CHAPTER 54

Pathway of Industry 5.0 Present and Future

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ABSTRACT

Industrial transformation is not only technological but also sociotechnical in nature. The concept of Industry 5.0 has recently emerged to describe this shift. It represents a more human-centered approach to industrial change, where technological progress is balanced with the needs of workers, society, and sustainability. This includes efficient use of energy, responsible material processing, and extending product lifecycles. The present study reviews thirty existing literature surveys on Industry 5.0, along with a bibliometric analysis based on the Scopus database. The findings indicate that Industry 5.0 research has evolved through three main phases since 2018, beginning with its distinction from Industry 4.0. The most recent focus lies in promoting circular manufacturing models, enabled by human-centric digital technologies that can predict and address potential impacts in advance. Thus, Industry 5.0 is positioned as a forward-looking and cross-sectoral framework, marking a clear departure from the original vision of Industry 4.0. From a theoretical standpoint, this work consolidates insights from the reviewed literature and points to areas for further research. From a practical perspective, it highlights societal priorities that industries must integrate into their digital transformation strategies, which are equally important as enhancing economic competitiveness.

Keywords: Industry 5.0; Bibliometric analysis; Tertiary study; Research agenda.

1.0 Introduction

Industry 4.0 began as a policy-driven initiative to transform manufacturing through digital technologies [36]. First introduced in 2011, it became part of Germany's high-tech strategic agenda [36].

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The technological spectrum of Industry 4.0 is broad, covering cloud computing, the Internet of Things (IoT), artificial intelligence, autonomous robotics, augmented reality, and blockchain, all aimed at building smart factories [19]. Over the last decade, research on Industry 4.0 has led to major advances in manufacturing connectivity and laid the groundwork for Industry 5.0 [31,19], which emerged with a stronger emphasis on the role of humans within cyber-physical systems [12].

Currently, the transition is shifting toward a more societal-oriented and future-focused transformation of industry. Policy frameworks play an important role in this evolution, as illustrated by the European Union's initiatives for Industry 5.0, aligning it with objectives such as "an economy that works for people," the "European Green Deal," and "Europe fit for the digital age" [10]. Academia has also been instrumental from the very beginning of this transformation. Industry players are gradually engaging, evidenced by the roundtable held on 27 April 2022 [10], which highlighted societal disruptions and emphasized the need to move away from unsustainable industrial practices. Expert discussions particularly underscored the importance of resilience, governance, and cross-sectoral collaboration, along with a transition from Industry 4.0's competitiveness-driven approach to "digitalization with a purpose" [10].

Several systematic reviews have already examined Industry 5.0, offering valuable insights for further study. These include a bibliometric analysis of Industry 5.0 research in the Web of Science and a review of 22 related papers [12], a comprehensive assessment of 196 abstracts [1], and another review of 92 Scopus-indexed papers published between 2015 and 2021 [22]. However, a consolidated review of these reviews (a tertiary study) has not yet been undertaken. As noted by [22], "Industry 5.0 will continue to grow, at least in the short term (…) and it will be interesting to follow [its] future evolutionary trajectory." Against this backdrop, the present research sets out to analyze the evolution of Industry 5.0 scholarship, clarify the state of current research, and propose directions for future work.

The methodology adopted includes two stages. First, a bibliometric analysis was performed using the Scopus database, extending the work of [22] by incorporating 277 publications (including 185 new papers published in 2021–2025). Following the guidelines for systematic literature reviews in information systems research [29], the process began with defining objectives, developing a review protocol, and preparing the groundwork by two independent reviewers. Using VOSViewer [9], 277 Scopus-indexed papers from 2018 onwards were analyzed, excluding three unrelated items published prior to 2018. This stage helped in mapping the different phases of Industry 5.0 research and identifying key characteristics such as authorship and geographic distribution.

The second stage focused on literature reviews published in journals. From an initial pool of 184 review articles, two selection methods were applied: automatic filtering

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through Scopus (document type = review) and manual screening by the two reviewers, yielding 16 and 53 papers, respectively. After removing duplicates and applying content analysis, a final set of 32 papers was retained. Studies were excluded if they lacked a distinct conceptualization of Industry 5.0, only briefly mentioned the concept, or did not apply a scientific approach (e.g., opinion pieces).

The structure of this paper is as follows: Section 2 details the bibliometric analysis; Section 3 presents the tertiary review of 30 selected literature reviews (see Appendix A); Section 4 offers the discussion; and Section 6 concludes with the main findings and future research directions.

2.0 Bibliometric analysis of Industry 5.0

The aggregated bibliometric analysis identified four distinct clusters of Industry 5.0 research. The first cluster encompasses the core concepts, including Industry 4.0, digital transformation, manufacturing, personalization, sustainability, and the vision of Society 5.0. The second cluster focuses on the evolving workplace, highlighting human–machine collaboration (such as the operator 4.0) and the growing attention to supply chain resilience. The third cluster emphasizes the relevance of digital twins, particularly in simulation, optimization, and predictive modeling of physical systems. Finally, the largest cluster is centered on enabling technologies, with blockchain, IoT, augmented reality, and advanced communication networks (5G and 6G) emerging as key themes. Figure 1 illustrates how research has progressed since 2018 across three major stages.

The first stage (2018–2020) is characterized by discussions around the consequences of digital transformation, marking the transition from Industry 4.0 to Industry 5.0. At this point, topics such as human–machine interaction and enabling technologies provided the foundational links, while customer experience and social aspects of digitalization began to surface. The second stage (2020–2022) shifted toward societal priorities, embedding sustainability within a technological background still rooted in Industry 4.0. This period also established stronger links with concepts like operator 4.0 and Society 5.0. The third and most recent stage (from 2022 onward) reflects more sophisticated scenarios, including the development of smart cities, the expansion of digital twin applications, and a heightened focus on security and blockchain technologies. While early research revolved around broader terms and general paradigms, recent work demonstrates an increasing integration of technological advances with visions for sustainable and human-centered futures.

In terms of geographical distribution, India, China, and the United States lead Industry 5.0 research output, followed by several European countries such as Italy, Spain,

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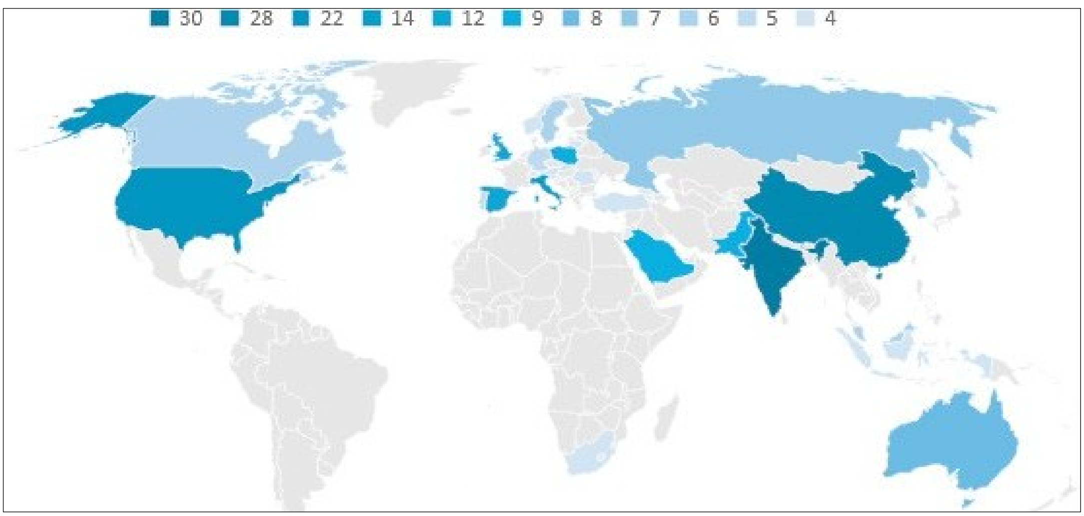
and the United Kingdom. Other regions contributing significantly include South Asia (Pakistan), the Middle East (Saudi Arabia), and Australia. However, contributions from Africa and Latin America remain limited. South Africa is the only African country with more than four publications, while Egypt and Morocco each contribute two. Similarly, in Latin America, Brazil and Mexico account for fewer than three studies each.

Regarding disciplinary scope, approximately half of the research originates from engineering and computer science, reflecting Industry 5.0's strong connection to Industry 4.0. Social sciences and economics contribute close to 20%, while additional work spans energy, mathematics, materials science, and environmental studies, confirming the interdisciplinary nature of the topic. The most influential publication outlets include *IEEE Transactions on Industrial Informatics* (seven articles), along with multidisciplinary journals such as *Sustainability* and *Applied Sciences*, the *Journal of the Knowledge Economy*, and *Computers and Industrial Engineering*. Leading information systems journals, such as the *Journal of Industrial Information Integration* and *Information Systems Frontiers*, have also begun publishing Industry 5.0 research.

Funding patterns reveal that European Union programs—including the European Commission and Horizon 2020—are among the most active supporters, each associated with five to six publications. The National Natural Science Foundation of China also plays a significant role, sponsoring six studies. Additionally, the Slovak Republic ranks within the top three with four funded publications. Beyond these, a wide range of funders from across the globe are contributing to the development of this field.

Figure 1: Country Map for Industry 5.0 Journal Publications, Indexed in Scopus Since 2018



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Overall, the analysis of 184 Scopus-indexed articles published since 2018 highlights three key findings: (1) steady growth in Industry 5.0 research, (2) broad international engagement, with a concentration in technologically advanced economies grappling with sustainability challenges, and (3) a strong orientation toward computing and engineering disciplines, reflecting its evolutionary roots in Industry 4.0

3.0 A review of Industry 5.0 Literature Reviews

The body of literature reviewed presents a heterogeneous focus. Nevertheless, two major themes can be identified: (1) a broad outlook on global issues such as sustainability, healthcare, and societal well-being, and (2) industry- and technology-centered approaches designed to address these challenges. A smaller portion of contributions highlights education and skills development as part of the Industry 5.0 discourse. Importantly, the reviewed articles do not converge on a single definition of Industry 5.0; some interpret it as a paradigm shift distinct from Industry 4.0, while others regard it as an evolutionary stage responding to consumer behavior trends, such as the demand for personalization that emerged during Industry 4.0. For instance, Rowan et al. [38] emphasize the role of digital technologies—including automation, data processing, and control systems—in driving sustainable innovation in sectors like peatland management. Their approach frames Industry 5.0 as inherently human-centered, aligned with the principles of the United Nations Sustainable Development Goals. Similarly, Rowan [39] explores the use of artificial intelligence (AI) and human-computer interfaces to address food chain challenges, while also introducing the concept of social marketing as a mechanism for influencing behaviors at the interface of human and natural systems. This framing emphasizes mass personalization, human-computer interaction, and the transition from Industry 4.0 to a more socially responsive Industry 5.0 [17].

Other works adopt a more technology-oriented stance. Dhawan et al. [7], for example, discuss transport optimization, data sharing, and collaboration as tools for decarbonizing New Zealand's construction industry, viewing these as pathways toward Industry 5.0. Orea-Giner et al. [30] investigate customer experiences with hotel robots, associating Industry 5.0 with enhanced customer satisfaction through AI and robotics. Kaasinen et al. [16], meanwhile, highlight human-centricity, sustainability, and resilience as core elements of future Industry 5.0 factories, where human operators and smart machines collaborate seamlessly, echoing the European vision [10].

Healthcare emerges as another important application domain. Popov et al. [35] describe Industry 5.0 as a trajectory influencing healthcare systems, while Coronado et al. [6] position it as a paradigm shift addressing societal and environmental challenges via

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human-centered environments and human-robot interaction. Their interpretation mirrors the European Union's emphasis on human-centric, sustainable, and resilient industries [6,10]. Some authors, such as Carayannis et al. [5], explicitly differentiate between Industry 5.0 and Society 5.0, where the former restructures industrial production, and the latter refers to a human-centered societal infrastructure supported by advanced digital platforms. Technologies such as AI, blockchain, and IoT are identified as key enablers [5]. Along similar lines, Maier et al. [23] associate the human-centric production approach with the broader framework of Society 5.0.

Several scholars focus on collaboration between humans and machines. Duggal et al. [8] propose a roadmap built on co-production and bio-upgradation, emphasizing robotics-human synergy and personalized bioengineering. Shahbakhsh et al. [41] point to human-robot cooperation and personalization as central change factors, while Maddikunta et al. [21] outline potential applications in intelligent healthcare, cloud manufacturing, and supply chain customization. Fatima et al. [11] view Industry 5.0 as the natural evolution of Industry 4.0, characterized by close collaboration between human creativity and intelligent systems in manufacturing and logistics, enabling greater efficiency and scalability. Paul et al. [33] and Pereira Guimarães et al. [34] also see Industry 5.0 as an extension of Industry 4.0, emphasizing personalization, human-computer interaction, and specific applications like temperature measurement in production processes.

Despite its promise, Industry 5.0 faces critical challenges. Technological safety, cybersecurity, legal frameworks for AI and human-robot interaction [42,44], and workforce adaptation [27,41] are recurring concerns. Two articles specifically address the educational dimension: one focusing on developing the necessary worker skills [13], and the other examining implications for higher education institutions [5].

Many scholars acknowledge the continuity between Industry 4.0 and 5.0. Some analyze overlapping technologies and concepts [2], while others dedicate sections of their work to envisioning more personalized, human-machine collaborative environments [19]. Examples include the progression of "Ergonomics 4.0" into "Ergonomics 5.0," the use of cyber-physical systems, digital twins, and real-time monitoring as protective tools for workers [33]. Such technologies, initially associated with Industry 4.0, are increasingly seen as enablers of the human-centered focus in Industry 5.0.

Other contributions expand the scope of Industry 5.0 research to societal needs. These include applications in sustainable housing [17], synergies with Society 5.0 [37], robot cognition and digital twin technologies [28], and strategies to advance sustainable development goals [25]. Taken together, both Industry 4.0 and 5.0 are highly relevant, and their integration offers opportunities for cumulative knowledge building in the ongoing industrial transformation.

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4.0 Discussion and Near Future Recommendations for Industry 5.0

The main directions in Industry 5.0 research emphasize a future-oriented and cross-sectoral perspective. While Industry 4.0 was primarily technology-driven, focusing on applying digital tools to address manufacturing challenges and increase productivity, Industry 5.0 adopts a broader, more human-centered vision [41,38,44]. Its goal is not limited to technological advancement but extends to addressing environmental, social, and energy-related issues. In this sense, Industry 5.0 integrates the technologies of Industry 4.0 into a wider societal framework, going beyond the factory floor. This transition highlights that Industry 5.0 is guided by values rather than purely by technology [45].

From this standpoint, humans play multiple roles: as consumers, they demand personalized products on a large scale; as workers, they collaborate with intelligent machines and robots, requiring new skills and capabilities; and more broadly, humanity itself is positioned as part of global challenges that demand sustainable solutions. Thus, Industry 5.0 can be regarded as a paradigm shift that combines industrial production with strategies for addressing worldwide crises through value-driven innovation. A central requirement of Industry 5.0 is the ethical use of technology [16]. Research priorities already focus on improving worker well-being, while the adoption of artificial intelligence must incorporate sustainability considerations from the outset. For example, AI could help select suppliers based on transport reduction or carbon-cutting practices, predict demand to reduce waste, and ensure fairness in production decisions. Developing new and reliable performance indicators (KPIs) is equally vital to demonstrate that industries follow responsible practices. Current European policy initiatives, such as energy conservation and water management, show the growing importance of verifiable sustainability standards. Emerging tools such as blockchain and advanced data analytics are promising in this regard.

The regulatory framework of Industry 5.0 is also expanding. While voluntary standards from Industry 4.0, such as IoT interoperability, remain relevant for data exchange, legally binding regulations concerning resource use, workplace practices, and environmental accountability are gaining importance. For instance, in the textile sector, regulations now require traceability, circularity, and waste reduction across all stages—from raw material extraction to recycling—through mechanisms like digital product passports. Therefore, the digitalization challenge of Industry 5.0 extends across regulatory, cultural, and sectoral domains, influencing how industries invest and how consumers make informed choices. Practical applications of Industry 5.0 are essential to guide practitioners and expand the literature. Research could explore the design of protective technologies for both workers and consumers, such as wearables for workplace safety, medical devices, or autonomous vehicles, as well as solutions that reduce environmental footprints through

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data-driven approaches. Industry 5.0 also plays a key role in shaping future smart cities [15], where technologies may support zero-carbon production and transport, circular waste management, and the creation of healthier and more adaptive workplaces. At present, there is a lack of comprehensive reviews on Industry 5.0 safety, security, and regulatory issues. To strengthen its foundation, systematic reviews should examine how Industry 5.0 supports resilience in regional economies, promotes sustainable practices (e.g., water conservation), and delivers measurable benefits for workers and other stakeholders. The central theme of Industry 5.0 research should remain its transformative impact on society. Future research lines include using technology for human-centered concerns such as healthcare, ergonomics, workplace safety, and collaborative robotics, while also advancing the shift toward sustainable factories. Additional areas of investigation include: (1) evaluating the sustainability of technologies [5], (2) analyzing the impacts of technological transitions, (3) linking sustainability-driven improvements with competitiveness, and (4) applying technology to prevent resource depletion and support decarbonization.

A critical challenge is ensuring that Industry 5.0 is not restricted to advanced economies. For it to have a global impact, developing countries must also be active participants. While industrialized regions contribute significantly to current problems, meaningful solutions require global cooperation. Future studies may therefore focus on digital transformation strategies that enable circular manufacturing, promote decent work practices, and foster sustainable growth in emerging economies. Furthermore, cross-sectoral supply chain resilience can be enhanced through Industry 5.0 technologies, involving not only large corporations but also small firms, local communities, and individual producers.

Finally, the future-oriented character of Industry 5.0 creates both opportunities and challenges for researchers. Forecasting methods, impact analysis, and scenario planning can be employed to anticipate long-term outcomes. In addition, design-oriented approaches are needed to strengthen the practical foundation of Industry 5.0. Whereas Industry 4.0 research often relied on proofs-of-concept to demonstrate technological feasibility, Industry 5.0 requires "proofs-of-impact" through longitudinal and multidisciplinary studies that show how technology-driven change leads to sustainable, inclusive, and resilient futures.

5.0 Conclusion

This study provided a bibliometric analysis along with a tertiary review of existing research on Industry 5.0. The findings highlight three distinct phases of Industry 5.0 since it separated from the framework of Industry 4.0 in 2018. The most recent phase demonstrates how Industry 5.0 has established itself as a future-focused, cross-sectoral, and socially driven transformation of manufacturing. The tertiary review carried out in this work is

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among the first in the field and compiles valuable recommendations for future research and practice. Nonetheless, a few limitations should be acknowledged. First, the analysis was based on a single database, even though it is a widely recognized source. Relevant studies are also emerging in conference proceedings and other platforms that were not considered here. Second, the boundaries between Industry 4.0 and Industry 5.0 remain closely linked. Although strict inclusion and exclusion criteria were applied, the extent to which a paper focused specifically on Industry 5.0 involved some level of subjectivity. Future studies may benefit from including different types of publications, other review methods, and a wider range of databases. Moreover, the recommendations proposed here were partly influenced by European policy priorities and early collaborative initiatives between academia and industry. Given the complexity of cross-sectoral contexts [45], effective collaboration among universities, industries, and policymakers is essential. Both Industry 4.0, with its technology-driven nature, and Industry 5.0, with its sociotechnical orientation, are expected to continue advancing in parallel, reshaping manufacturing.

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