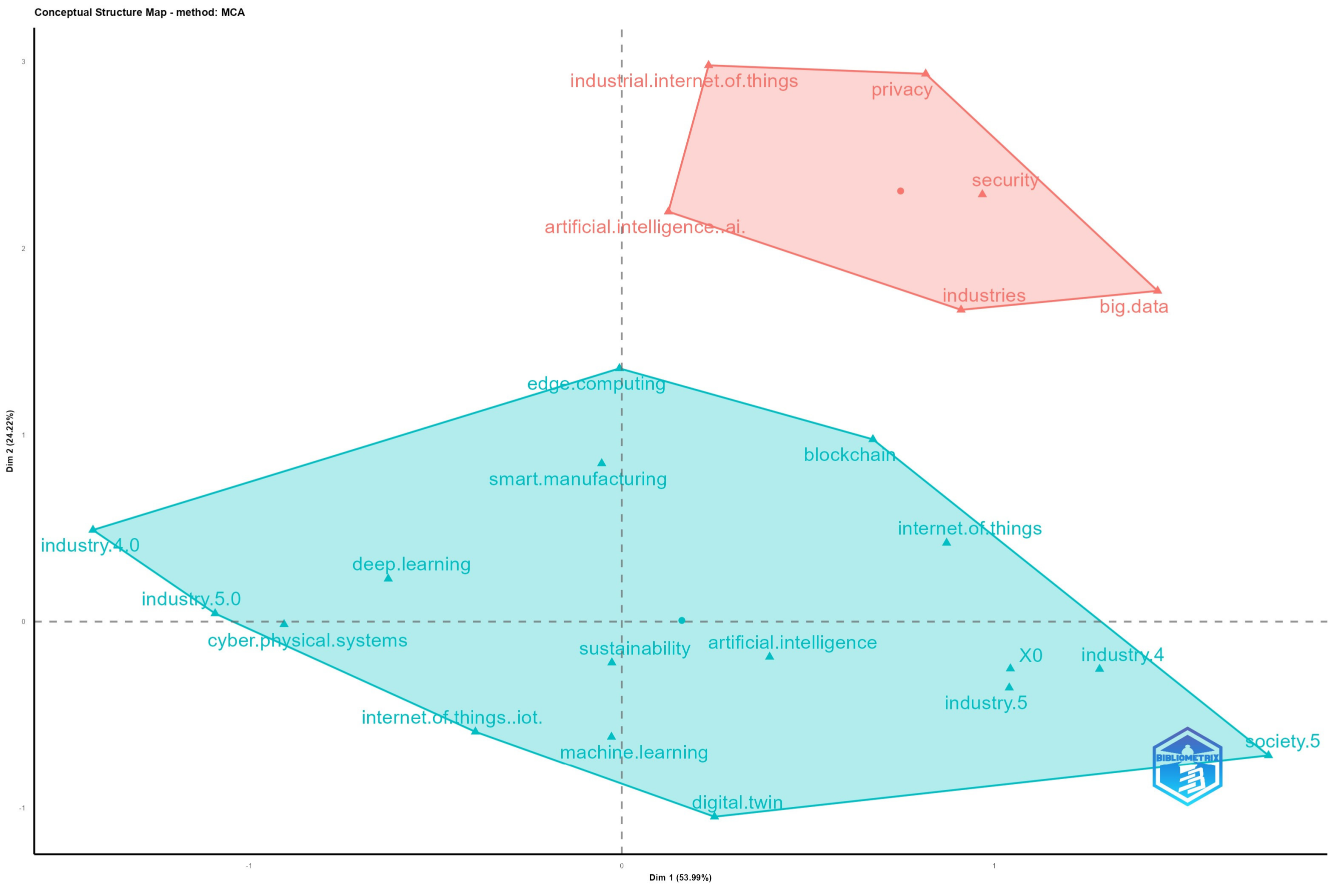


Figure 14. Factorial analysis.

4.3. Mixed Analysis

Using mixed analysis, we aim to test if there is any connection between the data and identify some patterns. There are two graphs created with different combinations of labels.

The three-fields plot depicted in Figure 15 offers a perspective on the connection between countries, authors, and journals. The most influent country is Saudi Arabia, with eight different authors that worked with the main authors described in the middle field. The researchers published in one of the most known journals (*IEEE Access* and *Production and Operations Management*). The UK, Greece, Slovenia, and Italy each had seven authors with different impacts that worked with the main authors presented in the middle field. The authors also published in top journals, as described in the field on the right side of Figure 15.

In Figure 16, the combination of affiliations, authors, and most-used keywords is presented. Josef Stefan Institute from Slovenia, the National Technical University of Athens from Greece, and the Slovenian Academy of Sciences and Arts (SASA) worked on seven papers, similar to the information presented previously in Figure 15. In the United Kingdom, there are two different universities, Queen Mary University London and University College London, each with a contribution of four articles. The most frequently used keywords are "smart manufacturing", which stands as the main benefit of Industry 5.0, ML, and big data implementation. The rest of the keywords belong to Industry 5.0, Industry 4.0, AI, ML, and digital twin areas.

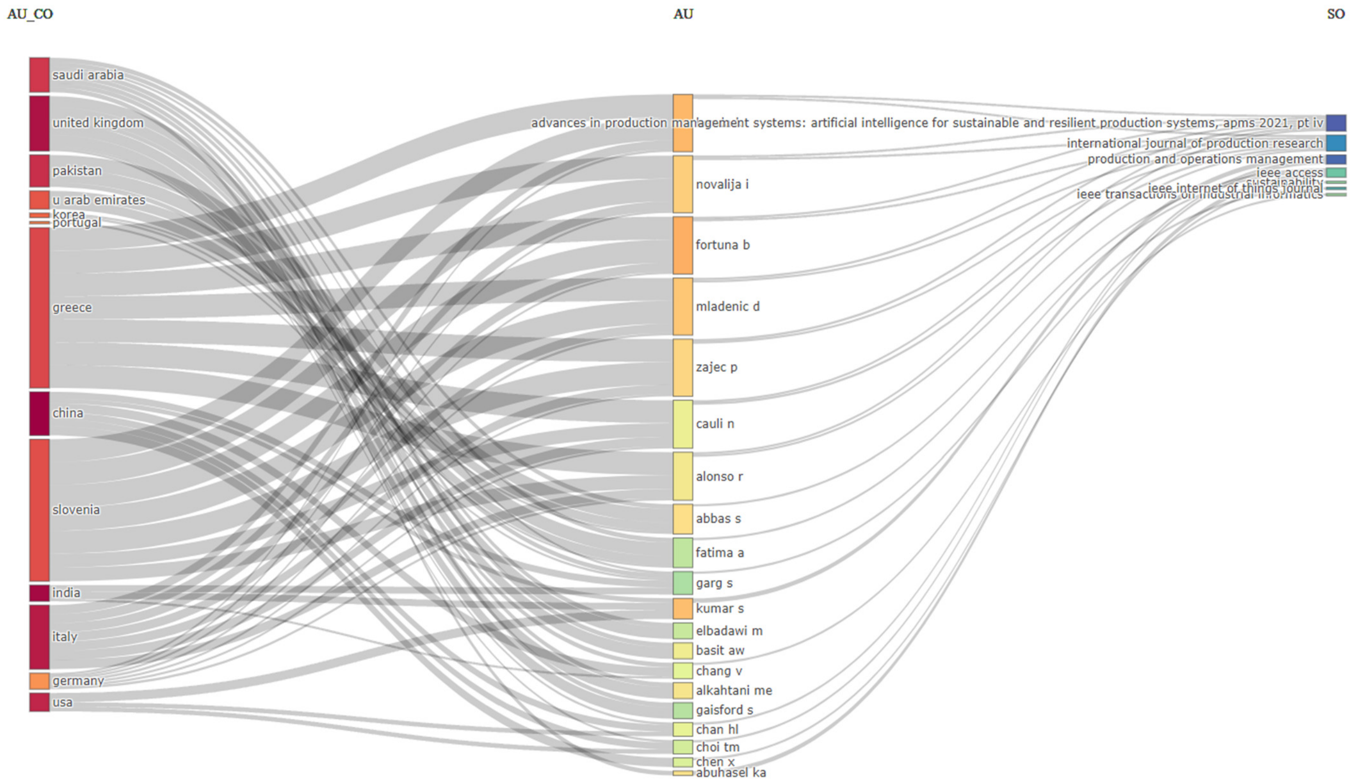


Figure 15. Three-fields plot: countries (**left**), authors (**middle**), journals (**right**).

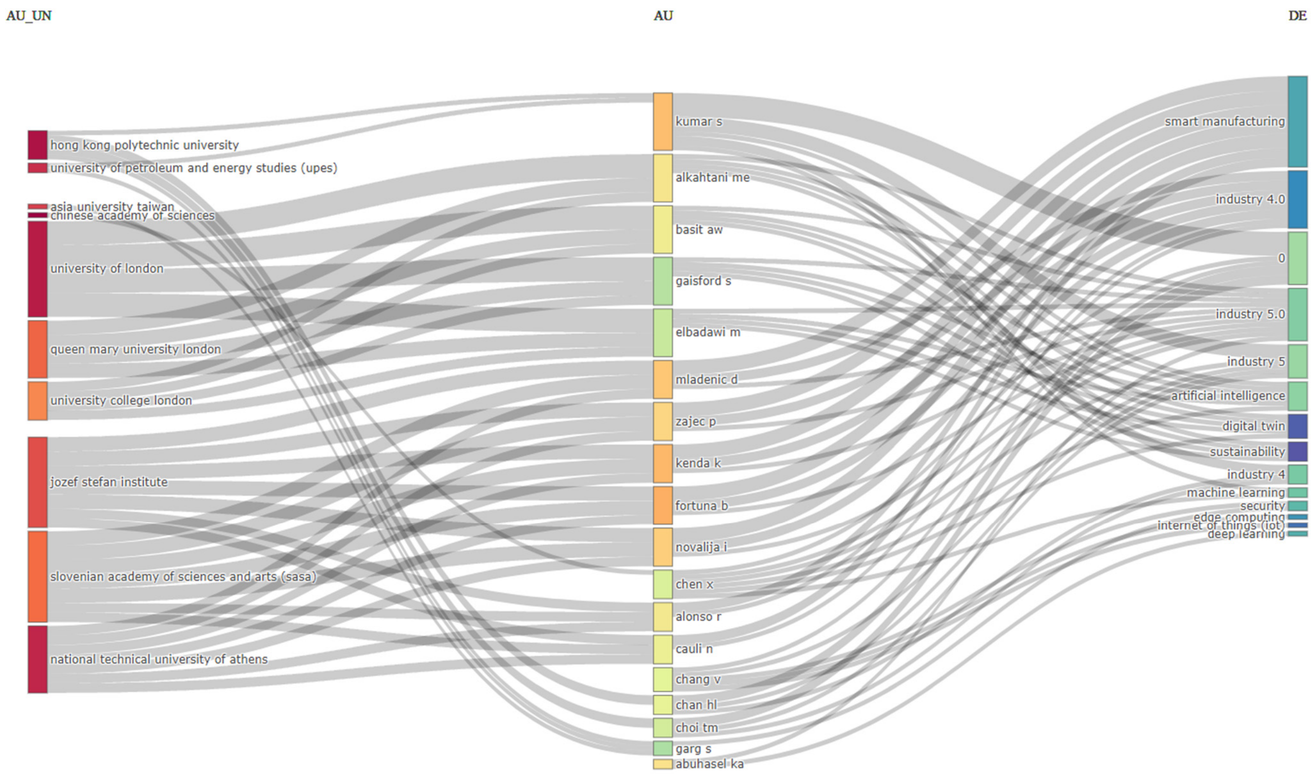


Figure 16. Three-fields plot: affiliations (**left**), authors (**middle**), keywords (**right**).

5. Limitations

The subject described in the article has some limitations, mainly on data selection. The first limitation is related to the database. Since, in this article, only WoS documents were analyzed, one of the most recognized databases in the academic community, excluding any other databases, the total number of extracted papers can vary when compared to other databases. The dataset extracted was between 2016 and 2023, having only 3 documents with missing keywords, 2 with missing DOIs, and 31 keywords plus, which had a minor impact on the results.

The filters applied to the dataset during the extraction process represent another limitation. The language of the papers was exclusively English, removing documents published in other languages. The paper type was explicitly defined to contain only "articles", not considering other types of papers. With all these, it should be mentioned that, according to the WoS site information [36] related to the types of papers included under the "article" umbrella, one can find both the papers published in the scientific journals and presented to conferences, as well as any other research considered relevant (new and original) research. The keywords used to search the WoS database were only English terms, representing another limitation. Any changes to search parameters, filters, or databases could modify the results in a positive or negative way.

Also, it shall be noted that all the figures provided in connection with the bibliometric analysis, namely Figures 2–16, are created through the use of the Bibliometrix package [38], and sometimes the entire logo of the package or just a part of it appears on the bottom-right corner of the figures in blue color.

6. Conclusions

The present research group includes all papers that mention Industry 5.0 and the latest technologies, such as AI, ML, or big data analytics, extracting the total number of citations, the collaboration patterns discovered between countries, affiliations, and authors, and the most relevant journals indexed in the WoS database.

The Fifth Industrial Revolution had a significant impact on workers lives, offering new possibilities for evolution, creating a comfortable environment where employees could co-work with robots, achieving new levels of productivity, creating more personalized goods and services, and facilitating daily tasks. Even if the domain was recently discovered, academic interest has increased significantly in the last 2 years, with researchers discovering more and more tools and processes that make the implementation of Industry 5.0 easier.

Future analysis will be performed with an even more detailed analysis of the evolution of Industry 5.0 and the most suitable tools for a variety of domains. The implementation of the Fifth Industrial Revolution is a continuous process due to the technological advance that is rapidly evolving, as it was presented during the research, and the next step will be to point out the most crucial factors that simplify the implementation of the newest technologies, not only in the manufacturing domain. As it was presented, there are multiple industries where Industry 5.0 has been implemented (tourism, medicine). Moreover, we can include other databases in the analysis to increase the number of documents, such as Scopus or PubMed.

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