

Katarzyna Bentkowska, PhD
SGH Warsaw School of Economics
Collegium of Business Administration
Institute of Markets and Competition
e-mail: kbent@sgh.waw.pl
ORCID: 0000-0002-2063-2529

Joanna Korpus, PhD
SGH Warsaw School of Economics
Collegium of Business Administration
Institute of Markets and Competition
e-mail: jkorpus@sgh.waw.pl
ORCID: 0000-0002-3583-4676

Barbara Ocicka, PhD, Prof. SGH
SGH Warsaw School of Economics
Collegium of Business Administration
Institute of Corporate Finance and Investment
e-mail: barbara.ocicka@sgh.waw.pl
ORCID: 0000-0003-4898-9594

Mariusz Sagan, PhD
SGH Warsaw School of Economics
Collegium of Business Administration
Institute of Markets and Competition
e-mail: nsagan@sgh.waw.pl
ORCID: 0000-0003-3454-691X

Keywords:

Industry 5.0, crisis resilience, enablers, barriers, digital transformation, human-centricity, sustainable development

Enablers and barriers to Industry 5.0 implementation for building enterprise resilience to crises

Czynniki sprzyjające i bariery dla wdrożenia Przemysłu 5.0 w celu zwiększenia odporności przedsiębiorstw na kryzysy

Abstract: The aim of this article is to identify factors that facilitate and hinder the implementation of the Industry 5.0 concept in the context of building enterprise resilience to crises. The rationale for undertaking this topic stems from the growing frequency of economic, technological, and environmental disruptions, which expose the limitations of existing industrial systems and highlight the need to transition toward human-centric, more sustainable and resilient business models. The scope of the analysis covers scientific literature published between 2015 and 2025 on digital transformation, Industry 5.0, and business resilience. The subject of the study includes technological, social, economic, ecological, and political-legal factors influencing the implementation of Industry 5.0. It is assumed that the adoption of 5.0 technologies is shaped by both enablers and barriers, and that their simultaneous interaction affects enterprises' ability to adapt the Industry 5.0 concept in the context of building resilience to crises. The findings indicate that the key enablers of Industry 5.0 implementation in this context include the development of advanced technologies, rising societal expectations for sustainable and personalized production, and increasing regulatory and environmental pressures. At the same time, significant barriers include high implementation costs, technological immaturity,

Słowa kluczowe:

Przemysł 5.0, odporność na kryzysy, czynniki sprzyjające, bariery, transformacja cyfrowa, podejście zorientowane na człowieka, zrównoważony rozwój

JEL:

M11, M14, M15, Q01, Q55, Q56

infrastructural constraints, and ethical and competency-related challenges. The authors present the implications of their research findings for the activities of enterprises and institutions, as well as for the development of education and research. The study is based on a structured narrative literature review aimed at synthesizing the main categories of enablers and barriers discussed in the literature.

Streszczenie: Celem artykułu jest identyfikacja czynników sprzyjających i hamujących wdrażanie koncepcji Przemysłu 5.0 w kontekście budowania odporności przedsiębiorstw na kryzysy. Uzasadnieniem podjęcia tematu jest rosnąca częstotliwość zakłóceń gospodarczych, technologicznych i środowiskowych, które ujawniają ograniczenia dotychczasowych systemów przemysłowych oraz potrzebę przejścia do zorientowanych na człowieka, bardziej zrównoważonych i odpornych modeli biznesowych. Zakres rozważań obejmuje analizę literatury naukowej z lat 2015–2025 dotyczącą transformacji cyfrowej, Przemysłu 5.0 i odporności przedsiębiorstw. Przedmiotem badań są czynniki technologiczne, społeczne, ekonomiczne, ekologiczne oraz polityczno-prawne wpływające na implementację Przemysłu 5.0. Przyjęto, że wdrażanie technologii 5.0 jest determinowane zarówno przez czynniki wspierające, jak i bariery, a ich równoczesne oddziaływanie wpływa na zdolność przedsiębiorstw do adaptacji koncepcji Przemysłu 5.0 w kontekście budowania odporności na kryzysy. Wyniki analizy źródeł literatury wskazują, że kluczowymi czynnikami sprzyjającymi wdrożeniu Przemysłu 5.0 w badanym kontekście są: rozwój zaawansowanych technologii, rosnące oczekiwania społeczne wobec zrównoważonej i spersonalizowanej produkcji oraz presja regulacyjna i środowiskowa. Jednocześnie istotnymi barierami są: wysokie koszty wdrożeń, niedojrzałość technologii, ograniczenia infrastrukturalne oraz kwestie etyczne i kompetencyjne. Autorzy prezentują implikacje wniosków ze swoich badań dla działalności przedsiębiorstw i instytucji, a także dla rozwoju edukacji i działalności badawczej. Badanie ma charakter narracyjnego przeglądu literatury ukierunkowanego na syntezę głównych kategorii czynników sprzyjających oraz barier wskazywanych w dotychczasowych publikacjach.

Introduction

Industry 5.0 is a concept of transformation in which technology ceases to be an end in itself and becomes a tool for building more human-centric, sustainable and resilient economies and business models. On the one hand, existing achievements – nota-

bly in the domain of technology – enable further development and facilitate change; on the other hand, the role of identified problems requiring urgent solutions becomes increasingly pronounced. Against this background, one of the most significant drivers of change is therefore the lack of stability and resilience of existing industrial systems. Industry 4.0 has encountered numerous challenges that threaten systemic stability [Khan et al., 2023], rendering these systems insufficiently resilient to crises. Frequently criticized is its excessive focus on “performance”, with insufficient attention paid to the impact on human beings. Today, the need to focus on socioeconomic systems is becoming increasingly apparent, and resilience requires the coexistence of humans and technology. To harness the opportunities arising from the development of Industry 5.0, it is essential to recognize the necessary conditions, actively shape them, and responsibly build an ecosystem that supports future socio-economic development.

Although Industry 5.0 has attracted growing scholarly attention, existing studies often focus on its enabling technologies, applications, and conceptual characteristics [Maddikunta et al., 2022; Khan et al., 2023; Ghobakhloo et al., 2024]. Resilience is also discussed as one of the key dimensions of Industry 5.0, alongside sustainability and human-centricity [Ivanov, 2022]. However, the reviewed literature suggests that enablers and barriers of Industry 5.0 implementation are less often integrated specifically from the perspective of enterprise crisis resilience. This article addresses this gap by synthesizing these factors within a single analytical framework.

The aim of this article is to identify factors that facilitate and hinder the implementation of the Industry 5.0 concept in the context of building enterprise resilience to crises. The study is based on a structured analysis of scientific literature. The scope of the analysis covers scientific literature published between 2015 and 2025 on digital transformation, Industry 5.0 and crisis resilience. The literature was selected from scientific publications addressing Industry 5.0, digital transformation, enterprise resilience, sustainability and human-centricity. The analysis focused on identifying recurring factors that either facilitate or hinder Industry 5.0 implementation and on grouping them into technological, social, economic, environmental and political-legal categories.

This study builds on our previous research on technology and enterprise crisis resilience in the context of Industry 5.0 [Bentkowska et al., 2026]. While the earlier study focused on the role of technologies and the readiness of Polish enterprises for digital transformation, the present article broadens the perspective by identifying and synthesizing the technological, social, economic, environmental, and political-legal enablers and barriers to Industry 5.0 implementation.

The study addresses the following research question: What factors facilitate and hinder the implementation of Industry 5.0 for building enterprise resilience to crises?

The next part of the article presents the factors supporting the implementation of Industry 5.0 and their classification into technological, social, economic, environmental,

and political-legal categories. Subsequently, in the discussion of barriers hindering the transformation of business models in Industry 5.0, a similar classification of factors was adopted, grouping them into corresponding categories. The article concludes with a summary containing key findings and recommendations for strengthening the conditions that facilitate the implementation of Industry 5.0 in efforts to build enterprise crisis resilience, as well as directions for further research on the transformation of business models in this area.

Enablers of Industry 5.0 Implementation for Building Enterprise Resilience to Crises

The lack of stability and resilience in existing systems has intensified the imperative to reassess prevailing industrial paradigms. Consequently, **the need to develop technologies that can enhance resilience** has emerged as a central priority in the transition toward Industry 5.0. Technologies particularly relevant to resilience include predictive maintenance, which enables early fault detection and the planning of maintenance activities, thereby enhancing the resilience of production systems to disruptions and crises [Khan et al., 2023]. Cyber-Physical Cognitive Systems support improved human decision-making and foster trust between humans and machines [Khan et al., 2023], while edge computing enhances cybersecurity and reduces latency [Maddikunta et al., 2022]. Big data analytics facilitates more effective decision-making processes and enables real-time forecasting [Maddikunta et al., 2022]. The Internet of Everything contributes to cost reduction, increases resource productivity, and supports efficient supply chain management [Maddikunta et al., 2022]. Digital twins enable cost optimization, prediction of potential failures, and their prevention [Maddikunta et al., 2022]. Artificial intelligence increases operational efficiency, improves quality control, and enables rapid decision-making. In turn, blockchain technologies enhance resilience by improving transparency and traceability within supply chain management [Ivanov, 2022]. At the same time, existing achievements motivate further change: the digital technologies employed in Industry 5.0 are also present in Industry 4.0, yet in Industry 5.0, they deliver additional value when viewed through the lens of resilience, sustainability, and a human-centered approach [Ivanov, 2022]. Advanced solutions applied in industry reinforce stability in crises, enable earlier problem detection, improve decision-making, and facilitate better resource utilization and cost control. At the same time, they enhance operational safety and transparency, thereby enabling faster responses to disruptions.

Beyond technological drivers, **change is driven by social transformations**. An analysis of factors conducive to change reveals a discernible shift in social norms and attitudes (informal institutions) – opinions have been voiced that the ongoing indus-

trial revolution will bring about fundamental changes in our approach to industry and production [Maddikunta et al., 2022]. The so-called “human-technology interaction” influences various human factors (perceptual requirements, cognitive requirements, physical requirements, psychosocial environment) that determine the performance of the individual and the system as a whole [Grosse et al., 2023]. By focusing on human-centricity – placing the human being at the center of attention and integrating humans into production processes – it is anticipated that technology acceptance will increase, the risk of social exclusion will decline, and societal resilience will be enhanced [Adel, 2022].

In line with these changes, societal expectations are also evolving across a range of domains. For instance, in both production and consumption, greater accountability is becoming desirable: stakeholders (including consumers) have expectations regarding the sustainability of corporate activities [Chih-Hung et al., 2024]. Concurrently, the need for product and service personalization is growing – enterprises are supplying tailor-made offerings, drawing on AI analytics and intelligent manufacturing systems to achieve high efficiency and minimize environmental impact [Tanjung et al., 2025]. The ability to create products tailored to individual customer needs enhances competitiveness and adaptability in market crises [Adel, 2022]. Aligning offerings with customer needs through precise market positioning enables the development of personalized, secure solutions, thereby strengthening customer loyalty and enhancing the firm’s flexibility in supply chain management [Chih-Hung et al., 2024].

A growing need for changes in human resource management is evident, with a focus on fostering a positive work environment and meeting employees’ developmental needs [Chih-Hung et al., 2024]. Appropriate training for employees to implement changes in practice and raise their awareness is imperative – research indicates that adequate training programs can reduce resistance and improve acceptance of changes, such as digitalization [Castillo et al., 2025]. An important role is played here by an appropriate organizational culture grounded in trust, fairness, and innovation, which supports the development of employees’ capacity to understand their market position and fosters innovation; this can facilitate sustainable corporate development and increase organizational flexibility [Chih-Hung et al., 2024]. In this context, effective leadership is a critical factor in building resilience, as it not only accelerates the adoption of new technologies but also supports cultural transformation by integrating sustainability and resilience into organizational strategies [Castillo et al., 2025].

At the same time, however, traditional **economic factors that drive continuous corporate adaptation** – such as competitive market pressures and the need to respond to changes in the business environment – must not be overlooked [Chih-Hung et al., 2024]. The motivation for change must be sought in the growing scale of potential threats and crises of various kinds occurring in the surrounding environment. Recent

years have underscored the paramount importance of resilience to sudden threats, including COVID-19, natural disasters, cybersecurity risks, and disruptive digital innovations [Yoşumaz, Uzun, 2024]. The COVID-19 pandemic itself has led to greater emphasis on long-term “resilience” rather than merely short-term “disaster recovery strategies” [Maddikunta et al., 2022]. The need to deploy new technologies – such as AI – to modernize traditional manufacturing processes has become more pronounced, as these technologies offer enormous potential to build an inclusive digital future by ensuring supply chain resilience and sustainability [Ahmed et al., 2023]. The COVID-19 pandemic temporarily halted the development of smart technologies but, in the long term, became a catalyst for industrial transformation, confirming that crises have historically accelerated technological progress [Suciu et al., 2023]. Meanwhile, crises of diverse character are intensifying in the broader environment – climatic, financial, demographic aging, armed conflicts, trade wars, protectionism, and others. Industry 5.0 technologies assist in designing businesses that are resilient, flexible, and capable of operating under diverse conditions [Szara, 2025].

From an economic perspective, these developments translate into additional drivers of Industry 5.0 implementation. New opportunities are emerging to reduce corporate operating costs – for example, through the aforementioned predictive maintenance technology, which uses sensor data to predict equipment lifespan, thereby reducing costs and improving productivity [Khan et al., 2023]. Effective cost management within the supply chain strengthens the firm’s market position, increases flexibility and competitiveness, prevents capital shortfalls, and builds trust and risk awareness at all stages of the chain [Chih-Hung et al., 2024]. In addition, a further favorable factor is the potential for increased productivity and safety, for instance, through the use of robots that can work alongside humans to perform repetitive or hazardous tasks [Khan et al., 2023].

An important group of factors conducive to Industry 5.0 implementation concerns **the need to address climate challenges** that threaten organizational stability. The need to reduce resource consumption, address climate problems, and increase energy efficiency – challenges that Industry 4.0 had already grappled with – is becoming particularly pronounced [Khan et al., 2023]. A significant relationship exists between resilience and environmental sustainability efforts. If both individual firms and society at large focus on the environmental processes of individual actors, the resilience of business and society to environmental threats will increase [Yoşumaz, Uzun, 2024]. The development of green technologies enables wide-ranging changes within enterprises and implementing solutions that reduce resource consumption and waste generation contributes to resilience to climate and regulatory crises [Adel, 2022]. Energy savings and emissions reduction support sustainable development, while environmentally responsible practices in packaging, transport, and marketing reinforce production-market alignment and increase corporate flexibility [Chih-Hung et al., 2024].

These developments are also reflected in the political and legal environment. At the EU level, policies supporting industrial change are being developed [EC, 2021]. Industry 4.0 does not provide the framework necessary to achieve Europe's 2030 targets [Khan et al., 2023]. In accordance with the European Commission's approach to sustainable development goals within Industry 5.0, its primary objective is to promote the economic, environmental, and social dimensions of sustainable development at the micro, meso, and macro levels [Ghobakhloo et al., 2024]. New European strategies support the development of a human-centric industry [Mourtzis et al., 2022]. They emphasize adaptation to climate change (e.g., the European Green Deal) and contribute to developing programs that support digitalization and innovation – the “Europe Fit for the Digital Age” initiative positions digitalization as a priority for Europe and offers enormous innovative potential. The European Research Area (ERA) is intended to connect and stimulate research and innovation across Europe. At the same time, the new European Industrial Strategy and Skills Agenda aims to address the skills shortage [EC, 2021]. Regulations drive the integration of environmental goals and policies into corporate development strategies [Tanjung et al., 2025], thereby enhancing resilience.

In this regard, compliance with regulations can support resilience in numerous indirect ways. It offers many potential benefits, such as enabling stable inter-firm cooperation, increasing attractiveness to partners, and supporting international expansion. This is evident, for example, in the case of environmental regulations: compliance facilitates commercial cooperation between enterprises and access to foreign markets. Firms failing to meet requirements may encounter export barriers, which weaken their resilience and capacity to adapt to market changes [Yoşumaz, Uzun, 2024].

Overall, the factors conducive to Industry 5.0 implementation described in this study may be classified into social, technological, economic, environmental, and political-legal categories. Table 1 presents such a classification. It should be emphasized, however, that some factors exert complex, multidimensional effects and may be analyzed jointly – for instance, as socioeconomic or techno-economic factors. These categories were adopted as an analytical framework because they reflect the main dimensions in which Industry 5.0 implementation is discussed in the reviewed literature.

Summing up, the reviewed literature points in particular to technological development, sustainability-related expectations and regulatory support as relevant enablers of Industry 5.0 implementation in the context of enterprise resilience to crises [EC, 2021; Ivanov, 2022; Maddikunta et al., 2022; Khan et al., 2023; Chih-Hung et al., 2024; Ghobakhloo et al., 2024; Tanjung et al., 2025].

Following the above discussion and the classification presented in Table 1, it is possible to distinguish between **internal and external factors** conducive to implementing Industry 5.0 in the context of building crisis resilience. This distinction is significant,

as it highlights which elements an enterprise may shape independently and which arise from its external environment. Internal factors primarily concern the management of technology, organizational culture, and operational strategies that a firm can develop autonomously to build resilience. External factors, by contrast, emanate from the market, legal, and social environment – they require adaptation, yet can also stimulate internal change and innovation.

Table 1. Enablers of Industry 5.0 Implementation for Building Enterprise Resilience to Crises

Type	Factor Description
Technological	Lack of stability and resilience of existing systems
	Critical assessment of Industry 4.0 and recognition of threats to systemic stability
	Development of new technologies enabling enhanced resilience
Social	Shifts in social norms and attitudes (informal institutions)
	Growing need for human-centricity as a means of achieving greater stability
	Development of socially responsible consumption and production
	Growing demand for product and service personalization
	Changes in organizational culture – need to prepare employees for new challenges and ensure effective leadership.
Economic	Necessity to address potential threats and crises of various kinds in the business environment (e.g., climate, financial, demographic aging, armed conflicts, trade wars, protectionism)
	Necessity to adapt to changes in the business environment
	Competitive market pressure
	Changes in approach and adaptations triggered by the COVID-19 pandemic and the associated crisis
	Potential for cost reduction
	Potential for increased productivity and safety
	Resilience benefits derived from product and service customization
Environmental	Necessity to address climate challenges that threaten systemic stability
	Development of green technologies
	Energy savings and emissions reduction
Political-Legal	EU policies supporting industrial change
	New regulatory requirements
	Benefits of compliance with new regulatory requirements, e.g., facilitated cooperation with other firms

Source: own elaboration.

Barriers to Industry 5.0 Implementation for Building Enterprise Resilience to Crises

Similarly to the enabling factors, the barriers to the implementation of Industry 5.0 technologies can be categorized into social, technological, economic, environmental, and political-legal groups. A structured overview of these barriers is presented in Table 2.

Table 2. Barriers to Industry 5.0 Implementation for Building Enterprise Resilience to Crises

Type	Factor Description
Technological	Early stage of technological development
	Level of technological advancement
	High complexity of systems integration
	Interdisciplinary nature of Industry 5.0 solutions; multi-dimensionality of aspects involved
Social	Insufficient digital competencies among employees
	Employee resistance to change; difficulties in engaging and aligning human resource activities
	Ethical and psychological aspects
	Organizational culture
Economic	High costs of technology projects
	Difficult-to-estimate return on investment (ROI)
	High risk associated with technology projects
Environmental	Energy consumption
	CO ₂ emissions
	Impact on biodiversity loss and environmental pollution
	Use of natural resources and circular economy challenges in high-tech value chains
Political-legal	Challenges related to data security
	Lack of coherent strategies, policies, and regulations at the international level
	Regulatory changes and the need for continuous adaptation

Source: own elaboration.

The current, **early stage of Industry 5.0 technological development** is identified as one of the factors impeding large-scale deployment of Industry 5.0 across the economy. Industry 5.0 technologies are still in the installation phase, which makes it difficult to fully understand the consequences, limitations, and future challenges of their applications [Khan et al., 2023].

Moreover, the barriers to Industry 5.0 implementation vary with the level of technological development in individual economies and societies. In many developing

countries, progress in implementing innovative Industry 5.0 technologies is constrained by limited technological advancement, including inadequate digital infrastructure, outdated facilities, and a lack of trained workers [Tanjung, 2025]. In contrast, in developed countries, challenges arise from the complexity and the necessity of integrating existing and new technological solutions, which impedes smooth and effective implementation. It is noted that integrating advanced technologies (AI, IoT, cobots) increases the risk of errors and the likelihood of failure [Khan et al., 2023]. The execution of projects employing Industry 5.0 technologies is inherently multidimensional and requires an interdisciplinary approach, which constitutes a significant barrier to Industry 5.0 development. The multidisciplinary nature of Industry 5.0 technologies requires integrating achievements from engineering, humanities, environmental sciences, and information technology. Addressing such multi-dimensional challenges demands a local and flexible strategy, one that takes cultural sensitivity and regional constraints into account on the one hand, while also leveraging global technological advances on the other [Tanjung, 2025].

Beyond technological barriers, **social factors also play a critical role**. From a social perspective, the key challenges are related to human capital. Insufficient workforce preparation hampers the adoption of new technologies [Adel, 2022], and this barrier may give rise to social tensions, particularly during periods of crisis. The social and economic impact of Industry 5.0 development – particularly that of artificial intelligence – will be significant over the long term; it is therefore important to prepare economic actors and engage society in the digital transformation. This requires certain characteristics, skills, and core competencies. Attention must also be drawn to a range of new challenges associated with human-robot collaboration, including legal and regulatory issues, psychological challenges, ethical concerns, difficulties regarding capacity and openness to collaborating with robots, and unfair competition between humans and robots. As scholars argue, for the transition to Industry 5.0 to be sustainable, resilient, and inclusive – and thereby generate long-term positive effects – it is necessary to equip human resources with a set of new professional and transversal competences, including: skills in operating, monitoring, and controlling technological devices; analytical and innovative thinking; lifelong learning; development of technological and programming solutions; creativity, originality, and initiative-taking; emotional intelligence; leadership; and the ability to solve complex problems [Suciu et al., 2023]. The implementation of Industry 5.0 technologies is closely tied to change management, and employees may resist these changes, creating difficulties in engaging and aligning human resource activities with digital transformation. Employee resistance manifests, for example, in the context of accepting cobots [Khan et al., 2023]. Organizational culture may provide a basis for opportunistic employee behavior in implementing technology and transforming the enterprise's business model within Industry 5.0. Deeply embedded norms cause enter-

prises to hesitate to transition to more human-centered and sustainable models [Castillo et al., 2025]. Taking into account reluctance to change, fears of job loss, and potential conflicts between corporate technological development objectives and employees' values, organizational culture may delay or undermine the sustainability of Industry 5.0 projects [Tanjung, 2025].

Economic barriers constitute another important dimension of the problem. A fundamental factor impeding the implementation of Industry 5.0 technologies is the cost of technology projects, encompassing various cost drivers: the acquisition of hardware and software, infrastructural and systemic adjustments, employee training, and the maintenance and further development of technological solutions. Awareness of the need to calculate the total costs of technology projects and the accuracy of those calculations is crucial to determining the financial viability of an investment project. Financial viability remains a key obstacle to implementing Industry 5.0, particularly for organizations with limited resources. Many organizations perceive sustainability and digital transformation as costly investments rather than strategic undertakings. Traditional return on investment (ROI) models often fail to capture the long-term financial and operational benefits of digitalization and sustainability initiatives, thereby limiting their strategic appeal [Castillo et al., 2025]. Budget constraints in financing this type of project affect the majority of enterprises in crisis conditions [Khan et al., 2023] and – when considered by enterprise size – are particularly pronounced for SMEs [Tanjung, 2025]. These barriers may be particularly significant for SMEs, which usually have more limited financial, technological and human resources than large enterprises. Technology projects are inherently innovative and characterized by high implementation risk, which, for risk-averse managers, is a significant impediment to digital transformation [Tanjung, 2025].

Environmental barriers also represent a growing area of concern. In this article, they are understood mainly as risks and external costs associated with the large-scale deployment of digital and high-tech solutions. This group encompasses aspects such as total energy consumption and total CO₂ emissions over the technology life-cycle; the share of high-tech sectors in natural resource consumption; the impact of high-tech value chains on air pollution, biodiversity loss, and ecosystem stability; and waste management efficiency in circular-economy high-tech supply chains. There is a pressing need to develop measures to make the digital economy system sustainable and crisis-resilient [Ferreboeuf et al., 2021]. Although modern technologies offer enormous potential to support sustainable development, their implementation must be carefully managed to minimize associated adverse environmental impacts [Khajeh Naeeni, Nouhi, 2023].

Finally, **political and legal barriers** further complicate the implementation process. From a political and legal perspective, modern technologies give rise to numerous

challenges, such as data piracy, hacking, and data security breaches (cybercrime) [Khan et al., 2023], which will continue to act as barriers to technological development and must, in particular, be overcome in the pursuit of using Industry 4.0 and 5.0 technologies to build the resilience of economies and enterprises to crises. Industry 5.0 technologies involve the collection and analysis of large datasets, and enterprises may be reluctant to implement them due to concerns about protecting intellectual property rights and the legal challenges of liability for unauthorized data use. At the international level, significant barriers to implementation progress include the lack of coherent strategies, policies, and regulations, which increases the complexity of preparatory initiatives and projects, as enterprises must negotiate and satisfy diverse certification procedures or compliance criteria [Tanjung, 2025]. Monitoring evolving regulations and continually ensuring compliance with applicable standards can be demanding and may impede the application of Industry 5.0 technological solutions [Laddha, Agrawal, 2024].

The reviewed literature identifies implementation costs, technological immaturity, integration complexity and competence gaps as important barriers to Industry 5.0 adoption [Khan et al., 2023; Suci et al., 2023; Laddha, Agrawal, 2024; Castillo et al., 2025; Tanjung et al., 2025].

Conclusion

Industry 5.0 builds upon the foundations of Industry 4.0, but places stronger emphasis on human-centricity, sustainability and crisis resilience. The article addresses the identification of factors that facilitate and hinder the implementation of the Industry 5.0 concept in the context of building enterprise resilience to crises.

The factors conducive to Industry 5.0 implementation from the perspective of crisis resilience are closely intertwined with the challenges encountered in the development of Industry 4.0. These factors can be classified into five main categories: technological, social, economic, ecological, and political-legal. Technologies such as AI, digital twins, and blockchain enable earlier detection of disruptions and enhance operational transparency, while parallel social shifts – including rising expectations for sustainable production and the growing demand for personalization – drive innovation. Economic, climate-related, and regulatory challenges, in turn, necessitate adaptation but simultaneously act as catalysts for the development of green technologies and more efficient enterprise management. Together, these factors create a framework within which organizations can build long-term resilience and flexibility, preparing themselves to address potential threats in their environment.

The literature review also made it possible to identify factors that hinder the implementation of Industry 5.0 technologies, which include social, technological, economic,

ecological, and political-legal dimensions. Key barriers involve the high costs and risks associated with innovative technological projects, regulatory issues, divergent policies and standards, and the need to ensure data security. Moreover, Industry 5.0 technologies are advanced solutions that require integration with existing infrastructure and systems used within enterprises and supply chains. It should be noted that knowledge and experience related to the implementation of such projects have not yet been fully accumulated, and many modern technologies remain at an early stage of their life cycle. The development of Industry 5.0 is also subject to evaluation in terms of ecological factors (e.g., high energy consumption) and social considerations (e.g., ethical and psychological aspects). Importantly, digital transformation requires the development of new employee attitudes and competencies, as well as changes in organizational culture, to enable the effective use of 5.0 technologies in building crisis resilience while maintaining a human-centric and sustainable orientation.

The presented results and conclusions have significant implications for the activities of enterprises and institutions, as well as for the development of education and research.

Implications for enterprises

Whether a company can strengthen the drivers in its business environment and leverage them to implement Industry 5.0 solutions – as well as gradually eliminate barriers to their adoption – will depend on sound business strategies, the ability to anticipate future developments, and effective operational actions. This will enable firms to build sustainable competitive potential for the future. Businesses should adapt to changes in the global environment more quickly than they do today, and a key strategy for achieving this will be expansion into competitive international markets. Such expansion can increase operational scale and reduce the unit costs of implementing Industry 5.0 technologies. Funding for these initiatives is available through various support programs for innovative enterprises, sourced from both domestic mechanisms and EU funds, which companies should leverage more extensively than they currently do.

An extremely challenging task facing companies in the context of implementing Industry 5.0 solutions is the gradual removal of implementation barriers. This requires a long-term strategy rooted in local innovation ecosystems, supported by the acquisition of external financing and the development of specialized teams. Another essential component involves initiatives aimed at identifying market best practices and establishing potential network partnerships to strengthen organizational capabilities during the early stages of technological development.

Implications for institutions

The findings have important implications for institutions at both the macro and meso levels in shaping the conditions for Industry 5.0 implementation and crisis resilience. At the macro level, policymakers should ensure regulatory coherence in areas such as data governance, AI, and cybersecurity, as fragmentation increases compliance costs and weakens systemic resilience. Given the long-term and uncertain returns of Industry 5.0 investments, there is also a need for adapted policy instruments, including targeted funding, public guarantees, and support mechanisms that account for broader societal benefits. Moreover, Industry 5.0 should be integrated into national resilience strategies, as recent crises – including the COVID-19 pandemic and climate-related disruptions – have shown that resilience is a system-level challenge. Coherence between industrial, skills, and environmental policies is therefore essential to avoiding fragmented responses to systemic risks.

At the meso level, intermediary institutions – such as sectoral organizations, clusters, technology platforms, and industry associations – play a key role in reducing coordination failures between public policy and firm-level implementation. Their role is particularly important given the complexity, interdisciplinarity, and high risk of Industry 5.0 projects. These institutions can support sector-specific standards, shared pilot projects, knowledge diffusion, and competence-building initiatives, thereby lowering implementation barriers for individual firms. By facilitating cooperation among enterprises, research organizations, and public authorities, meso-level institutions can strengthen sectoral resilience and support the human-centric and sustainable orientation of Industry 5.0.

Implications for education system

At the macro level, it is essential to enhance coherence between educational, industrial, digital, and environmental policies, as these jointly shape the demand for future competencies. The education system should therefore prioritize the development of advanced digital skills alongside transversal skills (e.g., analytical thinking, problem-solving, and lifelong learning), while also promoting interdisciplinary education that integrates technical, social, and humanistic domains.

At the meso level, educational institutions – including universities, research organizations, and training centers – should play a key role in aligning education with labor market needs through strengthened university – industry collaboration, the development of dual education systems, and engagement in joint R&D and pilot projects. They should also contribute to the development of competence standards and foster responsible approaches to technology use by incorporating issues such as AI ethics, data

governance, and cybersecurity into educational programs, thereby supporting increased societal trust and acceptance of emerging technologies.

At the micro level, organizations should foster a learning-oriented culture and invest in systematic upskilling and reskilling initiatives to support employees in adapting to environments characterized by human – machine interaction and the increasing use of cyber-physical systems and AI-based solutions. Developing adaptability and readiness to work with advanced technologies becomes a critical factor in building both individual and organizational resilience.

Implications for research

The study demonstrates that researching Industry 5.0 requires holistic analytical frameworks capable of integrating technological, social, economic, ecological, political, and legal dimensions. It highlights the need for interdisciplinary research, as the complexity of Industry 5.0 cannot be captured within a single scientific field. Another determinant supporting interdisciplinary inquiry is the large number and diverse nature of the identified factors. The diversity of identified factors calls for the creation of integrated assessment tools to evaluate Industry 5.0 readiness at multiple levels. The identification of advanced technologies as key enablers suggests a research agenda focused on human-centric technology design and its organizational implications. High implementation costs and technological immaturity point to gaps in understanding scalable adoption pathways and economic feasibility models. Ethical and competency-related barriers emphasize the need for research on workforce transformation, including new educational frameworks and skill development. The study also underscores the importance of analyzing regulatory and environmental pressures that shape Industry 5.0 adoption.

The findings determine the call for studying innovation ecosystems that support collaboration among enterprises, institutions, research organizations, and other stakeholders. Social innovations and eco-innovations gain greater importance, given the sustainability orientation of Industry 5.0. The successful implementation of Industry 5.0 requires a broad spectrum of different types of innovations – product, process, marketing and organizational innovations. Special attention should be given to open innovation processes. Overall, the study indicates that advancing Industry 5.0 requires a multi-disciplinary research agenda that bridges technology, management, and sustainability fields.

The study is subject to limitations typical of literature-based research. The findings are derived from published studies and have not been validated through empirical research in enterprises. Future studies may verify the identified framework using surveys, case studies of Industry 5.0 implementation, sectoral comparisons or analyses of SME readiness for Industry 5.0 solutions.

References

- Adel A. [2022], Future of industry 5.0 in society: human-centric solutions, challenges and prospective research areas, *Journal of Cloud Computing*, vol. 11, pp. 1–15.
- Ahmed T., Karmaker Ch.L., Nasir S.B., Moktadir M.A., Paul S.K. [2023], Modeling the artificial intelligence-based imperatives of industry 5.0 towards resilient supply chains: A post-COVID-19 pandemic perspective, *Computer & Industrial Engineering*, vol. 177, p. 109055.
- Bentkowska K., Korpus J., Ocicka B., Sagan M. [2026], Leveraging technology for enterprise crisis resilience in Industry 5.0, *Kwartalnik Nauk o Przedsiębiorstwie*, vol. 80(2), pp. 21–36, <https://doi.org/10.33119/KNOP.2026.80.2.2>.
- Castillo C., Otero-Romero T., Alvarez-Palau E.J. [2025], Navigating the transition to industry 5.0: advancing sustainability, resilience, and human-centricity in Spanish supply chain management, *Discover Sustainability*, vol. 6, p. 331.
- Chih-Hung Hsu, Jin-Zheng Wu, Ting-Yi Zhang, Jia-Yi Chen [2024], Deploying Industry 5.0 drivers to enhance sustainable supply chain risk resilience, *International Journal of Sustainable Engineering*, vol. 17, pp. 211–238.
- EC [2021], *Industry 5.0: Towards a sustainable, human-centric and resilient European industry (R&I Paper Series, Policy Brief)*, European Commission, https://research-and-innovation.ec.europa.eu/knowledge-publications-tools-and-data/publications/all-publications/industry-50-towards-sustainable-human-centric-and-resilient-european-industry_en (access: 20.11.2025).
- Ferreboeuf H., Efoui-Hess M., Verne X. [2021], *Environmental impacts of digital technology: 5-year trends and 5G governance*, https://theshiftproject.org/app/uploads/2025/02/Environmental-impacts-of-digital-technology-5-year-trends-and-5G-governance_March2021.pdf (access: 16.11.2025).
- Ghobakhloo M., Mahdiraji H.A., Iranmanesh M., Jafari-Sadeghi V. [2024], From Industry 4.0 Digital Manufacturing to Industry 5.0. Digital Society: a Roadmap Toward Human-Centric, *Information Systems Frontiers*, pp. 1–33.
- Grosse E.H., Sgarbossa F., Berlin C., Neumann W.P. [2023], Human-centric production and logistics system design and management: transitioning from Industry 4.0 to Industry 5.0, *International Journal of Production Research*, vol. 61, pp. 7749–7759.
- Ivanov D. [2022], The Industry 5.0 framework: viability-based integration of the resilience, sustainability, and human-centricity perspectives, *International Journal of Production Research*, vol. 61, pp. 1683–1695.
- Khajeh Naeeni S., Nouhi N. [2023], The Environmental Impacts of AI and Digital Technologies, *AI and Tech in Behavioral and Social Sciences*, vol. 1(4), pp. 11–18.
- Khan M., Haleem A., Javaid M. [2023], Changes and improvements in Industry 5.0: A strategic approach to overcome the challenges of Industry 4.0, *Green Technologies and Sustainability*, vol. 1, p. 100020.
- Laddha S., Agrawal A. [2024], Unveiling barriers to Industry 5.0 adoption in supply chains: a DEMATEL approach, *RAUSP Management Journal*, vol. 59, pp. 123–137.
- Maddikunta P.P.K., Pham Q.V., Prabadevi B., Deepa N., Dev K., Gadekallu T.R., Ruby R., Liyanage M. [2022], Industry 5.0: A survey on enabling technologies and potential applications, *Journal of Industrial Information Integration*, vol. 26, p. 100257.

- 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*, vol. 15(17), p. 6276.
- Suciu M.C., Plesea D.A., Petre A., Simion A., Mituca M.O., Dumitrescu D., Bocaneala A.M., Moroianu R.M., Nasulea D.F. [2023], Core Competence – As a Key Factor for a Sustainable, Innovative and Resilient Development Model Based on Industry 5.0, *Sustainability*, vol. 15(9), p. 7472.
- Szara K. [2025], Resilience in Industry 5.0 – Systematic Literature Review, *Scientific Papers of Silesian University of Technology, Organization and Management Series*, vol. 224, pp. 523–551.
- Tanjung T., Ghazali I., Mahmood W.H.W., Gazali Herawan S. [2025], Drivers and barriers to Industrial Revolution 5.0 readiness: A comprehensive review of key factors, *Green Technologies and Sustainability*, vol. 3, p.100217.
- Yoşumaz İ., Uzun. H. [2024], The relationship between industry 5.0 Process and ESG process: A qualitative analysis in the context of Türkiye's BIST Sustainability 25 Index white good sector, *Environmental Research & Technology*, vol. 7(4), pp. 512–529.

