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IDENTIFICATION OF KEY RESEARCH AREAS OF INDUSTRY 5.0 BASED ON BIBLIOMETRIC ANALYSIS

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ABSTRACT

Ten years after the introduction of the Industry 4.0 concept, which aimed to revolutionize industry and dehumanize production systems, trends and directions in industrial development are evolving. There is a shift away from viewing technology development solely as a means to increase productivity and production flexibility, towards building a future based on core values. The European Commission has identified key pillars that should be emphasized when considering contemporary industrial development. These pillars include a human-centric approach, sustainable economic growth, and the development of the economy's resilience to crises. The new concept of Industry 5.0 focuses on the digital transformation of the economy by prioritizing socio-economic well-being, environmental sustainability, and human safety. Based on a bibliometric literature analysis and a systematic literature review, this article aims to identify key research areas related to the implementation of the Industry 5.0 concept. In addition, in the article, the authors made their own assessment of the impact of the identified research areas on achieving the social, economic and environmental goals of implementing the Industry 5.0 concept.

Introduction

The fourth industrial revolution (also known as Industry 4.0) was born in 2011 as part of the project to increase industrial production in Western Europe as part of the high-tech strategy of the German government. Digital technologies such as the Industrial Internet of Things, Big Data, and Cloud Computing have become the basis for the development of Cyber-Physical Production Systems (CPPS) consisting of intelligent machines and devices communicating with each other without human intervention. The fourth industrial revolution has had a transformative effect on the modern economy, especially caused by the dynamic development of automation and digitization of production processes and systems.

The orientation towards a high level of digitalization, high productivity, and flexibility of cyber-physical systems resulted in a slow process of dehumanization of industry and a weakening of its social role in the economy. The orientation towards technological innovations raised concerns among employees and politicians regarding uncertain working conditions and future social problems. In addition, rising energy costs and disruptions of various origins forced the transformation of the goals of the previous concept of Industry 4.0 and the adoption of new priorities for developing the future industry.

The new concept called Industry 5.0 is currently being strongly developed by a large group of experts, scientists and the European Commission (European Commission, 2022). Numerous scientific studies, which will be presented later in the chapter, indicate the need to pay more attention to human participation in the processes of digitalization of production, which will allow for the synergism of human cooperation with intelligent machines (Eschbach, 2021, Breque et al., 2022). In Industry 5.0, in addition to the essential factors of developing cooperation between human capital and intelligent machines, fundamental environmental aspects related to sustainable development and aspects of the resilience of systems, processes and management were considered (Sindhwani et al., 2022). Due to the correction of the direction of the fourth industrial revolution, there is a need to research the implementation of the Industry 5.0 concept in various problem areas. Hence, the article attempts to identify key research areas based on a systematic review of the literature on the Industry 5.0 concept. In addition, the impact of the identified research areas on achieving the social, economic and environmental goals of implementing the Industry 5.0 concept was assessed.

Development of the Industry 5.0 concept

The Industry 5.0 concept goes beyond the efficiency and productivity of industrial digitalization and the orientation towards implementing intelligent technologies, which were the domain of the previous Industry 4.0 concept. The new approach mainly strengthens the social and ecological responsibility of the economy and the active participation of humans in the development of intelligent industry (Rupa and Saif 2022). In addition to the need to consider the human factor in the fourth industrial revolution and the universal digital transformation, numerous scientific studies pay special attention to sustainable development goals and broadly understood economic resilience. The adverse effects of implementing the concept of Industry 4.0 are mainly concerned with social, ecological, and market aspects (Saniuk et al., 2020; Bonilla et al., 2018). The main threats include unemployment, changes in work organization, social inequalities combined with digital exclusion and an increase in the risk of cyberattacks on the socio-economic infrastructure.

The Industry 5.0 concept builds upon and extends the features of Industry 4.0, addressing social concerns related to dehumanization. While Industry 4.0 emphasizes system flexibility and productivity, Industry 5.0 places greater importance on environmental and social factors (Demir et al., 2019). In this new paradigm, humans are at the center of focus, and cyber-physical systems are integrated with human intelligence (Romero et al., 2016; Longo et al., 2020). This approach anticipates a symbiosis of human labor and intelligent machines, including collaborative robots. A comparison of the goals of Industry 4.0 and Industry 5.0 is illustrated in Figure 1.

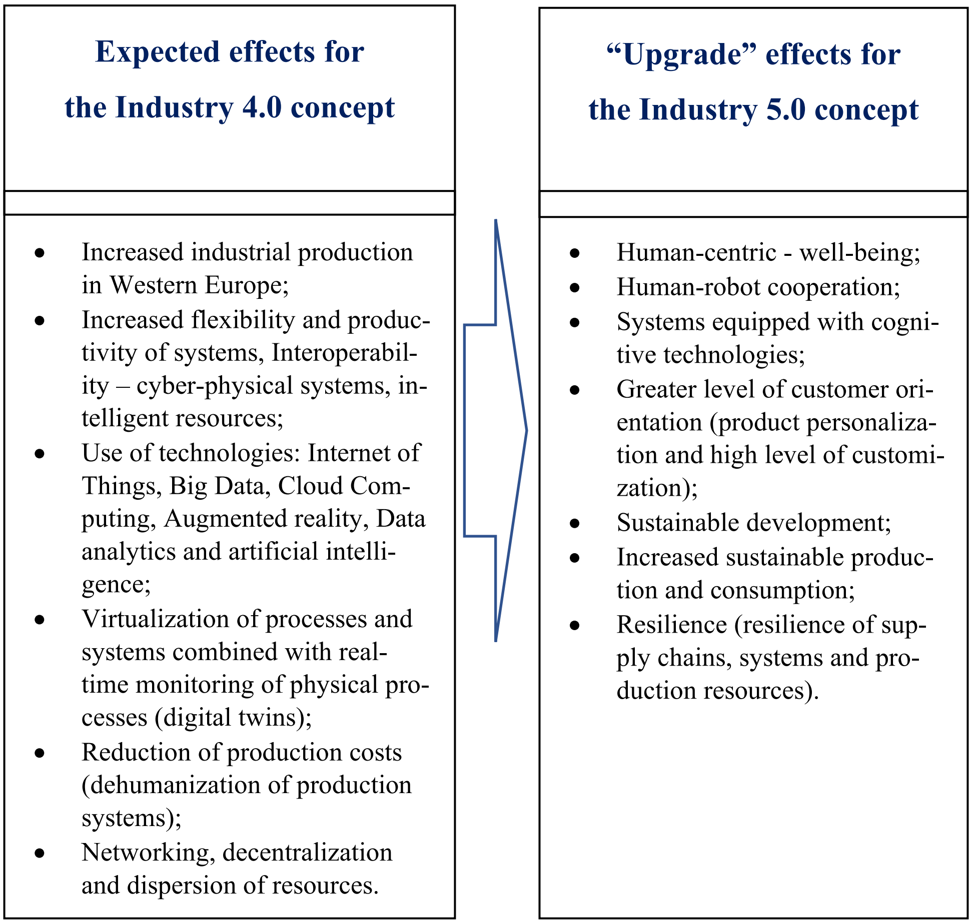

Figure 1. Expected results of Industry 4.0 versus Industry 5.0

The concept of Industry 5.0 represents an evolution from Industry 4.0, aimed at addressing the negative impacts caused by the careless implementation of technology and digitization in the industry (Saniuk, 2023). According to the European Commission, Industry 5.0 is founded on three main pillars (European Commission, 2022):

– Sustainable development focuses on protecting the natural environment and utilizing renewable energy sources. Future enterprises are required to adopt sustainable development

strategies and promote sustainable production and consumption. According to Voulgaridis et al. (2022), the industry should transition from being fully automated to a sustainable model that combines artificial intelligence and machine learning with active human involvement.
- A human-centric approach means a greater focus on using human potential in machine learning or close cooperation between humans and collaborative robots (cobots).
- Resilience is understood as the ability to respond quickly to disruptions. Industry 5.0, using digital technologies and focused on three pillars-sustainable development, people, and resilience-can cope more effectively with disruptions in supply chains. Modern supply chains supported by digital technologies should, therefore, be resistant to anomalies, perturbations, and the effects of failures or malfunctions caused by various causes.

In the literature, Industry 5.0 is defined as an evolutionary paradigm that complements Industry 4.0, driving innovations that promote environmental and social values. Technologies enabling virtualization and machine integration are crucial for the industry (Xu et al., 2021). Industry 5.0 goes beyond the narrow and traditional focus on enterprises' technological and economic development in favour of reducing and transforming production into new forms of sustainable, circular and regenerative economic value creation. It is increasingly based on a regenerative approach that minimizes damage, reverses the planet's degradation, and restores a healthy relationship between people and the ecosystem (Mesjasz-Lech, 2023). In general, it can be assumed that Industry 5.0 is a concept that assumes synergistic and safe cooperation between humans and cyber-physical systems to ensure highly productive, resistant to disruptions and environmentally friendly personalized production.

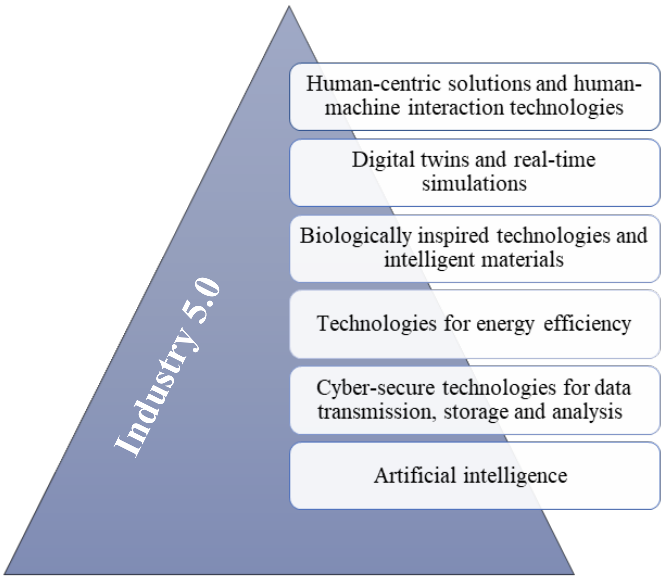

Figure 2. Industry 5.0 technological areas

The European Commission has identified six essential areas of technological solutions critical for implementing the Industry 5.0 concept (European Commission, 2022) (Figure 2):
- Human-centric solutions and human-machine interaction technologies. The most important of them include technologies related to the recognition of intentions, speech, and gestures of a human cooperating with technology, technologies for analyzing stress and mental and physical load during work, technologies supporting humans such as virtual and augmented reality, collaborative robots, etc.
- Digital twins and real-time simulations. A digital twin is a virtual copy of a real object, process, or system that allows for the accurate reproduction of its properties and behavior. Thanks to this, it is possible to simulate various operational scenarios, predict possible problems, and optimize production processes without the risk of introducing changes in the real world.
- Technologies inspired by biology and smart materials. These technologies can include biosensors, technologies for producing raw materials from waste, recycling technologies, etc.
- Technologies for energy efficiency focused on the development of the integration of renewable energy sources with cyber-physical industrial systems.
- Cybersecure technologies for data transmission, storage and analysis.
- Artificial intelligence.

Materials and Methods

The bibliometric analysis method was used to identify key research areas related to Industry 5.0. The authors proposed combining a systematic literature review (SLR) and a bibliographic network visualization analysis. The core collection of Web of Science (WoS), a database provided by Clarivate Analytics due to its interdisciplinarity (multidisciplinarity), was used to select scientific publications. The study used a systematic literature review (SLR) consisting of the following stages (Strozzi et al., 2017):
- Identification of the scope of the analysis;
- Identification and localization of keywords, type and type of documents, language, databases;
- Selection, evaluation and synthesis of the existing set of peer-reviewed and registered scientific works in the database.

Implementing the above stages allows for identifying a set of selected scientific publications that are chosen systematically, openly, comprehensively, and repeatably (Fink, 2019). This set of selected scientific publications is the basis for conducting quantitative research. In the next stage, it is necessary to identify the set of publications shown in the bibliographic network resulting from the analysis of keywords, which are developed based on reference lists selected as a result of a systematic review of the literature of scientific publications (Czakon, 2011).

According to the study's method, the following research stages were conducted: planning, implementation, and reporting. Figure 3 illustrates the process for analyzing literature and identifying Industry 5.0 research areas.

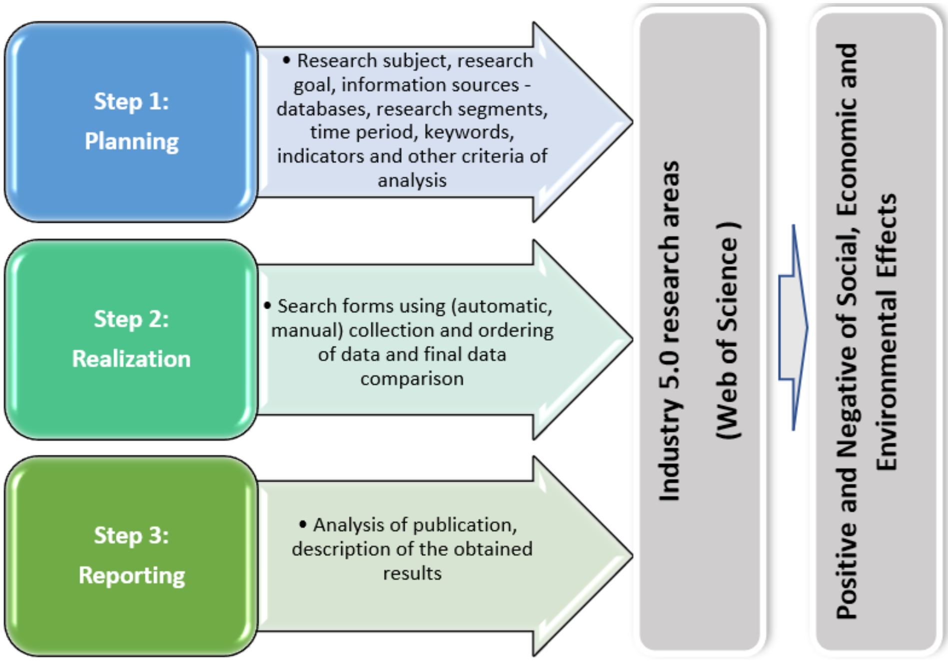

Figure 3. The process of identifying Industry 5.0 research areas

In identifying the scope of the analysis, it was decided to use the search phrase "Industry 5.0". The Web of Science database was searched according to the defined phrase in the "Topic" category, including the title, abstract, keywords determined by the authors and keywords plus (so-called "KeyWords Plus" – words and phrases extracted from the titles of cited articles, represented in the WoS database). Articles, conference materials, review articles, books and book chapters were searched in English. The search time range was adopted from January 1, 2016, to September 30, 2024. The search scope covers the period of development of the Industry 5.0 concept from the appearance of the first publication containing the keyword Industry 5.0.

Results of bibliometric analysis

The body of knowledge related to research on Industry 5.0 is growing dynamically, as is the trend of publishing scientific articles in this area. Based on the search results obtained, Figure 4 shows the dynamics of the growth of researchers' interest in Industry 5.0. In total, 1240 articles, conference materials, review articles, books, and book chapters written in English were indexed in the WoS database.

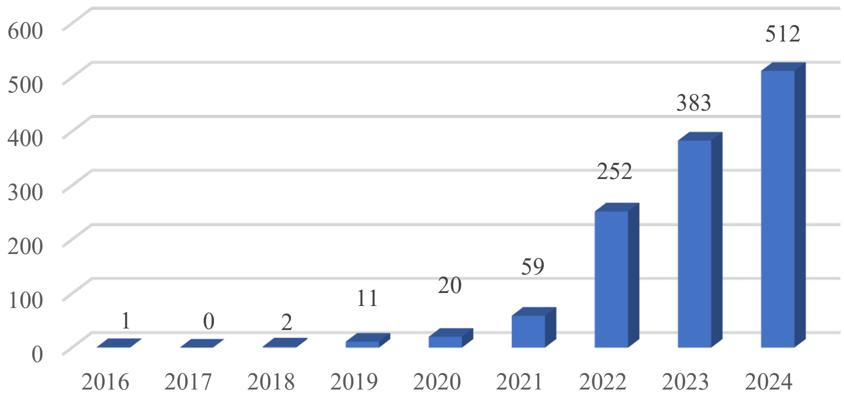

Figure 4. Analysis of publication growth in the WoS database from 2016 to 2024 regarding Industry 5.0.

The analysis of the selected publications revealed that the top ten countries most frequently represented by the authors were as follows: China (202), Italy (183), India (156), England (115), the United States (87), Spain (76), Germany (70), Saudi Arabia (62), Portugal (59), and Sweden (59). Poland ranked 11th, with 57 published papers.

In the subsequent analysis step, the list of WoS categories to which the retrieved works were assigned was checked. Ten categories with the most significant number of works were selected. The largest number of retrieved works was assigned to the WoS category: Electrical and Electronics Engineering 263, Industrial Engineering 219, Production Engineering 178, Computer Science and Information Systems 173, Interdisciplinary Applications of Computer Science 165, Telecommunications 164, Automation Control Systems 122, Operational Research and Management Science 104, Green, Sustainable Science and Technology 99, Multidisciplinary Engineering 99.

In the further part of the bibliometric study, keyword analysis was performed from all retrieved publications indexed in the WoS database in the field of Industry 5.0. Then, using the VOSviewer software, a keyword map was created (Figure 5). As can be seen, the dominant keywords are related to:

– Sustainable development (in the figure they form a cluster/assemblage marked in red), which is a pillar of Industry 5.0. In this area, one can clearly see the connections with the enterprise, supply chain, digital transformation, employees, skills, competencies, economy;
– Human (Human-centric approach), which is understood as a focus on the human and connections with collaborative robots, flexibility, operator 4.0;
– Data connected to big data, data analytics, algorithms, AI, networks, industrial internet, communication, development, security, and blockchain technology.

It is surprising to see the lack of interest in resilience, one of Industry 5.0's key pillars.

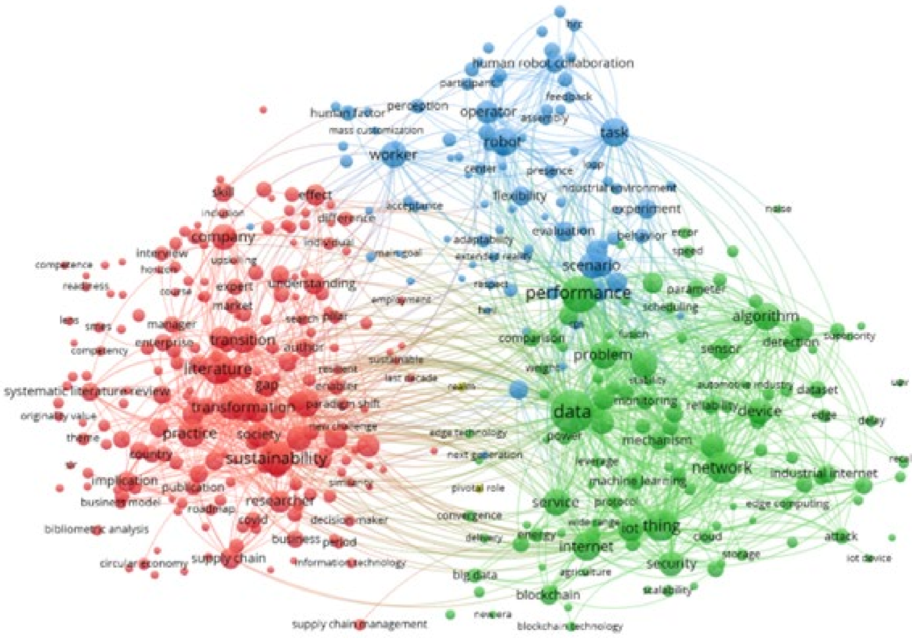

Figure 5. Industry 5.0 KeywordMap

For in-depth research, 42 papers marked in the Web of Science database as “Highly Cited Papers”[1] were selected for content analysis. Table 1 summarizes these papers.

Table 1. Selected papers in the Industry 5.0 area, marked in the WoS database as “Highly Cited Papers”

[1] Citation rates vary across disciplines, and older articles are cited more often than newer ones; the selection procedure for highly cited articles considers these factors when selecting them for the “Highly Cited Papers” category.

No.	Article	Citation count
1.	Xu, X., Lu, Y., Vogel-Heuser, B., & Wang, L. (2021). Industry 4.0 and Industry 5.0 – Inception, conception and perception. Journal of manufacturing systems, 61, 530-535.	647
2.	Maddikunta, P. K. R., Pham, Q. V., Prabadevi, B., Deepa, N., Dev, K., Gadekallu, T. R., ... & Liyanage, M. (2022). Industry 5.0: A survey on enabling technologies and potential applications. Journal of Industrial Information Integration, 26, 100257.	612
3.	Nahavandi, S. (2019). Industry 5.0 – A human-centric solution. Sustainability, 11(16), 4371.	501
4.	Leng, J., Sha, W., Wang, B., Zheng, P., Zhuang, C., Liu, Q., ... & Wang, L. (2022). Industry 5.0: Prospect and retrospect. Journal of Manufacturing Systems, 65, 279-295.	277
5.	Choi, T. M., Kumar, S., Yue, X., & Chan, H. L. (2022). Disruptive technologies and operations management in the Industry 4.0 era and beyond. Production and Operations Management, 31(1), 9-31.	245
6.	Lu, Y., Zheng, H., Chand, S., Xia, W., Liu, Z., Xu, X., ... & Bao, J. (2022). Outlook on human-centric manufacturing towards Industry 5.0. Journal of Manufacturing Systems, 62, 612-627.	216
7.	Longo, F., Padovano, A., & Umbrello, S. (2020). Value-oriented and ethical technology engineering in industry 5.0: A human-centric perspective for the design of the factory of the future. Applied Sciences, 10(12), 4182.	213
8.	Javed, A. R., Shahzad, F., ur Rehman, S., Zikria, Y. B., Razzak, I., Jalil, Z., & Xu, G. (2022). Future smart cities: Requirements, emerging technologies, applications, challenges, and future aspects. Cities, 129, 103794.	191
9.	Yin, S., & Yu, Y. (2022). An adoption-implementation framework of digital green knowledge to improve the performance of digital green innovation practices for industry 5.0. Journal of Cleaner Production, 363, 132608.	184
10.	Ivanov, D. (2023). The Industry 5.0 framework: viability-based integration of the resilience, sustainability, and human-centricity perspectives. International Journal of Production Research, 61(5), 1683-1695.	180
11.	Adel, A. (2022). Future of industry 5.0 in society: human-centric solutions, challenges and prospective research areas. Journal of Cloud Computing, 11(1), 40.	170
12.	Huang, S., Wang, B., Li, X., Zheng, P., Mourtzis, D., & Wang, L. (2022). Industry 5.0 and Society 5.0 – Comparison, complementation and co-evolution. Journal of manufacturing systems, 64, 424-428.	155

No.	Article	Citation count
13.	Pillai, S. G., Haldorai, K., Seo, W. S., & Kim, W. G. (2021). COVID-19 and hospitality 5.0: Redefining hospitality operations. International Journal of Hospitality Management, 94, 102869.	137
14.	Carayannis, E. G., & Morawska-Jancelewicz, J. (2022). The futures of Europe: Society 5.0 and Industry 5.0 as driving forces of future universities. Journal of the Knowledge Economy, 13(4), 3445-3471.	126
15.	**Mourtzis, D., Angelopoulos, J., & Panopoulos, N. (2022). A Literature Review of the Challenges and Opportunities of the Transition from Industry 4.0 to Society 5.0. Energies, 15(17), 6276.**	**120**
16.	Ivanov, D., Dolgui, A., & Sokolov, B. (2022). Cloud supply chain: Integrating Industry 4.0 and digital platforms in the "Supply Chain-as-a-Service". Transportation Research Part E: Logistics and Transportation Review, 160, 102676.	118
17.	Ghobakhloo, M., Iranmanesh, M., Mubarak, M. F., Mubarik, M., Rejeb, A., & Nilashi, M. (2022). Identifying industry 5.0 contributions to sustainable development: A strategy roadmap for delivering sustainability values. Sustainable Production and Consumption, 33, 716-737.	113
18.	Grabowska, S., Saniuk, S., & Gajdzik, B. (2022). Industry 5.0: improving humanization and sustainability of Industry 4.0. Scientometrics, 127(6), 3117-3144.	107
19.	Hassoun, A., Aït-Kaddour, A., Abu-Mahfouz, A. M., Rathod, N. B., Bader, F., Barba, F. J., ... & Regenstein, J. (2023). The fourth industrial revolution in the food industry – Part I: Industry 4.0 technologies. Critical Reviews in Food Science and Nutrition, 63(23), 6547-6563.	106
20.	Sigov, A., Ratkin, L., Ivanov, L. A., & Xu, L. D. (2022). Emerging enabling technologies for industry 4.0 and beyond. Information Systems Frontiers, 1-11.	104
21.	Bhat, S. A., Huang, N. F., Sofi, I. B., & Sultan, M. (2021). Agriculture-food supply chain management based on blockchain and IoT: a narrative on enterprise blockchain interoperability. Agriculture, 12(1), 40.	101
22.	Sindhwani, R., Afridi, S., Kumar, A., Banaitis, A., Luthra, S., & Singh, P. L. (2022). Can industry 5.0 revolutionize the wave of resilience and social value creation? A multi-criteria framework to analyze enablers. Technology in Society, 68, 101887.	88
23.	Al-Qaness, M. A., Dahou, A., Abd Elaziz, M., & Helmi, A. M. (2022). Multi-ResAtt: Multilevel residual network with attention for human activity recognition using wearable sensors. IEEE Transactions on Industrial Informatics, 19(1), 144-152.	74

No.	Article	Citation count
24.	Wang, B., Zhou, H., Li, X., Yang, G., Zheng, P., Song, C., ... & Wang, L. (2024). Human Digital Twin in the context of Industry 5.0. Robotics and Computer-Integrated Manufacturing, 85, 102626.	63
25.	Wang, X., Yang, J., Wang, Y., Miao, Q., Wang, F. Y., Zhao, A., ... & Vlacic, L. (2023). Steps toward industry 5.0: Building “6S” parallel industries with cyber-physical-social intelligence. IEEE/CAA Journal of Automatica Sinica, 10(8), 1692-1703.	57
26.	Alves, J., Lima, T. M., & Gaspar, P. D. (2023). Is industry 5.0 a human-centred approach? a systematic review. Processes, 11(1), 193.	55
27.	Wu, H., Chen, J., Nguyen, T. N., & Tang, H. (2022). Lyapunov-guided delay-aware energy efficient offloading in IIoT-MEC systems. IEEE Transactions on Industrial Informatics, 19(2), 2117-2128.	51
28.	Chi, H. R., Wu, C. K., Huang, N. F., Tsang, K. F., & Radwan, A. (2022). A survey of network automation for industrial internet-of-things toward industry 5.0. IEEE Transactions on Industrial Informatics, 19(2), 2065-2077.	49
29.	Karmaker, C. L., Bari, A. M., Anam, M. Z., Ahmed, T., Ali, S. M., de Jesus Pacheco, D. A., & Moktadir, M. A. (2023). Industry 5.0 challenges for post-pandemic supply chain sustainability in an emerging economy. International Journal of Production Economics, 258, 108806.	48
30.	Ivanov, D., Dolgui, A., Blackhurst, J. V., & Choi, T. M. (2023). Toward supply chain viability theory: from lessons learned through COVID-19 pandemic to viable ecosystems. International Journal of Production Research, 61(8), 2402-2415.	47
31.	Destouet, C., Tlahig, H., Bettayeb, B., & Mazari, B. (2023). Flexible job shop scheduling problem under Industry 5.0: A survey on human reintegration, environmental consideration and resilience improvement. Journal of Manufacturing Systems, 67, 155-173.	45
32.	Otoum, S., Al Ridhawi, I., & Mouftah, H. (2022). A federated learning and blockchain-enabled sustainable energy trade at the edge: A framework for industry 4.0. IEEE Internet of Things Journal, 10(4), 3018-3026.	43
33.	Laghari, A. A., Khan, A. A., Alkanhel, R., Elmannai, H., & Bourouis, S. (2023). Lightweight-biov: blockchain distributed ledger technology (bdlt) for internet of vehicles (iovs). Electronics, 12(3), 677.	42
34.	Leng, J., Zhu, X., Huang, Z., Xu, K., Liu, Z., Liu, Q., & Chen, X. (2023). ManuChain II: Blockchained smart contract system as the digital twin of decentralized autonomous manufacturing toward resilience in industry 5.0. IEEE Transactions on Systems, Man, and Cybernetics: Systems, 53(8), 4715-4728.	41

No.	Article	Citation count
35.	Dwivedi, A., Agrawal, D., Jha, A., & Mathiyazhagan, K. (2023). Studying the interactions among Industry 5.0 and circular supply chain: Towards attaining sustainable development. Computers & Industrial Engineering, 176, 108927.	41
36.	Tlili, A., Huang, R., & Kinshuk, X. (2023). Metaverse for climbing the ladder toward 'Industry 5.0'and 'Society 5.0'?. The Service Industries Journal, 43(3-4), 260-287.	37
37.	Javeed, D., Gao, T., Kumar, P., & Jolfaei, A. (2023). An explainable and resilient intrusion detection system for industry 5.0. IEEE Transactions on Consumer Electronics, 70(1), 1342-1350.	16
38.	Leng, J., Zhu, X., Huang, Z., Li, X., Zheng, P., Zhou, X., ... & Liu, Q. (2024). Unlocking the power of industrial artificial intelligence towards Industry 5.0: Insights, pathways, and challenges. Journal of Manufacturing Systems, 73, 349-363.	15
39.	Guo, L., Sun, D., Warraich, M. A., & Waheed, A. (2023). Does industry 5.0 model optimize sustainable performance of Agri-enterprises? Real-time investigation from the realm of stakeholder theory and domain. Sustainable Development, 31(4), 2507-2516.	15
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41.	Mathkor, D. M., Mathkor, N., Bassfar, Z., Bantun, F., Slama, P., Ahmad, F., & Haque, S. (2024). Multirole of the internet of medical things (IoMT) in biomedical systems for managing smart healthcare systems: An overview of current and future innovative trends. Journal of infection and public health.	7
42.	Rathore, A. S., & Sarin, D. (2024). What should next-generation analytical platforms for biopharmaceutical production look like?. Trends in Biotechnology, 42(3), 282-292.	6

Discussion

The main research areas of Industry 5.0 discussed in the selected literature focus on humans and their cooperation in the human-technology and human-machine systems. The research mainly covered areas related to predicting future working conditions and education of industrial workers, integrating human and technological aspects, i.e. focusing on humans in production technology and the quality of human-robot cooperation in the future (Nahavandi, 2019; Huang, 2022; Grabowska et. al., 2022; Lu et al., 2022; Ivanov, 2023). Many authors have focused their attention on the challenges related to human resources in the fourth industrial revolution era. They draw attention to the simultaneous need to implement digital technologies based on enterprises' capabilities regarding employees' knowledge and competencies (Saniuk et al., 2022; Carayannis and Morawska-Jancelewicz, 2022). According to the authors, the critical role in the development of Industry 5.0 is played by the appropriate creation of a climate of effective learning and innovation (Al-qaness et al., 2023). The work (Longo et al., 2020) proposes best management practices that can promote a climate of innovation and learning in the organization and thus facilitate the enterprise's implementation of the Industry 5.0 concept. The authors indicated in their works that human-centricity will cause the following effects:

– Social - (positive effects): improving working conditions and quality of work; creating ergonomic and safe working environments by reducing the risk of accidents; reducing the number of injuries and work-related stress; flexible working hours; creating tools for remote work, the life-balance balance between private life and work; increasing job satisfaction; increasing employee autonomy; reducing technological isolation, i.e. reducing the digital divide; increasing social integration; increasing equal rights, (negative effects): monotony at the workplace.
– Economic - (positive effects): better use of human potential; more effective use of employee skills and talents; improvement of the quality of products and services by increasing precision and quality of work; increase in efficiency and productivity through cooperation with cobots; Employees can perform more complex tasks, while machines deal with routine and repetitive activities; increase in operational efficiency and cost reduction; (negative effects): increase in implementation and training costs.
– Environments - (positive effects): impacts include increased ecological responsibility, corporate social responsibility, pro-ecological innovations, enhanced resource efficiency, waste and pollution reduction, and greater inter-sectoral cooperation promoted by a human-centric industry, (no negative effects were identified in the publications).

The research discussed in the selected works focuses on the technological aspects of Industry 4.0, specifically popular technologies such as the Internet of Things, Virtual and Augmented Reality, Autonomous Vehicles, blockchain, and Collaborative Robots. The authors highlight the importance of developing production and logistics systems that support Operator 4.0. This includes the implementation of collaborative robots (cobots), augmented reality, and flexible workstations (Chi et al., 2022; Maddikunta et al. 2022; Choi et al. 2022; Ivanov et al. 2022). They indicate that digitizing production processes and systems will lead to several positive outcomes:

– Social - (positive effects): consolidation of new patterns of sustainable consumption; better redistribution of resources and social equality in access to the achievements of economic growth; increase in employment in ecological sectors related to renewable energy; increase in environmental awareness of society; increase in the quality of life; focus on the revitalization of degraded urban and post-industrial areas; more significant involvement of society in the process of ecological and digital transformation; (adverse effects): changes in the employment structure; need for retraining in many professions, e.g. mining, heavy industry.

- Economic (positive effects): increased operational efficiency through process automation and faster decision-making; reduced product manufacturing costs; increased manufacturing flexibility and productivity; better customer orientation; the emergence of new markets and business models; development of servitization; increased competitiveness of companies; improved quality of products and services; networking of the economy, including cooperation-oriented enterprises; increased flexibility of cooperation through the use of cloud technology; more precise data management; use of predictive analyses; increased transparency of processes; new forms of trade and transactions; development of the electronics industry; (negative effects): increased cyber threats caused by hacker attacks.
- Environmental (positive): reduction of resource consumption through the use of electronic documentation, digital signatures, e-invoices, reduction of paper consumption; an increase of energy efficiency through the use of digital energy management systems and automation of industrial processes, allows for better control of energy consumption; an increase of resource efficiency; reduction of carbon footprint through the development of intelligent transport systems (negative): increase of energy consumption for powering and cooling servers; an increase of e-waste from used devices (computers, smartphones, which contain toxic substances); increased production of electronic equipment; the necessity of using rare metals (lithium, cobalt, nickel, which are extracted from the ground), this leads to environmental degradation, water and soil pollution; (no negative effects were identified in the publications).

In works from the Industry 5.0 area, the authors devote much attention to the topic of sustainable development, which is the goal of Industry 5.0 (Tlili et al., 2023; Dwivedi et al., 2023; Karmaker et al., 2023; Otoum et al. 2022). The issues of a higher standard of living and creativity are raised thanks to high-quality, custom-made products, which lead to sustainable consumption. The authors emphasize that many companies have recently launched sustainable production programs. In addition, companies continue to implement social responsibility projects. Environmental awareness among people is growing. Customers are starting to choose products created by companies participating in the green economy (Ghobakhloo et al., 2022; Grabowska et al., 2022). The authors indicated in their works that focusing on sustainable development will result in the following effects:

- Social (positive effects): consolidation of new patterns of sustainable consumption; better redistribution of resources and social equality in access to the achievements of economic growth; increase in employment in ecological sectors related to renewable energy; circular economy; increase in environmental awareness of society; increase in the quality of life; focus on revitalization of degraded urban and post-industrial areas; more significant involvement of society in the process of ecological and digital transformation. (negative effects): changes in the employment structure, and the need for retraining in many professions related to mining, heavy industry, and automotive (combustion vehicles).
- Economic (positive effects): increased digitalization and investment in environmentally friendly technologies; orientation towards sustainable production; higher level of customization forced by the expectation of personalization of products better tailored to individual customer expectations; increased resource productivity; better use of raw materials;

reuse of end-of-life products (recycling); extension or reduction of the process of shortening the product life cycle; increased innovation in clean production technologies that save natural resources; focus on recycling and reuse of materials and raw materials; new business models promoting close cooperation with the customer, including involvement in the process of designing personalized products; development of local markets and economies; shortening of logistics chains, increased resistance to disruptions; (negative effects) changes in regulatory and fiscal policy; decreased competitiveness of companies using energy-intensive technologies; challenges related to Fit for 55 requirements, the need to incur costs of adaptation to new conditions, investment in new technologies, staff training, adaptation to very rigorous environmental regulations and reporting.
– Environmental (positive effects): reduction of environmental pollution; reduction of greenhouse gas emissions; saving of limited natural resources; reduction of waste through the development of a circular economy; reduction of the use of plastic will affect the purity of water in the seas and oceans; reduction of the demand for natural resources through a circular economy will affect the restoration of forests (reforestation process); reduction of the consumption of crude oil and coal will affect the quality of air and increase the quality of life; improvement of well-being and protection of biodiversity; (no negative effects were identified in the publications).

In terms of resilience and risk management, the papers propose management decision support systems for designing, planning and controlling resilient and digital production networks and supply chains. Sustainable production techniques, such as closed-loop supply chains, are another trend in research development identified by the authors (Sindhwani et al., 2022; Ivanov, 2023; Karmaker et al., 2023; Choi et al., 2022; Pillai et al., 2021). The authors Emphasize that infrastructure is needed to support loose coupling and evolving systems. An interesting observation is the vision of the overall contribution of the research community to changing the understanding of human-machine interactions and the emergence of new production models in which humans and machines, together with virtual agents, create hybrid teams. The results of the empirical research "Socializing with robots" aimed to gain insight, especially into the conditions for the development and processes of hybrid human-machine teams. The study focuses on combining different aspects of the basic disciplines of social robotics and psychology, contributing to anthropomorphization. The authors indicated in their work that process resilience will only result in positive effects:
– Social - flexibility of the labour market; social cohesion; development of local communities; more significant involvement of the local social community; increased quality of life; increased social awareness of the threats and risks associated with crises; increased ecological awareness of the community; reduced risk of conflicts over natural resources.
– Economic - better resource management; development of the local economy; shortening supply chains; independence from raw materials imported from risky directions; development of cybersecurity technologies; development of renewable energy technologies; implementation of sustainable development policy.
– Environmental - decarbonisation; protection of ecosystems; development of recycling and circular economy; introduction of ecological risk management principles; orientation towards counteracting disasters resulting from climate change, floods, fires, droughts, etc.; increased environmental awareness.

Furthermore, the authors of many works also emphasize the multi-industry nature of the Industry 5.0 concept, which will support such industrial sectors as healthcare, smart agriculture, smart grids and production ecosystems in the supply chain. They emphasize the importance of data shared by many heterogeneous networks. Therefore, data security is an essential area of research, which is trusted and secure data transfer. They point to Blockchain (BC) technology as a guarantor ensuring the security of ecosystems (Laghari et al., 2023; Otoum et al., 2022).

Conclusions

The concept of Industry 5.0 is not a new revolution, but only an evolution of trends included in the concept of Industry 4.0. Analyzing the WoS database using the keyword "Industry 5.0", a significant increase in publications in this area can be identified in the years 2022-2024. Researchers emphasize the need to conduct research on the use of technological innovations that consider the EU's social, environmental and economic priorities. The authors of many analyzed publications predict significant changes in the approach to the implementation of digitization and emphasize the benefits for the European economy, value creation chains, as well as the improvement of working conditions and protection of the natural environment.

The main research areas of Industry 5.0 discussed in the selected literature focus on people and their cooperation in human-technology and human-machine systems. In particular, the authors of the analyzed publications draw attention to shaping future working conditions and educating industrial workers. The research discussed in the works also focuses on technological aspects concerning functionality and the impact on the environment, economy and sustainable development. The authors emphasize the importance of human-robot cooperation and Operator 4.0 in the smart factory. They pay particular attention to the issues of implementing collaborative robots (cobots), augmented reality and flexible workstations. In addition, in the works from the area of Industry 5.0, the authors devote much attention to the issue of sustainable development, which is the goal of Industry 5.0. The problem of resilience and risk management is at an early stage of development. It concerns cybersecurity, resilient supply chains, and designing, planning and controlling resilient and digital production networks.

The research conducted by the authors is associated with certain limitations. The literature review focused on only one publication database, Web of Science. For a more complete picture, the literature research should be expanded to include publication databases such as Scopus or Google Scholar. An additional limitation was the analysis of a set of articles written only in English.

Therefore, the Authors propose, in the continuation of further research, a more in-depth analysis of publication sets by combining the databases: Scopus, Google Scholar and WoS with the elimination of duplicate articles in the analyzed databases using the PRISMA methodology. During the content analysis, it may be interesting to analyze the digital technologies of the fourth industrial revolution to achieve the goals of Industry 5.0, i.e. sustainable development, human-centric approach and system resilience. The Authors hope that the presented, identified research areas of Industry 5.0 and their impact on the economy, environment and society will inspire researchers to conduct in-depth research. In addition, an important research area for the future is the identification of barriers related to the implementation of

Industry 5.0 technology areas and the construction of an appropriate business model for enterprises implementing the concept of Industry 5.0. According to the authors, an important research area may also be the identification of knowledge and competences of employees of enterprises of the future and the organization of the education system of engineering and management staff necessary for the implementation of digital technologies of the fourth industrial revolution.

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IDENTYFIKACJA KLUCZOWYCH OBSZARÓW BADAWCZYCH PRZEMYSŁU 5.0 NA PODSTAWIE ANALIZY BIBLIOMETRYCZNEJ

Streszczenie. Dziesięć lat po wprowadzeniu koncepcji Przemysłu 4.0, która miała na celu zrewolucjonizowanie przemysłu i odczłowieczenie systemów produkcyjnych, trendy i kierunki rozwoju przemysłowego ewoluują. Następuje odejście od postrzegania rozwoju technologii jedynie jako środka do zwiększenia produktywności i elastyczności produkcji na rzecz budowania przyszłości opartej na podstawowych wartościach. Komisja Europejska zidentyfikowała kluczowe filary, które powinny być uwzględniane przy rozważaniu współczesnego rozwoju przemysłowego. Filary te obejmują podejście skoncentrowane na człowieku, zrównoważony wzrost gospodarczy oraz rozwój odporności gospodarki na kryzysy. Nowa koncepcja Przemysłu 5.0 koncentruje się na cyfrowej transformacji gospodarki, kładąc nacisk na dobrobyt społeczno-ekonomiczny, zrównoważony rozwój środowiskowy i bezpieczeństwo człowieka. W oparciu o analizę bibliometryczną literatury oraz systematyczny przegląd literatury, niniejszy artykuł ma na celu identyfikację kluczowych obszarów badawczych związanych z wdrażaniem koncepcji Przemysłu 5.0. Dodatkowo autorzy dokonali własnej oceny wpływu zidentyfikowanych obszarów badawczych na realizację społecznych, ekonomicznych i środowiskowych celów wdrażania koncepcji Przemysłu 5.0.

Słowa kluczowe: Przemysł 5.0, analiza bibliometryczna, koncentracja na człowieku, zrównoważony rozwój, odporność