

Industry 5.0 in Informatics: Bibliometric Analysis of Human-Centric Automation with Cross-Country Collaboration and Funding Agency Mapping

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ABSTRACT

This paper examines the conceptual and collaborative framework of Industry 5.0 in informatics, concentrating on the growing paradigm of human-centric automation. This research employs a bibliometric analysis of publications indexed in the Scopus database from 2016 to 2025 to investigate publication trends, thematic progression, international collaborations, and contributions from funding agencies. Data were examined using Bibliometrix (R) and VOSviewer to illustrate co-authorship, keyword co-occurrence, and institutional networks. The findings indicate that Industry 5.0 research is transitioning from a focus on technology issues—like automation and cyber-physical systems—to a comprehensive framework that prioritizes human-machine collaboration, sustainability, and ethical innovation. Principal theme clusters focus on artificial intelligence, the Internet of Things, ergonomics, and decision-making, constituting the intellectual foundation of human-centric informatics. European and Asian nations, notably Italy, the United Kingdom, India, and China, lead in scientific output, bolstered by robust institutional collaboration and varied funding mechanisms. The research offers novel perspectives on how informatics facilitates the shift towards human-centered industrial ecosystems, integrating engineering, data science, and social innovation. The results advance the theoretical framework of Industry 5.0 as a socio-technical system and provide practical recommendations for policymakers, researchers, and funding bodies in promoting sustainable and equitable digital transformation.

Keywords: Industry 5.0, Human-Centric Automation, Informatics, Artificial Intelligence, Internet of Things, Bibliometric Analysis.

1. INTRODUCTION

The advent of Industry 5.0 signifies a fundamental change in industrial evolution, transitioning from the automation-focused Industry 4.0 to a human-centered, sustainable, and resilient value generation model. Industry 4.0 emphasized digital connectivity, cyber-physical systems, and machine autonomy, whereas Industry 5.0 re-establishes humans as creative and decision-making collaborators with machines [1], [2]. It anticipates a period of cooperation between humans and intelligent systems, incorporating technologies such as artificial intelligence (AI), the Internet of Things (IoT), robotics, and digital twins to attain social and environmental sustainability in conjunction with economic efficiency [3], [4].

In this new paradigm, informatics functions as the foundation facilitating human-centric automation. Informatics research propels advancements in machine learning, data analytics, decision-support systems, and human-machine interfaces, enabling smooth collaboration between humans and digital technologies [5]. The field contributes through algorithms and software design, as well as by incorporating ethical, cognitive, and ergonomic factors into automation designs [6]. Consequently, human-centric automation in Industry 5.0 has evolved into a multidisciplinary convergence of computer science, information systems, and engineering with human factors, management, and social sciences [7].

Recent scholarly discourse has started to characterize Industry 5.0 as a reaction to the shortcomings of its predecessor. The focus of Industry 4.0 on productivity and efficiency frequently

overlooks human well-being, creativity, and inclusivity [3]. Conversely, Industry 5.0 emphasizes co-creation, personalization, sustainability, and resilience—principles that correspond with the European Commission's goal of a "human-centric, sustainable, and resilient industry" [8]. Thus, human-centric automation represents not merely a technological enhancement but a conceptual shift prioritizing ethics, accountability, and societal value [9], [10].

The proliferation of Industry 5.0 research has markedly intensified within the realm of global studies. Bibliometric data indicates a significant surge in publications after 2019, especially in domains associated with informatics, robotics, and digital transformation [11]. Prominent topics are "human-robot collaboration," "sustainability," "cognitive automation," and "resilient manufacturing" [6]. However, the current research is disproportionately allocated among various countries, academic fields, and funding environments. Europe and East Asia predominate in publication output, whilst contributions from the Global South are comparatively limited [11], [12]. Comprehending these differences is essential for fostering inclusive innovation and guaranteeing that the global shift to Industry 5.0 advantages varied societies.

Bibliometric analysis offers a robust scientific framework for examining such patterns. This analysis quantitatively delineates the scientific landscape by examining publication metadata—authors, institutions, nations, keywords, and citations—to discern collaborative networks, intellectual frameworks, and theme trends [13]. Bibliometric studies in the context of Industry 5.0 can elucidate the role of informatics in human-centric automation, identify emerging knowledge clusters, and assess the impact of international collaboration and funding on this progression. Notwithstanding its promise, prior bibliometric studies have predominantly concentrated on manufacturing, sustainability, or technological convergence without methodically incorporating cross-country collaboration and funding agency [11], [12].

Moreover, bibliometric mapping helps elucidate the impact of funding systems on research paths. Funding organizations, including national science foundations and international programs like Horizon Europe, frequently influence the trajectory, extent, and magnitude of innovation ecosystems [14]. By correlating funding data with publication and collaboration metrics, researchers can elucidate how financial assistance promotes interdisciplinary or transnational cooperation in Industry 5.0 research. Currently, there is no thorough analysis that integrates informatics-driven human-centric automation, global cooperation networks, and funding landscapes under a unified framework.

The integration of informatics and human-centered automation corresponds with the Sustainable Development Goals (SDGs) and the European Union's digital policy, highlighting ethical technology and digital inclusion [8]. Comprehending the role of global research in achieving these objectives is crucial for policymakers, researchers, and funding organizations aiming to promote the Industry 5.0 vision. A bibliometric study examining this nexus can provide essential insights into the current state, partnership dynamics, and financing arrangements of the growing research frontier.

Despite the rapid expansion of literature on Industry 5.0, systematic research regarding the informatics aspect of human-centric automation remains disjointed. Current bibliometric reviews have examined overarching Industry 5.0 trends [11], [12], however they seldom focus on informatics-driven methodologies or delineate worldwide collaboration and funding patterns. As a result, scholars and policymakers possess an inadequate comprehension of the entities (countries, institutions, authors) that propel this research, the dynamics of cross-national cooperation, and the funding agencies that shape the agenda. The lack of integrative mapping obstructs information

sharing, research coordination, and the equitable advancement of human-centric automation technologies globally.

This study intends to provide an extensive bibliometric analysis of Industry 5.0 research within the field of informatics, concentrating on human-centric automation. The aims are to:

1. Examine publishing trends, citation patterns, and thematic development of human-centric automation in Industry 5.0.
2. Chart the interconnections of cross-disciplinary and institutional collaborative networks within the informatics research community.
3. Analyze and illustrate the contributions of funding agencies to global research output.

This study aims to elucidate the intellectual framework, international collaborations, and funding landscapes that support informatics-driven human-centric automation research, providing direction for future policies, research partnerships, and investment strategies consistent with Industry 5.0 principles.

2. METHODS

This study employs a quantitative bibliometric methodology to systematically examine the evolution, structure, and collaborative dynamics of Industry 5.0 research in informatics, with a focus on human-centric automation. Bibliometric analysis facilitates the detection of publication trends, prominent authors, institutions, and nations, in addition to mapping thematic and funding patterns [13]. The approach integrates performance analysis, assessing productivity and impact metrics like publication counts, citations, and h-indices, with scientific mapping to illustrate intellectual frameworks and collaborative networks [15]. This research integrates approaches to present descriptive statistics of scholarly production and relational insights into the evolution of human-centric automation in Industry 5.0 across several nations and disciplines.

The data were obtained from the Scopus database, selected for its extensive multidisciplinary scope and detailed metadata regarding funding sources and author connections [16]. The search query integrated controlled keywords and Boolean operators for precision: ("Industry 5.0" OR "human-centric automation" OR "human-robot collaboration") AND ("informatics" OR "computer science" OR "information systems"). The timeframe was established from 2016 to 2025, encompassing the growth and consolidation of Industry 5.0 literature. Only English-language journal articles, reviews, and conference papers were included to ensure quality and comparability. Duplicate and extraneous records were eliminated following a manual review of titles and abstracts. The resulting dataset, exported in CSV format, included bibliographic information such as authors, titles, keywords, affiliations, nations, funding agencies, and citation data, which became the basis for further studies.

Data processing and visualization were performed with the Bibliometrix package in R [17] and VOSviewer [18]. Bibliometrix was utilized to produce descriptive metrics like annual scientific output, highly cited publications, and source impact, whilst VOSviewer was employed for the construction and visualization of co-authorship, co-occurrence, and co-funding networks. Collaboration networks were examined at three tiers—author, institution, and country—to discern prominent nodes and international research alliances. Data from funding agencies were standardized using OpenAlex identities and aggregated by countries to illustrate the financial impact on publication output. An examination of thematic evolution was conducted utilizing keyword co-occurrence and trend mapping to elucidate the temporal shifts in research themes. Collectively, these measures guaranteed a meticulous, transparent, and reproducible bibliometric examination of the informatics-oriented human-centric automation study domain.

3. RESULTS AND DISCUSSION

3.1 Network Visualization

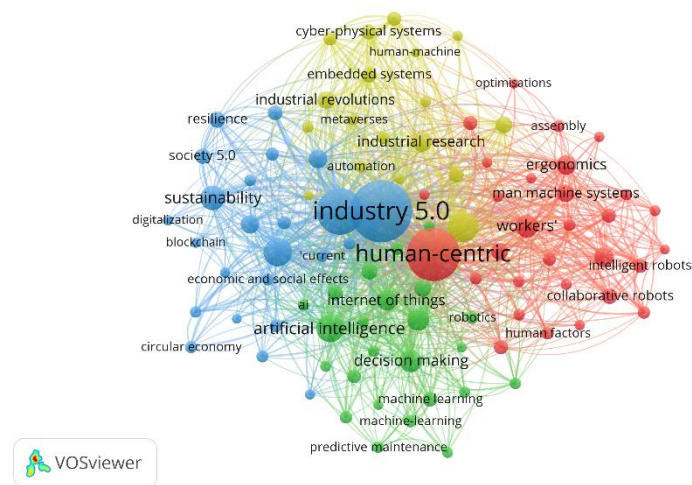


Figure 1. Network Visualization

Source: Data Analysis Result, 2025

The largest nodes—“industry 5.0” and “human-centric”—constitute the conceptual nucleus of this study domain at the network's center. Their pivotal positioning and dense connectivity suggest that the majority of studies closely associate Industry 5.0 with human-centered principles, including collaboration, ethics, and social sustainability. The intricate interconnection of these nodes with technological and societal concepts (e.g., sustainability, resilience, society 5.0) indicates that Industry 5.0 is perceived not merely as an extension of digital industrial transformation but also as a paradigm that integrates human well-being, intelligent automation, and socio-economic advancement. This validates the current transition from only cyber-physical optimization (Industry 4.0) to human-centric, purpose-oriented innovation [1], [9].

The blue cluster (bottom-left quadrant) encompasses terms including sustainability, society 5.0, circular economy, digitization, and blockchain. This cluster embodies the socio-economic and sustainability aspects of Industry 5.0. It associates digital transformation with responsible innovation, sustainable production, and societal resilience [11]. The relationship between economic and social impacts and digitization demonstrates how informatics supports sustainable growth models, such as data-driven policymaking, environmental monitoring, and circular value chains. The significance of blockchain and AI in this group signifies a developing dialogue on transparent, traceable, and ethically responsible industrial systems. Thus, this cluster represents the policy- and ethics-focused direction of Industry 5.0 research.

The green cluster emphasizes technical enablers such as artificial intelligence, machine learning, the Internet of Things, predictive maintenance, decision-making, and robots. This signifies the foundational informatics and computational intelligence of Industry 5.0. This research emphasizes the creation of intelligent algorithms, adaptive decision-making systems, and integrated sensor networks that facilitate real-time, data-informed human-machine collaboration [5], [6]. The convergence of AI, decision-making, and IoT suggests that informatics research prioritizes autonomy under human supervision, demonstrating that cognitive computing and analytics serve to enhance rather than supplant human intelligence. The intersection of this green cluster and the central human-centric node represents the amalgamation of computational design with human values, epitomizing the core of human-centric automation.

To the right, the red cluster encompasses topics including ergonomics, man-machine systems, collaborative robots, workers, and human factors. This cluster encompasses the aspects of human-robot collaboration and workplace ergonomics under Industry 5.0. It illustrates how

automation is engineered to accommodate human comfort, safety, and skill augmentation. This cluster of studies frequently examines sensor-based support, collaborative robot safety, cognitive ergonomics, and adaptive interfaces that facilitate cooperation between humans and intelligent machines [2], [7]. The robust internal connections within this cluster signify a developed and highly specialized study domain centered on the physical and cognitive interactions between humans and robots. Its proximity to the central human-centric node highlights its direct contribution to the fundamental goal of Industry 5.0.

The yellow cluster (upper area) includes keywords such as cyber-physical systems, embedded systems, industrial revolutions, metaverses, and industrial research. This signifies the technology integration and digital infrastructure aspect of Industry 5.0. The integration of metaverses with embedded systems signifies a transition towards immersive, simulation-driven, and digital-twin settings in which human operators engage inside hybrid physical-virtual realms [19]. This cluster integrates industrial engineering and informatics by linking traditional automation with advanced human-machine systems. The comparatively smaller node sizes indicate that it is an emerging yet rapidly expanding research frontier, suggesting that cyber-physical informatics will be crucial in the forthcoming phase of human-centric industrial transformation.

The graphic demonstrates that Industry 5.0 research in informatics is multifaceted, integrating sustainability, intelligent automation, and ergonomics within a cohesive human-centric framework. The intimate interconnection of these clusters indicates a developed yet progressing knowledge base that amalgamates technology and humanity. Future bibliometric and thematic analyses may investigate the chronological evolution of these clusters, revealing whether sustainability-oriented or robotics-oriented themes have predominated in recent years, so providing critical insights into the trajectory of human-centric automation research globally.

3.2 Overlay Visualization

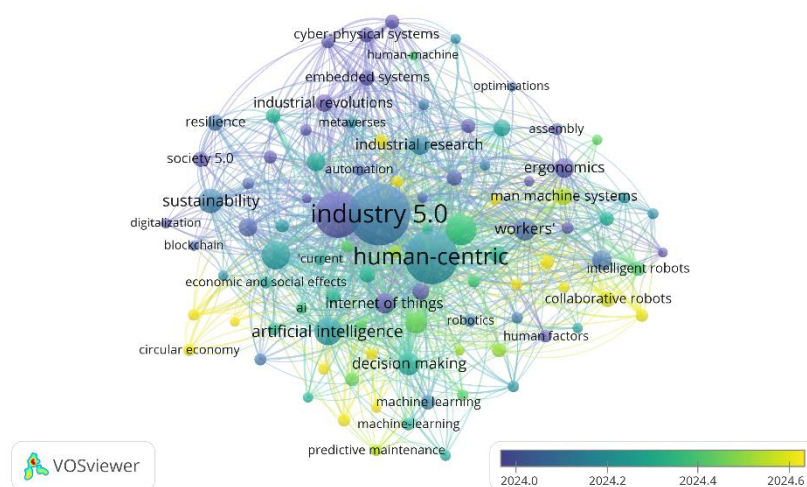


Figure 2. Overlay Visualization

Source: Data Analysis Result, 2025

The overlay visualization from VOSviewer illustrates the temporal progression of keywords associated with Industry 5.0 and human-centric automation in informatics from early to mid-2024. The color gradient—from dark blue (older publications) to brilliant yellow (most recent)—illustrates the temporal evolution of research interests. During the initial period (blue–green tones), the primary emphasis was on fundamental constructions like cyber-physical systems, automation, embedded systems, and industrial research. The phrases located at the upper section of the map signify the foundational conceptual and technological framework of Industry 5.0, wherein academics have built upon the heritage of Industry 4.0 via cyber-physical integration and digital control

systems. This phase focused predominantly on system design and technological optimization, rather than on social or cognitive collaborative elements.

As the area advanced (transitioning to green tones in 2023–2024), focus shifted towards informatics-driven and cognitive technologies, including artificial intelligence, machine learning, the Internet of Things, and decision-making. This transformation marks the second developmental stage in Industry 5.0 research—moving from mechanical automation to intelligent, data-driven collaboration between humans and machines. Informatics has become crucial in facilitating predictive maintenance, adaptive learning, and decentralized decision-making systems. The intersection of human-centric design, artificial intelligence, and sustainability in mid-hued nodes signifies the initiation of research connecting computer intelligence with ethical and environmental concerns. During this time, multidisciplinary convergence intensified, integrating computer science, engineering, and human-factors research within the framework of Industry 5.0.

The most recent developments (yellow-shaded nodes) indicate the emergence of new research horizons in late 2024, highlighting collaborative robotics, human aspects, ergonomics, circular economy, and blockchain. These phrases signify a definitive shift towards human-machine collaboration, accountable automation, and sustainable governance. The emergence of collaborative robots and human factors as recent focal points indicates that contemporary research prioritizes worker well-being, cognitive ergonomics, and ethical human-robot collaboration, in accordance with the European Commission's vision of a "human-centric industry" (Breque et al., 2021). The emergence of the circular economy and blockchain indicates that digital traceability and environmental accountability are essential components of Industry 5.0 informatics. The overlay graphic illustrates a chronological progression from technological underpinnings (2020–2022) to the integration of intelligent systems (2023), culminating in ethical, sustainable, and collaborative human-centric applications (2024 forward).

3.3 Citation Analysis

Table 1. The Most Impactful Literatures

Citations	Authors and year	Title
1126	[1]	Industry 5.0-a human-centric solution
604	[20]	Future of industry 5.0 in society: human-centric solutions, challenges and prospective research areas
498	[21]	Value-oriented and ethical technology engineering in industry 5.0: A human-centric perspective for the design of the factory of the future
487	[22]	Outlook on human-centric manufacturing towards Industry 5.0
450	[23]	Industry 5.0 and Society 5.0—Comparison, complementation and co-evolution
429	[24]	The Industry 5.0 framework: viability-based integration of the resilience, sustainability, and human-centricity perspectives
361	[25]	A Literature Review of the Challenges and Opportunities of the Transition from Industry 4.0 to Society 5.0
311	[26]	Rethinking engineering education at the age of industry 5.0
255	[27]	Industry 5.0: improving humanization and sustainability of Industry 4.0
251	[28]	Towards the Resilient Operator 5.0: The Future of Work in Smart Resilient Manufacturing Systems

Source: Scopus, 2025

3.4 Density Visualization

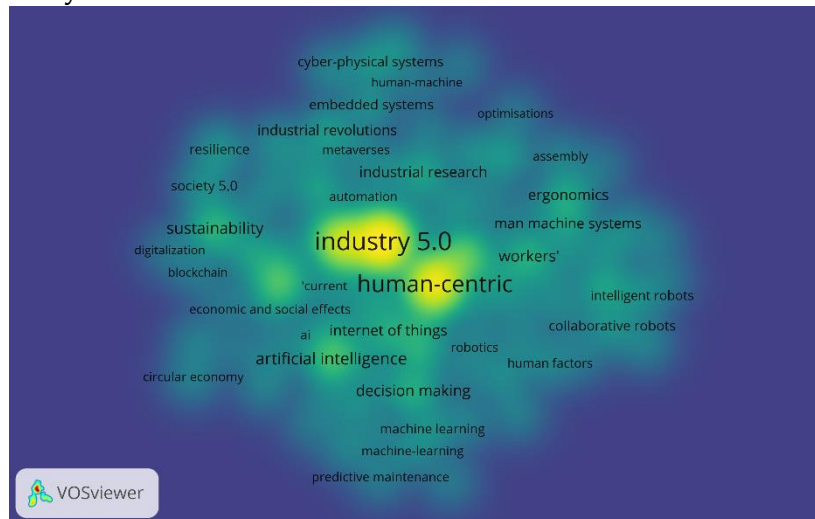


Figure 3. Density Visualization

Source: Data Analysis Result, 2025

The density visualization map generated by VOSviewer illustrates the most extensively researched domains within the literature of industry 5.0 and human-centric automation in informatics. The vivid yellow center encompassing the terms “industry 5.0”, “human-centric”, “artificial intelligence”, “Internet of Things”, and “decision making” signifies the peak concentration of research effort and co-occurrence frequency. This concentrated area illustrates the core scientific dialogue connecting intelligent technologies and human cooperation, indicating that the prevailing research focus centers on the integration of AI and IoT to improve human decision-making and system flexibility. The significance of these fundamental words indicates that researchers continuously regard human participation—not alone automation—as the primary catalyst for innovation and sustainability in Industry 5.0 ecosystems.

The density diminishes progressively from the core to the outside regions, indicated in green and blue, where terms like sustainability, circular economy, blockchain, collaborative robotics, human factors, and ergonomics are present. These domains signify nascent or multidisciplinary concepts that broaden Industry 5.0 beyond technological confines into ethical, economic, and environmental realms. Their moderate density indicates increasing academic attention but less integration compared to the primary AI-IoT-human link. This pattern indicates a developing field: core efforts have consolidated around informatics and intelligent systems, while ancillary subjects such as sustainable design and ergonomic collaboration are progressing into the next phase of exploration. The density map illustrates a research ecosystem that is technologically based and increasingly advancing towards socio-humanistic integration, reflecting the core of a human-centered industrial future.

3.5 Co-Authorship Network

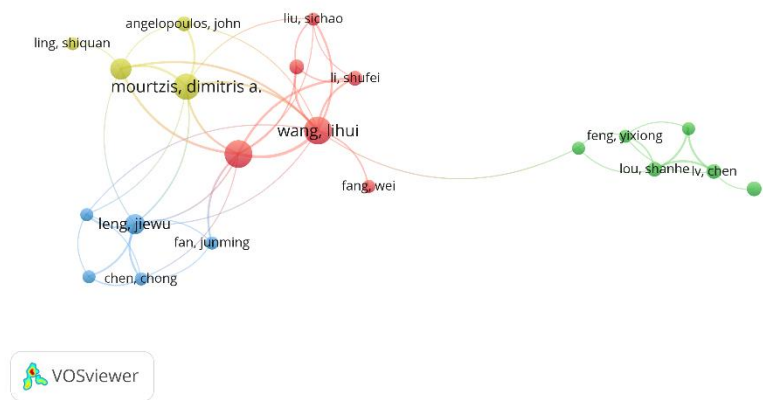


Figure 4. Author Visualization
Source: Data Analysis Result, 2025

Figure 4 illustrates the visualization of the author co-authorship network, highlighting the collaborative framework within Industry 5.0 and human-centric automation research. The network consists of multiple unique clusters, each signifying a group of researchers who commonly collaborate in publishing. The red cluster, spearheaded by Wang, Lihui, emerges as the most central and significant, linking co-authors Li, Shufei, Liu, Sichao, and Fang, Wei. This group exhibits robust internal connections, signifying a well-established research collaboration centered on intelligent manufacturing and human-robot interaction. The yellow cluster, centered on Mourtzis, Dimitris A. and Angelopoulos, John, signifies a notable European research hub focusing on digital transformation and intelligent industrial systems. The blue cluster, comprising Leng, Jiewu, Chen, and Chong, exemplifies a concurrent Asian collaboration in informatics and cyber-physical integration. The green cluster, comprising Feng, Yixiong, and Lou, Shanhe, signifies nascent research networks that are somewhat marginal yet expanding in global connection. The map depicts a globally spread yet relatively fragmented authorship structure, with Wang and Mourtzis acting as crucial connectors between Asian and European research communities in human-centric Industry 5.0.

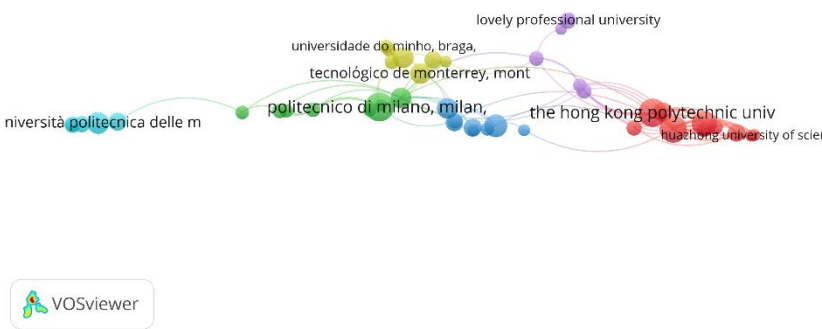


Figure 5. Affiliation Visualization
Source: Data Analysis Result, 2025

Figure 5 illustrates the institutional collaboration network demonstrates the connections across global universities and research institutes in publishing on Industry 5.0 and human-centric automation. The graphic illustrates a moderately interconnected yet regionally concentrated network, featuring prominent hubs in Europe and Asia. The Hong Kong Polytechnic University and Huazhong University of Science and Technology (red cluster) constitute the premier Asian collaboration hub, making substantial contributions to research in smart manufacturing and human–robot interaction. In Europe, Politecnico di Milano and Università Politecnica delle Marche (blue and green clusters) function as pivotal hubs, closely connected to Universidade do Minho and Tecnológico de Monterrey, exemplifying transcontinental collaborations between Europe and Latin America. The Lovely Professional University in India (purple cluster) is linked to the Asian network, indicating the increasing involvement of developing economies in Industry 5.0 research. The map illustrates a transnational collaboration framework centered around several prominent technical universities, indicating that although the subject is seeing global expansion, knowledge production is predominantly focused within a limited number of well-connected institutions in Asia and Europe.

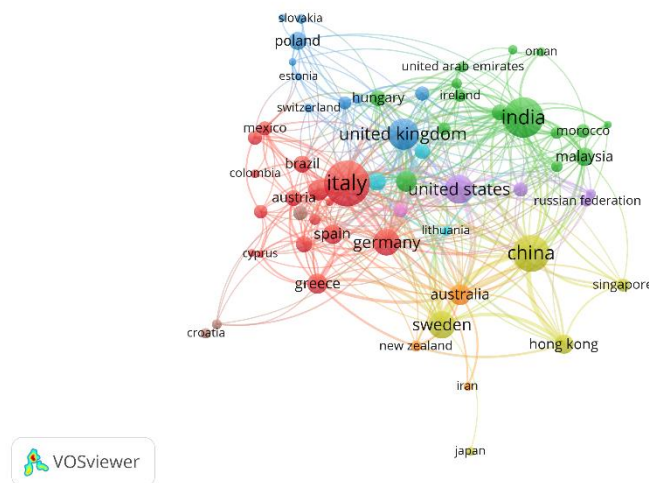


Figure 6. Country Visualization

Source: Data Analysis Result, 2025

Figure 6 illustrates the country cooperation network map illustrates the global research interconnections in Industry 5.0 and human-centric automation, showcasing a highly integrated framework predominantly led by Europe and Asia. The major nodes—Italy, the United Kingdom, India, China, and Germany—serve as the principal contributors, signifying substantial publishing production and robust international collaboration. Italy stands out as the primary hub, establishing robust ties with Spain, Germany, and Greece, exemplifying Europe’s leadership in sustainability and human-centric innovation. Simultaneously, India and China establish strong Asian networks that link with Malaysia, Singapore, and Australia, underscoring their increasing impact in informatics, artificial intelligence, and robotics research. The United States serves as a transcontinental conduit, connecting European and Asian research networks, while nations like Sweden, Poland, and Brazil contribute through specialized collaborations. This map depicts a polycentric yet collaborative global ecosystem, wherein cross-continental alliances—especially between Europe and Asia—propel the progression of Industry 5.0 knowledge generation and its human-centric technical implementations.

Discussion

1. Practical Implications

This bibliometric study's findings offer essential insights for policymakers, academic institutions, and business executives aiming to promote the human-centric paradigm of business 5.0. The identification of global cooperation networks underscores the strategic significance of cross-national relationships, especially between European and Asian universities, in fostering innovation in informatics and human-machine integration. Policy actors can utilize these insights to promote transnational research programs, funding initiatives, and collaborative PhD endeavors that link emerging economies with technologically advanced countries. The depiction of prevailing topics such as artificial intelligence, the Internet of Things, collaborative robotics, and sustainability highlights the necessity for cohesive technology development strategies that reconcile automation efficiency with human welfare and ethical governance. The mapping of funding agencies provides valuable insights for research planners and grant administrators, facilitating more focused investment in interdisciplinary initiatives that integrate informatics, social sciences, and engineering. This study emphasizes the necessity for industry practitioners to harmonize technology design with human values, transitioning from automation-centric productivity to human-empowering innovation, whereby data, cognition, and empathy coexist within intelligent industrial ecosystems.

2. Theoretical Contributions

This research advances theoretical understanding in multiple important aspects. Initially, it broadens the conceptual framework of Industry 5.0 by establishing informatics and human-centric automation as fundamental theoretical pillars that connect technology, cognition, and sustainability. This research progresses a human-centric informatics model that incorporates ethical AI, cyber-physical collaboration, and decision support systems inside an ecosystemic framework, moving beyond the efficiency-centric focus of previous Industry 4.0 frameworks. Secondly, it enhances the scientometric literature by delineating the intellectual framework, theme progression, and knowledge dissemination patterns within Industry 5.0 research—offering a macro-level theoretical perspective on the evolution and diffusion of ideas across several disciplines and regions. Third, the study enhances innovation systems theory by empirically demonstrating that knowledge generation in Industry 5.0 is not localized but rather networked, reliant on institutional and financing interdependencies that influence scientific advancement. This project integrates bibliometric mapping with network visualization to implement a data-driven theoretical framework for comprehending human-technology co-creation, thereby connecting industrial engineering, computer science, and social informatics.

3. Limitations and Future Research Directions

This study, while its extensive breadth, has some shortcomings that present opportunities for further research. The analysis predominantly depends on Scopus-indexed documents, potentially omitting pertinent papers from other databases like Web of Science or IEEE Xplore, which may restrict the inclusion of specialized or region-specific contributions. Secondly, bibliometric methods elucidate structural relationships among publications but fail to evaluate the qualitative depth or practical significance of research findings; subsequent studies could enhance this work through systematic literature reviews or content analyses to elucidate conceptual subtleties. Third, whereas funding agency mapping indicates principal sponsors, a comprehensive assessment of funding efficacy or socio-economic effects fell outside the purview of this study. Future study should investigate the impact of financing variety, policy tools, and interdisciplinary collaboration on innovation performance in human-centric automation. Finally, the domain of Industry 5.0 is advancing swiftly, and keyword dynamics may undergo substantial changes with the incorporation of emerging paradigms such as AI ethics, digital twins, and metaverse-centric industrial design—requiring continuous bibliometric surveillance to document the forthcoming wave of theoretical and technological advancements.

CONCLUSION

This study offers an extensive bibliometric analysis of Industry 5.0 research in informatics, highlighting the progression of human-centric automation, international collaboration networks, and the dynamics of funding agencies. The findings indicate that the discussion surrounding Industry 5.0 has evolved from a focus on technology efficiency to a comprehensive framework that incorporates artificial intelligence, the Internet of Things, robots, and decision-support informatics with ethical, sustainable, and human-centric concepts. Europe and Asia—specifically Italy, the United Kingdom, India, and China—stand out as the primary contributors, bolstered by robust institutional collaborations like Politecnico di Milano, the Hong Kong Polytechnic University, and Huazhong University of Science and Technology. Research clusters thematically converge on intelligent systems, ergonomics, and sustainability, illustrating the multidisciplinary integration of computer science and human factors. This synthesis emphasizes that the future of industrial innovation depends on harmonizing automation with empathy, efficiency with ethics, and intelligence with inclusion. This study elucidates the intellectual, geographical, and financial framework of Industry 5.0 in informatics, establishing a basis for enhanced collaboration, equity, and human-centric digital changes across global innovation ecosystems.

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