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RESILIENCE IN INDUSTRY 5.0 – SYSTEMATIC LITERATURE REVIEW

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Purpose: This paper attempts to explore the concept of resilience in the context of Industry 5.0. It is believed that this is the next stage of the industrial revolution of Industry 4.0. The issues addressed are new and little recognized in the literature. The aim of the paper is to examine "resilience in Industry 5.0".
Design/methodology/approach: The article uses a systematic literature review method to identify and map key words related to this topic.
Findings: The results indicate an ambiguous understanding of the concept of "resilience", but also highlight its key elements. They are common to the problem addressed in the context of Industry 5.0. These include sustainable development and human focus. The synergy between technology and people is associated with the need to adapt to changing market and crisis conditions.
Research limitations/implications: they concern the scientific works that were used to review the literature and scientific databases, the initial stage of development of the Industry 5.0 concept and the theoretical nature of the work.
Practical implications: Resilience in the context of Industry 5.0 is the least recognized pillar of this concept. The analysis indicates not only the directions of development of enterprises, but also the need to adapt employees, structures, resources and production systems in the event of a crisis.
Social implications: Knowledge of the topic of resilience does not only concern industry. The issue addressed is important in various areas of life.
Originality/value: The problem under consideration is relatively little known, mainly in the area of resilience. The mapping shows the development of work related to the problem under consideration in the context of focusing on humans and sustainable development, but also on new technologies. The need for further research has been identified, which can bring benefits to both scientists and practitioners, while promoting all pillars of Industry 5.0. The obtained results of the bibliographic analysis can constitute a knowledge base in the design of elements of production systems in enterprises, be a good example for decision-makers or the community. They can provide a background for discussions and polemics.
Keywords: resilience, Industry 5.0; literature review; sustainability, human-centric.
Category of the paper: Literature review.

1. Introduction

Rapid changes in the environment require businesses to adapt. Thanks to the integration of technologies such as artificial intelligence, automation and the Internet of Things, the industry has experienced unprecedented changes in efficiency and productivity levels. These are part of the digitalisation characteristic of Industry 4.0.

The transition to Industry 5.0, which emphasises human collaboration, sustainability and resilience, is expected to bring new opportunities and challenges for both employers and employees. The integration of technology with human skills is expected to provide a remedy in the form of 'industry resilience' to economic changes and crises. The ability to adapt and respond to changing conditions not only for industrial companies but also for other organisations is the future of building their 'resilience' to change.

The 'resilience' trend shaping Industry 5.0 is precisely linked to the ability to adapt and respond quickly to changing conditions.

In the literature, despite numerous items on Industry 5.0, 'resilience in Industry 5.0' is not explained in depth. This constitutes a research gap which is also a research problem addressed in the question: what is “resilience in Industry 5.0”?

The relevance of this study and its contribution to the scientific literature is determined by the fact that in human communication every word has a meaning. Understanding the nature of words, especially in science, is important in terms of communicating information accurately and building shared understanding. The expressions 'resilience' and 'Industry 5.0' are used by the European Commission to indicate the direction of the economies and societies of the associated countries. Not only governments, but also all members of the EU member states should be aware of the concept of 'resilience in Industry 5.0'. This formulation will be analysed in this paper.

The issue addressed by combining the word 'resilience' with Industry 5.0 stems not only from technological developments, but also from changes taking place in the political, economic and environmental arenas. The pace of change through digitisation, the use of technological solutions in various spheres of life, is so fast that we are often unable to keep up with the information that is also coming at us exponentially.

The volatility of the environment under the influence of crises should also be mentioned. The pandemic revealed weaknesses in global supply chains, demonstrating the importance of adapting quickly to disruptions (DeWit et al., 2020; Villar et al., 2023; Huang et al., 2022; Mourtzis et al., 2022b).

The production process can also be disrupted by weather events (Foresti et al., 2019; Bakon et al., 2022). Increasingly frequent floods or droughts point to the need to build production systems that can quickly adapt to the prevailing condition. In the Industry 5.0 concept, this involves the implementation of new technologies. Related to this is the integration and adaptation that protects the environment as a priority in sustainable development. Human beings and their place in the transformation processes taking place during the implementation of technological solutions are also important. Therefore, the aim of this paper is to explore 'resilience in Industry 5.0'.

In addressing the stated objective, the following research questions were formulated:

1. How is 'resilience in Industry 5.0' defined in the literature?
2. In which areas can 'resilience in Industry 5.0' be considered?
3. What were the main research trends in the field of Industry 5.0 and resilience in 2021-2024?

The present work is structured as follows.

The Introduction section provides context and introduces the topic, also indicating the motivation and research gap of this paper. The second section presents definitions of resilience in Industry 5.0. The next covers the methodology of the systematic literature review. The fourth presents the findings gathered from the literature review based on qualitative studies of theses. The fifth covers the network analysis of publications using VOSviewer. The next section includes a discussion. The final section concludes this paper with conclusions including practical implications and suggestions for future research.

2. Definition of „resilient in Industry 5.0"

In 2021 The European Commission formally called for a fifth industrial revolution (Industry 5.0) in the document 'Industry 5.0: Towards a sustainable, people-centred and resilient European industry' issued on 4 January 2021 (European, 2021).

It states "building resilience within our existing economy and transforming to a new set of economic ecosystems that are more resilient to future shocks and stresses should be Europe's mission henceforth. Ensuring that European industrial development is oriented towards resilience whilst enabling and accelerating the transition to the age of sustainable wellbeing for all is an essential step for the future of the EU industrial strategy (European, 2021, p. 3).

It was noted that 'transformation means, first of all, mainstreaming resilience, sustainability, regenerative and circular economic principles in all its policies, and in the implementation of those policies, from Horizon Europe to the national plans for resilience and recovery' (European, 2021, p. 4).

The transformation from Industry 4.0 to Industry 5.0 (Fraga-Lamas et al., 2021; Golovianko et al., 2022; Grabowska et al., 2022; Mourtzis et al., 2022a) is the process of how we view and use technology in industry. Industry 4.0, focuses on the automation, digitisation and integration of manufacturing systems through technologies such as the Internet of Things (IoT), artificial intelligence (AI) and data analytics. A description of Industry 4.0 can be found in numerous works (Andres et al., 2024; Borchardt et al., 2022; Ghobakhloo et al., 2024; Grosse et al., 2023; Hansen et al., 2024).

The concept of Industry 5.0 allows companies to take a broader perspective and provide solutions to emerging societal challenges (Document, 2024). "Industry 5.0 updates and extends the concepts of Industry 4.0, focusing on what has been called the 'three Ps': people, planet and prosperity" (Document, 2024).

The concept of 'resilience' was known in the literature before it was defined in European Commission documents. The origin of the word is briefly presented below.

The word "resilience" has its origin in the Latin word "resi-lire", which means springing back. The concept of resilience has become a ubiquitous concept rooted in different worldviews and scientific traditions such as psychology, ecology, and engineering. The concept of resilience evolved from psychology in the 1940s. Resilience entered the field of ecology when systems thinking became popular. Crawford Stanley Holling (1973) defined a concept of ecological resilience in order to "understand the capacity of ecosystems with alternative attractors to persist in the original state subject to perturbations" (Resilience, 2021).

In social terms, it is defined by Adger (2000) as social resilience, the ability of groups or communities to cope with external stresses and disruptions caused by social, political and environmental change.

From an economic perspective, it is the innate ability and adaptive responses that allow companies and regions to avoid maximum potential losses (Rosa, Liao, 2005).

From a management point of view, it is the ability of an organisation to cope with stresses and improve performance despite adversity (Vogus, Sutcliffe, 2007).

In engineering terms, it is the ability of a system to survive a major failure with acceptable degradation parameters and to recover within an acceptable time, taking into account cost and risk (Haimes, 2009; Kaz, 2019).

This 'capacity' to withstand and quickly recover from disruption is referred to in the European Commission document. to the economic crisis caused by a pandemic. With the Instrument for Recovery and Resilience, the European Commission wants to support EU countries in reform efforts that ensure sustainable recovery (Breque, De Nul, Petridis, 2021).

Further challenges are related to climate change, financial crises, energy crises, an ageing population, armed conflicts, trade wars, protectionism, etc.). Both these and other challenges point to the need to adapt to them. Indusrty 5.0 points to designing businesses in such a way that the industry is robust, adaptable and able to maintain operational integrity under adverse conditions. Confirmation of these indications can be found in the work of Thomassen, Henriksen, (2023), Wachter et al. (2024), Atif, Qureshi, (2024), Wolniak (2023) among others.

Breque, Nul, Petridis (2021) point out that resilience refers to the need to develop a higher degree of robustness in industrial production, better arming it against disruptions and making sure it can provide and support critical infrastructure in times of crisis.

The industry of the future must be equipped to adapt quickly to changing circumstances. Only then can it cope with unforeseen situations (disruptions), which can occur at many levels, including the shop floor, the supply network and the industrial system.

Resilience is defined: as a response, a reaction to a situation that is different (e.g. illness, lack of energy, etc.) from the actual situation (expected, normal, functional).

Resilience is related to the capacity and ability of a business to recover from a disruption. Resilience, of a business can be measured by its ability to cope with risk and reduce vulnerability.

In the context of Industry 5.0, resilience is an important aspect that enables organisations to survive disruptions and continue operations seamlessly. As Industry 5.0 emphasises the integration of advanced technologies such as artificial intelligence, big data analytics and the Internet of Things (IoT), manufacturing systems are becoming more complex and vulnerable to failure. Therefore, building resilient production systems is crucial to mitigate the impact of disruptions and ensure business continuity (Kaasinen et al., 2022; Lee et al., 2022, Akungj et al., 2022).

3. Methodology

Documentation of the systematic review was carried out according to the guidelines given in the PRISMA (2020) statement (Fig. 1).

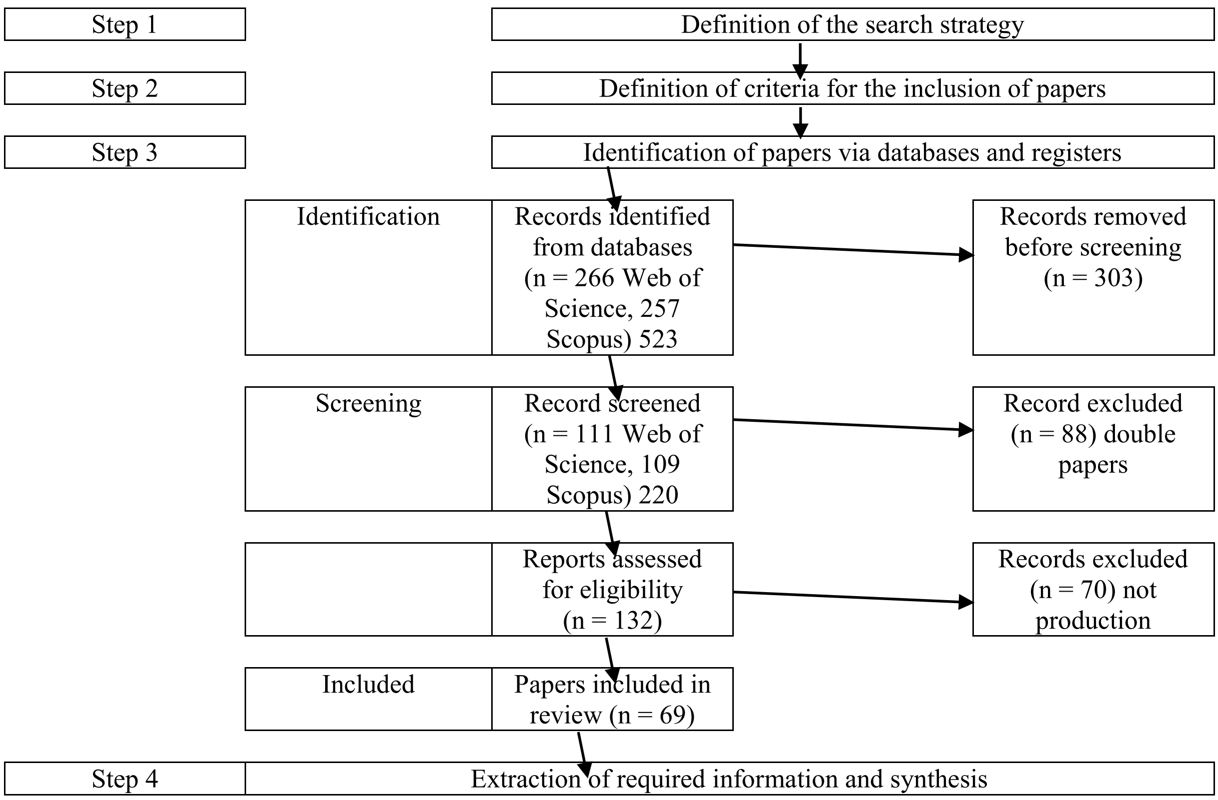

Figure 1. Steps of systematic literature review.

Source: based on The PRISMA 2020.

Planning the literature review involved selecting two databases: Web of Science and Scopus. Pre-determined keywords were used to search the database, which are related to the main purpose of the study. The keywords were chosen to be comprehensive and not to condition or limit the study. The predetermined search equation was ('resilience') AND ('Industry 5.0') OR ('resilient') OR ('Resilience') and was used in an advanced Web of Science search. The syntax was then adapted to the Scopus database: (TITLE-ABS-KEY). The search was conducted in English.

Selected article search locations were in the title and abstract. 523 papers were identified. The search period for the articles was limited to the years 2021-2024. 2021 was chosen as the beginning of the period because it was the year when Industry 5.0 began to be discussed. A selection process was then carried out for eligibility using the following inclusion/exclusion criteria: only full-text studies published in English, including research articles, review articles and conference proceedings that present and explore at least one of the two main themes of the study.

The fact that work occurring in databases without full access is not included should be considered as one of the research limitations.

Finally, a consolidated list of the remaining articles (220) was downloaded and saved to a file on the researcher's laptop for convenient access later (database status 26.01.2025). The documents retrieved from the Scopus and Web of Sciencie databases were collated in Excel baize and duplicates were removed manually.

Articles relating to resilience in agriculture, energy or areas of activity other than industry, or that did not reflect the main objective of the study, were also excluded. The hypothesis was accepted that the authors more often took up the issue of resistance analyzed in terms of technological solutions in their works. Finally, 69 papers were accepted for analysis and read against the research assumptions.

Next: graphical analyses were performed using VOSviewer No. 1.6.20.0, which is a software tool widely used to construct bibliometric studies and network analysis (Bajaj et al., 2022; Hanaa, Abdul, 2023). The category of analysis by keyword, visualisation by year, was used to evaluate and characterise the papers. The above categories helped the author to gain a deeper understanding of key variables in a structured way to uncover gaps in qualitative research. The maps work by categorising the field into distinct research clusters that illustrate keywords as points on a map. The spatial arrangement of these points - how close or far away they are - reflects the frequency with which related concepts are discussed in the literature. Points that are clustered close together suggest a large amount of published literature on these topics, while points that are more dispersed indicate areas with less scientific focus. Conceptual structure maps are particularly useful for detecting citations associated with specific keywords, which can help identify emerging research trends (Cobo et al., 2011).

4. Contextualised study of resilience

When starting the analysis of the papers, it was assumed that they would be reviewed in terms of the authors' take on the phrase 'resilience in Indusrty 5.0'. The following definition of resilience was adopted for comparison and analysis: the ability and capacity of an enterprise to return to its state after a disruption. From reading the papers, there were several areas with which the analysed phrase was linked.

In the 69 papers reviewed in detail (appendix 1), the authors emphasise that resilience is one of the three key pillars of Industry 5.0, alongside sustainability and human-centric.

In most of the papers analysed, 'resilience' is defined as the ability of a system to adapt and continue to operate effectively in the face of disruption. It can therefore be concluded that, in the most general terms, the authors adopt the definition of resilience proposed by the European Commission (see Aldea et al., 2021).

A similar definition is presented in the context of manufacturing systems, within which two areas of resilience use have been identified: supply chains and risk. Resilience refers to the design of resilient systems that incorporate strategic redundancy and flexibility so that they can adapt to various unforeseen factors, such as supply chain disruptions, changes in market demand or natural disasters (Agote-Garrido et al., 2023).

Alves, Lima, Gaspar (2023), Mourtzis et al. (2022 a) define 'resilience' as a key element in the context of Industry 5.0, which involves creating more resilient and sustainable production systems. The definitions cited are general in nature. In most of the papers, the authors combine the three components of Industry 5.0 capturing sustainability, human-centric and resilience together.

The concept of 'resilience' occupies a central place in the context of industrial transformation, (Johansen, Akay, 2022; Hunkova, Haviernikova, 2024). In this area, authors define 'resilience' in a variety of ways, including technological, organisational and social aspects. This allowed us to obtain answers to research questions 1 and 2.

This observation when reading the texts led to the formulation of an additional research question: do the phrases 'sustainability', 'human-centric' and 'resilience' have equivalent meanings, or does one of them override the others?

The term 'resilience' is often treated in close association with 'sustainability' and 'human-centricity' so it is difficult to clearly demarcate. This is particularly evident in works referring to the pandemic as a crisis (Romero, Stahre, 2021; Ahmed et al., 2023). As a result of the COVID19 pandemic, companies had to transform their business models. But not only that.

The articles show that the meaning of the words and their overarching nature depends on the context of the analysis. In works describing the transition from Industry 4.0 to Industry 5.0, the authors emphasise that the triad of relationships: human-centric, resilient and sustainability forms the basis of the Industry 5.0 concept (Grabowska, Saniuk, Gajdzik, 2022), treated equally.

Resilience is a key element of Industry 5.0, while at the same time it is the future of action not only for industry.

A different way of presenting the phrase 'resilience in Industry 5.0' refers to the presentation of 'resilience' as a 'sub-element' resulting in 'improvements' that translate into the environment or humans.

However, it similarly covers areas such as sustainability and human-centric. This points to a complex interaction between technological efficiency and social and environmental needs. It is resilience that is the connecting element, welding together the activities that translate into the other two pillars of Industry 5.0. It can be said that it 'fills', 'enriches' production activities. Mostly involuntarily because if something functions without errors little attention is paid to resilience. Perception changes in the event of disruptions, crises. Then the aim is to regain the agility of the production system and 'resilience' is in focus.

Central to this is respecting core values in the design of technologies to ensure that technologies serve people and improve social and environmental well-being (Agote-Garrido et al., 2023; Romero, Stahre, 2021). This approach points to a broader definitional context but still connects with the main pillars of the concept.

In the context of **sustainability**, the authors (Kour et al., 2024) indicate that resilience is supposed to lead to sustainable performance. After disruptions, production systems are supposed to maintain profitability and not have a negative impact on the environment.

At the same time, actions are identified to ensure 'resilience'. These include, for example, technology integration (Agote-Garrido et al., 2023), socio-technical design of production systems (Kour et al., 2024), cybersecurity challenges (Kour et al., 2024).

It should be noted that implementing sustainability in a company does not depend on 'resilience' alone. It requires extensive collaboration between multiple stakeholders'. The authors' work focuses on the mutual benefits of the synergies between sustainability and ensuring industry resilience (Chavez, 2022; Abuhasel, 2023; Ismail et al., 2024).

Human-centric as a pillar of Industry 5.0 aims to put people back at the centre by leveraging advances in digital technologies. Integrating resilience and human-centricity in Industry 5.0 involves creating systems that are not only efficient and sustainable, but also adapt to human needs and are able to withstand disruption.

The combination of 'resilience' and 'human-centric' is a key element of the new industrial paradigm. Industry 5.0 emphasises the integration of innovative technologies with the active participation of people, which means that production not only needs to be digitised, but also resilient, sustainable and human-centred. This strengthens not only the resilience of production systems to disruption, but also influences sustainability and social well-being (Alves et al., 2023). Again, despite the foregrounding of the 'human-cenrtica' this time, resilience has a servant function.

A resilient approach within Internet of Things (IoT) - based manufacturing strategies is crucial to maintain the continuity of manufacturing operations and the supply chain, especially in the face of global crises. The use of human-robot collaboration in assembly lines aims to increase productivity, which at the same time leads to better employee wellbeing (Nourmohammadi et al., 2022). The aforementioned authors also point to several areas specific to building resilience. Industry 5.0 proposes that employment structures and digital strategies should be tailored to people, highlighting the importance of human involvement in production processes (Leirmo, 2024; Leng et al., 2022). Data security is also important (Andres et al., 2024).

Resilience is also considered from the side of competence, skills, human adaptation to use, use of elements of the production system (Alves et al., 2023).

A trend towards **collaboration** can also be seen in the work. Resilience in Industry 5.0 not only strives for efficiency and productivity in production systems, but also strengthens the role of workers, all the while respecting global production constraints (Abdous et al., 2023). In this context, resilience is defined as the ability to develop innovative technologies and workplaces in a human-centred way. This is to enable the creation of an effective and safe working environment and also a robust collaboration between humans and machines (Barata, Kayser, 2024). Resilience is also described as a key element that strengthens these production systems so that they can respond effectively to unexpected problems and adapt to changing conditions over the long term (Afzal, Li, Hernández-Lara, 2024).

Contemporary approaches to resilience integrate human and technological aspects to lead to better management of operational systems and improved quality of life for workers. The use of assistive technology systems such as collaborative robots (cobots) and exoskeletons is mentioned, which aim to optimise production processes, ergonomics, taking into account the diversity of the workforce (Grosse, 2023).

In the context of human-robot collaboration in industry, ethical approaches are also being considered to create a well-structured framework to govern future practices (Callari et al., 2024). Ethical approaches must not only cover the operational aspects of collaboration in the factory environment, but also be guided by more broad principles of organisational and social governance, resulting in a more responsible integration of advanced robotics into the professional environment (Camarinha-Matos et al., 2024; Callari et al., 2024; Gródek-Szostak et al., 2023; Kehrbusch et al., 2023).

Related to collaboration is **technology integration** referring to the ability of technological systems to maintain functionality and continue production.

The articles analyse different resilience strategies that take into account the integration of modern technologies such as artificial intelligence, digital twins and blockchain (Leng et al., 2022). The authors point out that blockchain technology can help eliminate the risk of a single failure in the context of resilient manufacturing systems by decentralising IIoT (Industrial Internet of Things) data management.

Nourmohammadi et al. (2022) present digital twins that can support resilience in the manufacturing industry through real-time data collection and analysis. This enables faster decision-making in the face of disruption. The use of adaptive technologies, improves the quality of final products (Lerimo, 2024). With intelligent sensors and devices that collect realtime data, organisations can identify problems, minimise downtime and optimise resource utilisation (Lerimo, 2024).

An important solution highlighted by Domenteanu, Cibu, Delcea (2024) is predictive maintenance systems that monitor the condition of machines and predict failures before they occur, leading to less downtime and increased operational efficiency. This is an example of building resilience within a production system.

Adaptability is linked to the new technological solutions being introduced. In the adaptation perspective, resilience is presented as a key aspect needed to adapt and survive in a changing industrial environment (Camarinha-Matos, Rocha, Graça, 2024).

In detail, the term 'reilience' is replaced by 'transformative resilience', which describes systems that not only defend themselves against disruptions, but also reorganise, reconfigure, restructure and even reinvent themselves in response to these disruptions (Camarinha-Matos, Rocha, Graça, 2024).

In terms of adaptation, resilience is seen as the ability to anticipate and respond quickly to operational disruptions that may threaten the value of the business. For example, in relation to information systems, resilience is a function of an organisation's overall situational awareness of information systems gap management and the adaptability, risk intelligence, flexibility and agility of information systems in a complex, dynamic and connected environment (Aldea et al., 2021).

The integration of advanced technologies and the increasing complexity of modern production systems introduces new challenges, such as the risk of cascading failures. Therefore, identifying effective resilience strategies becomes crucial to maintain system integrity, minimise downtime and improve product and process quality (Watcher et al., 2024). Many works do not have a consistent line of analysis of 'resilience in Industry 5.0'. Multifaceted, multi-tracking is a feature of building resilience in different areas of the production system.

The most common work found in the literature describes resilience in the context of **supply chains** as the ability to respond and recover effectively from unexpected disruptions. It consists of two key elements: 'vulnerabilities' and 'capabilities'. Vulnerabilities refer to factors that increase an organisation's vulnerability to unpredictable disruptions, while capabilities refer to characteristics that allow organisations to anticipate, mitigate and recover from such disruptions (Dacre et al., 2024). Maintaining data integrity and enabling decentralised decision-making whether in the previously mentioned supply chains or cyber security are other areas where 'building resilience' is indicated (Fraga-Lamas et al., 2024; Radid et al., 2024). Supply chains are an area identified in European Commission documents, but resilience is important for companies to meet increasing demands and changing market conditions (Ahmed et al., 2023; Isamil et al., 2024).

Risk in the definition of 'resilience' is important for business continuity in the face of disruption, as pointed out by Atif (2023). Risks are already associated with the industrial transformation itself, especially in the context of the transition from Industry 4.0 to Industry 5.0. Identifying risks is a key element in assessing manufacturing innovation. A study by Ghobakhloo et al. (2024) presents a multi-criteria decision-making approach that uses fuzzy set theory, integrating different criteria to assess innovation.

Callari, Vecellio Segate, Hubbard, Daly, Lohse (2024) point to the challenges of skills gaps, that require collaboration between employers, employees and educational institutions to ensure the development of appropriate skills, which can also affect risk in production processes (Callari et al., 2024; Gartner et al., 2023).

In each of the contexts analysed, resilience appears in combination whether with the other pillars of Industry 5.0 or in the context of the areas to which adaptation applies. Such thematic diversity points to the need to harmonise and build on the concept of resilience in industry.

This is supported, for example, by the focus of 'resilience' on short-term and long-term functionality, where short-term refers to the ability to return to normal operating conditions after short-term consequences and long-term is defined as the ability to continuously adapt in response to long-term disruptions (Saniuk, Grabowska, Straka, 2022; Aldea et al., 2021).

"Resilience" in the context of Industry 5.0 is a complex concept that requires the integration of many elements. Examples include work on failure management, which points to the need to identify effective resilience strategies to maintain system integrity and minimise production downtime (Wachter et al., 2024). One can also find work pointing to building stakeholder value (Dacre, 2024; Castagnoli, 2024).

Rejeb points out that all systems (social, economic, economic, environmental) must in resileince avoid (anticipation), withstand (absorption), adapt (reconfiguration) and recover (restoration) in response to anticipated and unanticipated disruptions (Rejeb et al., 2024).

The work highlights the need for effective measurement methods to enable companies to determine their current level of resilience maturity and identify areas for improvement.

5. Network analysis of publication

After qualitative analysis of the papers using the VOSviwer programme, a keyword map was generated based on bibliometric data from the Web of Science and Scopus databases. The analysis included scientific papers published between 2021 and 2024 on Industry 5.0 and resilience topics. The aim of the analysis was to identify the main research themes and their interrelationships (Table 1).

Table 1.
Clustering keywords

Keyword	Occurrences	Total link strength
Industry 5.0	54	105
Industry 4.0	22	59
Sustainability	17	56
Resilience	15	49
Human-centricity	6	25
Human-centric	6	17
Society 5.0	5	17
Digital transformation	4	13
Human factors	4	12
Artificial intelligence	5	10
Digital twin	4	10
Digitalization	3	10
Resilient	4	10
Human-robot collaboration	4	9
Operator 5.0	3	8
Sustainable development	3	8
Digitalization	3	7
Ergonomics	3	7
Manufacturing	3	7
Sustainable manufacturing	3	7
Human-centric manufacturing	4	6
Resilient production	3	5
Smart manufacturing	3	3

Source: Authors' elaboration.

The analysis included 516 author keywords with 23 linking words. The map consists of 5 nodes (keywords) and 230 lines (links between keywords). The colours of the nodes represented the different 5 thematic clusters, and the size of the nodes reflects the frequency of the keyword in the articles analysed (fig. 2).

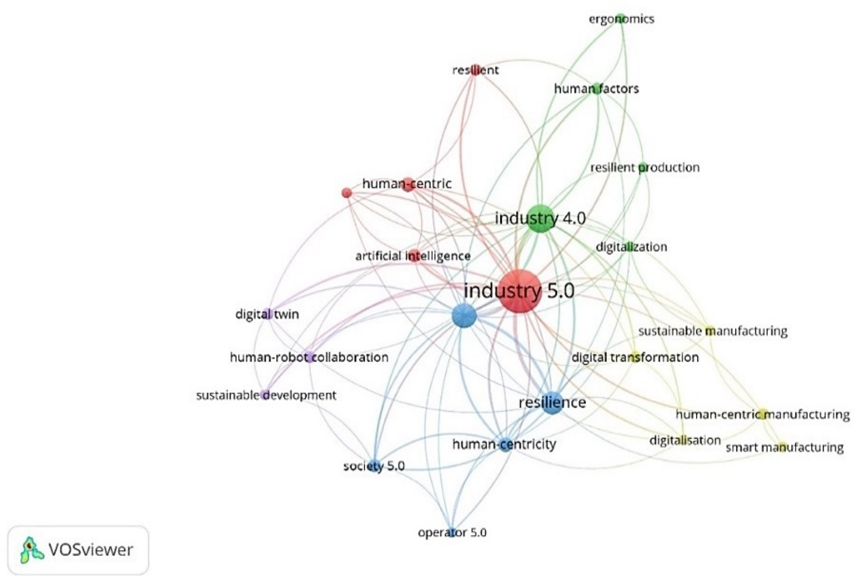

Figure 2. Keyword map.

The map shows the homogeneity of the data analysed. All keywords were clustered around Industry 5.0 forming the largest node of the red cluster. The words are clustered into one large node, which demonstrates the homogeneity and correctness of the selection of papers for analysis.

Red cluster: is a cluster centred around the Industry 5.0 theme, with the largest node indicating the popularity of the issue addressed by the authors. At the same time, it is a central theme that links all keywords with strong links (links: 22, total link strength: 105, occurrences: 54). Total link strength is a measure that indicates the total strength of all links of a node to other nodes in the network. It is the sum of the link strength values between a given node and all other nodes to which it is connected (VOSviewer map and network files - VOSviewer Online Docs). A high value of total link strength 105 suggests that a node is strongly connected to many other nodes, which also indicates its central role in the network. This is confirmed by the presence of links in 54 studies. Despite the central link in red, link sthrength 4 indicates an association with the keyword "resilient". The cluster also includes the words artificial intelligence, human-centric, manufacturing.

This cluster can be characterised as grouping publications on the directional principles of the Industry 5.0 concept, which connects through lines and links to the other clusters.

Green cluster: brings together themes relating to Indusrty 4.0, digitisation, ergonomics, human factors, resilient production. Total link strength in the green cluster was 59, occurrences 22, which also indicates a strong link with other nodes.

Blue cluster: contains two dominant nodes: "sustainability" and "resilience". The theme of 'sustainability' is very popular among authors. This is confirmed by the total link strength of the value 56. Similar link strengths and connects the theme of 'sustainability' with 'human-centricity', operator 5.0, resilience, sociality 5.0.

Yellow cluster: concerned digitisation. It was formed by the nodes 'digital transformation, digitisation, human-centric manufacturing, smart manufacturing, sustainable manufacturing'. It has a stronger link to the Industry 5.0 call and its location - more distant - indicates a focus on themes that will dominate the future.

Purple cluster: centred around human-robot collaboration. It is formed by digital twin, sustainable development. Connected is total link sthrehgh 9, occurrences 4.

The words 'resilience' included in the blue cluster, 'resilient' in the red cluster and 'resilient production' in the green cluster do not account for the difference in meaning in the key word. Assigning them to different clusters despite their similarity in meaning is due to the strength of the combination with other words and also the time (year) of publication of the work. Also related to this is the framing of the issue of 'resilience' in the context of 'Industry 4.0', where the focus was on other elements of the concept. In the 'Industry 5.0' concept, the keyword is one of the elements describing the concept. In contrast, 'resilience' in the blue cluster is linked by the themes of 'sustainability' and 'human centricity', indicating the need for specific adaptations to the context.

The map vividly reflects the keyword links in the articles analysed in four section of this thesis. The map clearly shows the linkages and attribution to word context. The quantitative analysis confirms the qualitative analysis, from which the linking of the issue of 'resilience' and 'Industry 5.0' to other issues (on the map by keywords) was evident.

Analysis of the keyword map identified the main research areas within 'Industry 5.0' and 'resilience' and their interrelationships. The key themes were advanced technologies 'Industry 5.0, Industry 4.0, sustainability, artifical intelligence, human-centric.

The Overlay Visualisation map indicates that Indusrty 5.0, resilience, and digital transformation in which digital twin and human-centric were the most popular issues in the latest 2024 analysis period (fig. 3).

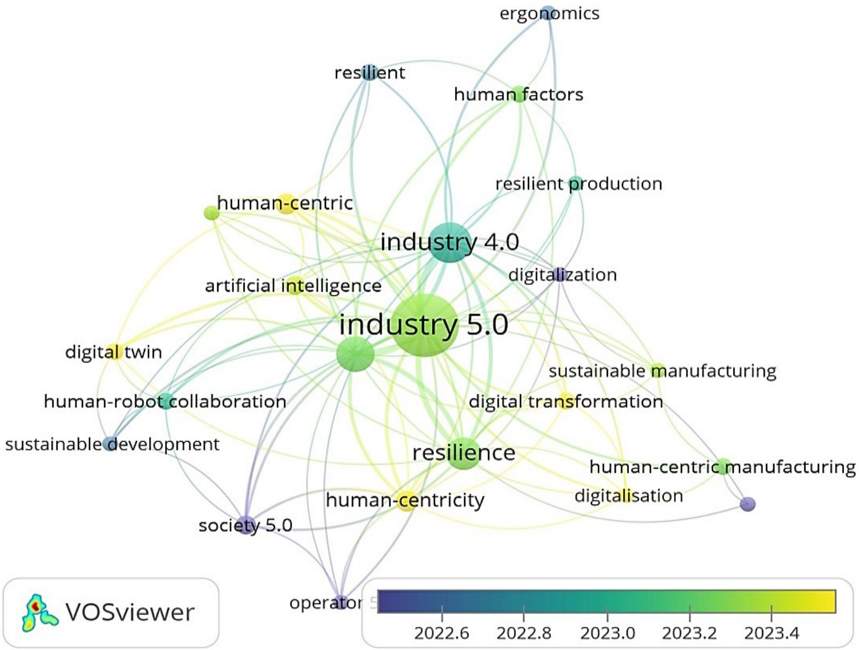

Figure 3. Overlay Visualization.

The keyword map generated in VOSviewer provides valuable information on the structure and dynamics of research in the field of 'resilience and Industry 5.0'. The analysis of the clusters and the links between them allows for a better understanding of the main research themes and their interrelationships. It also made it possible to answer the research question posed: what were the main research trends in the field of Industry 5.0 and resilience between 2021 and 2024?

The dominance of 'Industry 5.0' issues stems from the shift from 'Industry 4.0' analyses to a new concept that places greater emphasis on integrating advanced technologies with human skills and sustainability. The high value of total link strength between these keywords indicates intensive research into how Industry 5.0 technologies can support the resilience of manufacturing systems.

The keyword 'resilience' is linked primarily to the Industry 5.0 theme but also to 'sustainability' and 'human-centricity'. This confirms the exploration of topic that are embedded in the ideas of Industry 5.0.

Sustainability is a key element of Industry 5.0 and research often focuses on how technologies can support green and sustainable manufacturing practices.

The issue of 'sociality 5.0' and 'human-centricity' as areas of adaptation to change is and will continue to be important in the future. "Human-centricity", on the other hand, emphasises the role of humans in production and technological processes, which is key to Industry 5.0. Research often looks at what technologies can be adapted to the needs of humans and how they can support their development.

From the map you can see developments in the area of 'digitalisation' and 'artificial intelligence', The digitalisation of manufacturing processes and the use of artificial intelligence are key future elements of Industry 5.0, with research focusing on how these technologies can support the resilience of manufacturing systems and sustainability. These links suggest that future research will continue to explore these areas. This helped to confirm the authors' hypothesis of a more frequent interest in resilience in technology solutions.

The links between 'resilience' and 'Industry 5.0' are key to understanding how modern technologies can support 'resilience' in industry. Research in these areas is interdisciplinary, linking technology with ecology, risk management and human-centricity. Future research is likely to continue to explore these themes, looking for new ways to integrate advanced technologies into the worker and production.

6. Discussion

Industry 5.0 emphasises human-centricity, sustainability and resilience, building on the digital achievements of Industry 4.0.

Resilience in this context refers to the ability of production systems to withstand and rapidly recover from disruptions such as pandemics, energy crises and supply chain problems.

The multifaceted approach locates 'resilience in Industry 5.0' as one of the pillars, which intersect with descriptions indicating adaptations targeting one selected pillar, e.g. human-cenrtic. This allowed the question of defining 'resilience' to be answered. Definitions of resilience vary depending on the research perspective. Resilience in Industry 5.0 is a focus on creating a more sustainable, human-centred and adaptable industrial environment. The analysis shows that resilience is defined in terms of specific areas such as sustainability, human-centric, technology integration, adaptation and human-machine collaboration.

According to Cortés-Leal, Cárdenas, Del-Valle-Soto (2022), areas where resilience is relevant include, but are not limited to: production processes, risk management and people-resource connections. Increasingly, however, resilience is related to various aspects of an organisation, including its culture, leadership effectiveness and innovation skills.

In the literature, we also increasingly find work on 'resilience' framed, e.g. in the context of sustainibility relating not only to industry but to agriculture, urban planning (Kumareswaran, Jayasinghe, 2023).

Attention is also given to policy and planning for sustainable development goals (Roostaie et al., 2021; Roostaie et al., 2019; Keenan et al., 2021; Erp et al., 2024; Marlow et al., 2023).

In the context of the increasing importance of technology in responding to disruption, the literature highlights the importance of using advanced technological solutions as a key element in building resilience in the new industry.

Key research trends in Industry 5.0 and resilience in 2021-2024 include an interest in adaptive resilience, the integration of modern technologies with the pursuit of sustainability and human-machine collaboration. The literature highlights the need for an ethical framework for collaborating with robots and the challenges of skills gaps, which is essential for effective response to disruption. All research trends link to the concept of Industry 5.0.

"Resilience in Industry 5.0" is presented in a holistic approach. The multiple, diverse, complex, interpretations cause difficulties in analysing and evaluating the works.

The key role of resilience in the context of Industry 5.0 focuses on the industry's ability to adapt to changing conditions. Transformation, however, is more sustainable and human-centred (Wan, Leirmo, 2023; Kulkarni, Patil, 2024; Lu, 2022).

Central to the vision of a resilient industry is the inclusion of human input in manufacturing processes. The integration of human-robot collaboration patterns aims not only to improve efficiency, but also to free workers from monotonous, routine activities, which can ultimately increase the value that humans bring to industry (Davim, 2025).

As a result, the discussion on resilience in Industry 5.0 not only focuses on the technological aspects, but also on the integration of people. The whole thing, according to the European Commission, is to contribute to building sustainability.

7. Conclusion

The European Commission's Industrial Strategy for Europe presents a comprehensive vision for the future of European industry, emphasising the importance of digitalisation, innovation and sustainability. Industry 5.0 differs from Industry 4.0, which focused on automation and digitisation of processes, on the integration of human skills with advanced technologies. Industry 5.0 seeks to create a symbiotic relationship between humans and machines.

Industry 5.0 represents a transformational vision for the future of European industry. By seizing the opportunities offered by Industry 5.0, Europe can become a role model and shape a better future for future generations.

The concept of 'resilience in Industry 5.0' exhibits a multifaceted nature, encompassing technological as well as human and environmental dimensions. Faced with the increasing challenges of dynamic market changes and crises, integrating advanced technologies with human skills becomes crucial. Industry 5.0 focuses on sustainability, human-centric, functional and safety, which emphasises the need for adaptation and continuous learning in the working environment.

A systematic literature review presents a comprehensive approach to exploring the concept of resilience, especially in the context of a new industrial philosophy such as Industry 5.0. The definition of resilience is ambiguous. This variation makes it difficult to understand the key elements of building resilience, in this rapidly evolving industrial context.

The need to integrate technology with human skills and to adapt to rapidly changing market, environmental conditions was identified. This is important in the context of future research directions on digitalisation.

Ultimately, further exploration of resilience issues is needed. The interaction between technology and humans may prove to be the foundation of a future, more resilient and sustainable economy. This also requires promoting sustainable practices, innovative approaches and building partnerships that will benefit not only businesses but society as a whole in the long term. These transformations, while complex, represent an opportunity to create a better future for an industry that is responsible for shaping people's everyday lives.

Research limitations are related to a gap in research. There is a lack of standardised resilience solutions and a comprehensive framework to guide the integration of resilience in Industry 5.0. This is because research in the field of 'resilience' and 'Industry 5.0' is still at an early stage. It is difficult to identify directional syntheses from the studies analysed. The literature is fragmented across disciplines and methodologically rigorous quantitative, qualitative research is lacking.

The ambiguity of the definition and scope of Industry 5.0, as well as the limited understanding of its technological components, results in a lack of uniform consensus on the issue of 'resilience'. In the case of the present work, it is important to point out the methodological limitation associated with the use of open access articles. There are quite a few papers in databases where access is limited.

It should be noted that the issues addressed focus on theoretical approaches, while the few empirical works are limited to the analysis of case studies in the technological field.

The concept of Industry 5.0 encourages authors to undertake considerations within three pillars: human-centric, sustainability and resilience, which can introduce errors in the focus of research and its categorisation into the appropriate thematic group. Potential errors may arise from the emphasis on anthropocentricity, sustainability and resilience pillar.

Practical implications: The limitations identified may contribute to further work. The discussion may focus on the practical application of the research results.

Companies operating in the EU under the Indusrty 5.0 concept face new challenges and opportunities. However, the implementation of Industry 5.0 technology requires investment in employee training, digital infrastructure. Subsequently, there is a need to ensure compliance with regulations in the environmental area.

Practical implications relate to promoting the theme of resilience when implementing technological solutions, building human-machine interaction. This is in line with the framework of the European Industrial Strategy.

Suggestions for the future: the authors often suggest directions for future research that can develop or complement their findings. Exploring the issue of resilience, is essential to fully exploit the potential of Industry 5.0. Production systems need to be flexible, but also resilient to the various challenges posed by modern times.

Resilience has to take into account the economic sphere in addition to the social and sustainability elements. Related to this is the need for cost-effectiveness analyses of investments in innovative solutions, monitoring costs so as to develop the most effective production resilience strategies. The need to develop uniform tools to measure resilience so that the effects of adaptations can be compared.

In summary, the conclusions from the literature review suggest that for companies to operate effectively in the Industry 5.0 era, they need to focus on building flexible, adaptive structures that not only respond to change, but also re-engineer and improve their processes. Further research in this area will be key to understanding and developing the full concept of resilience in Industry 5.0 and its application in practice.

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Appendix 1

Analysis of the phrase "resilience in Indusrty 5.0" by most common areas

Areas linking to "resilience"	Authors papers
Sustainability	Abdous et al. (2023), Afzal et al. (2024), Agote-Garrido et al. (2023), Ahmed et al. (2023), Aldea et al. (2021), Alves et al. (2023), Andres et al. (2024), Atif (2023), Babkin et al. (2022), Barata, Kayser, (2024), Battini et al. (2022), Borchardt et al. (2022), Callari et al. (2024), Camarinha-Matos et al. (2024), Camarinha-Matos et al. (2024), Camarinha-Matos et al. (2024), Castagnoli et al. (2024), Chabane et al. (2023), Chavez et al. (2022), Chavez et al. (2022), Cortés et al. (2022), Dacre et al. (2024), Domenteanu et al. (2024), Erp et al. (2024), Fraga-Lamas et al. (2024), Gal et al. (2024), Ghobakhloo et al. (2024), Grabowska et al. (2022), Gródek-Szostak et al. (2023), Hansen et al. (2024), Ismail et al. (2024), Kehrbusch, Engels, (2023), Kour et al. (2024), Lei et al. (2024), Leirmo (2024), Mourtzis et al. (2022), Nourmohammadi et al. (2022), Omrany et al. (2024), Patalas-Maliszewska, Łosyk, (2024), Rahmani et al. (2024), Rejeb et al. (2024), Säfsten et al. (2022), Saniuk et al. (2022), Sindhwani et al. (2022), Suciu et al. (2023), Verdugo-Cedeno et al. (2024), Vyhmeister, Castane (2024), Wan, Leirmo (2023), Yang et al. (2022), Yitmen et al. (2023), Zeb et al. (2024).
Human-centric	Abdous et al. (2023), Abuhasel (2023), Afzal et al. (2024), Agote-Garrido et al. (2023), Ahmed et al. (2023), Aldea et al. (2021), Alves et al. (2023), Andres et al. (2024), Atif (2023), Babkin et al. (2022), Babkin et al. (2022), Barata, Kayser (2024), Battini et al. (2022), Berti et al. (2023), Borchardt et al. (2022), Braun et al.(2024), Callari et al.(2024), Camarinha-Matos et al. (2024), Castagnoli et al. (2024), Chabane et al. (2024), Cortés-Leal et al. (2022), Dacre et al. (2024), Domenteanu et al. (2024), Erp et al. (2024), Fraga-Lamas et al. (2024), Gal et al. (2024), Gärtner et al. (2023), Ghobakhloo et al. (2022), Grabowska et al. (2022), Grosse et al. (2023), Gródek-Szostak et al. (2023), Hansen et al. (2024), Hunkova, Haviernikova, (2024), Ismail et al. (2024), Kaasinen et al. (2022), Kehrbusch, Engels (2023), Kour et al. (2024), Lei et al. (2024), Leirmo, (2024), Mourtzis, Angelopoulos, (2023), Mourtzis et al. (2022), Nourmohammadi et al. (2022), Patalas-Maliszewska, Łosyk (2024), Rahmani et al. (2024), Rejeb et al. (2024), Romero, Stahre (2021), Sbaragli et al. (2024), Suciu et al. (2023), Villar et al. (2023), Vyhmeister, Castane (2024), Wan, Leirmo (2023), Yang et al. (2022), Yitmen et al. (2023), Zeb et al. (2024).
Collaboration human-machine	Alves et al. (2023), Babkin et al. (2022), Barata, Kayser, (2024), Battini et al.(2022), Borchardt et al. (2022), Braun et al. (2024), Callari et al. (2024), Camarinha-Matos et al. (2024), Castagnoli et al. (2024), Domenteanu et al. (2024), Golovianko et al. (2022), Grosse et al. (2023), Gródek-Szostak et al. (2023), Hansen et al. (2024), Hunkova, Haviernikova, (2024), Ismail et al. (2024), Kaasinen et al. (2022), Kour et al. (2024), Leng et al. (2022), Mazzoleni (2024), Mourtzis, Angelopoulos (2022), Nourmohammadi et al. (2022), Rahmani et al. (2024), Rejeb et al. (2024), Romero, Stahre (2021), Säfsten et al. (2022), Sbaragli et al. (2024), Sindhwani et al. (2022), Slavic et al. (2024), Sunmola, Baryannis, (2024), Terziyan et al. (2024), Toth et al. (2024), Villar et al. (2023), (2024), Wachter et al. (2024), Wan, Leirmo, (2023), Yang et al. (2022).
Technology Integration	Abuhasel (2023), Afzal et al. (2024), Agote-Garrido et al. (2023), Aldea et al. (2021), Andres et al. (2024), Atif S. (2023), Babkin et al. (2022), Barata, Kayser, (2024), Berti et al. (2023), Cortés-Leal et al. (2022), Dacre et al. (2024), Erp et al. (2024), Gärtner et al. (2023), Golovianko et al. (2022), Grosse et al. (2023), Hansen et al. (2024), Hunkova, Haviernikova, (2024), Ismail et al. (2024), Johansen, Akay (2022), Kaasinen et al. (2022), Kehrbusch, Engels (2023), Kour et al. (2024), Lei et al. (2024), Leirmo (2024), Leng et al. (2022), Mazzoleni (2024), Mourtzis, Angelopoulos, (2022), Nourmohammadi et al. (2022), Omrany et al. (2024), Patalas-Maliszewska, Łosyk (2024), Rahmani, Jesus, Lopes, (2024), Rejeb et al. (2024), Romero, Stahre (2021), Säfsten et al. (2022), Saniuk et al. (2022), Sbaragli et al. (2024), Seo et al. (2024), Sindhwani et al. (2022), Slavic et al. (2024), Suciu et al. (2023), Terziyan et al. (2024), Verdugo-Cedeno et al. (2024), Villar et al. (2023), Vyhmeister, Castane, (2024), Wachter et al. (2024), Wan, Leirmo, (2023), Yitmen et al. (2023), Zeb et al. (2024).

Ability to adapt	Abuhasel (2023), Ahmed et al. (2023), Andres et al. (2024), Atif (2023), Babkin et al. (2022), Battini et al. (2022), Berti et al. (2023), Braun et al. (2024), Callari et al. (2024), Castagnoli et al. (2024), Chabane et al. (2023), Cortés-Leal et al. (2022), Dacre et al. (2024), Erp et al. (2024), Gal et al. (2024), Gärtner et al. (2023), Golovianko et al. (2022), Grabowska et al. (2022), Grosse et al. (2023), Gródek-Szostak et al. (2023), Hansen et al. (2024), Hunkova, Haviernikova (2024), Ismail et al. (2024), Johansen, Akay (2022), Kaasinen et al. (2022), Kehrbusch, Engels (2023), Kour et al. (2024), Mourtzis, Angelopoulos, (2023), Nourmohammadi et al. (2022), Omrany et al. (2024), Patalas-Maliszewska, Łosyk, (2024), Rahmani et al. (2024), Rejeb et al. (2024), Romero D.; Stahre J. (2021), Säfsten et al. (2022), Saniuk et al. (2022), Sbaragli et al. (2024), Seo et al. (2024), Sindhwani et al. (2022),(2022), Slavic et al. (2024), Suciu et al. (2023), Sunmola, Baryannis (2024), Terziyan et al. (2024), Toth et al. (2023), Verdugo-Cede?o et al. (2024), Villar et al. (2023), Vyhmeister, Castane, (2024), Wachter et al. (2024), Wan, Leirmo, (2023), Yang et al. (2022), Yitmen et al. (2023), Zeb et al. (2024).
Supply chain flexibility	Ahmed et al. (2023), Andres et al. (2024), Barata, Kayser (2024), Camarinha-Matos et al. (2024), Chavez et al. (2022), Cortés-Leal et al. (2022), Dacre et al. (2024), Fraga-Lamas et al. (2024), Ismail et al. (2024), Patalas-Maliszewska, Łosyk (2024), Säfsten et al. (2022), Saniuk et al. (2022), Villar et al. (2023).
Risk management	Aldea et al. (2021), Borchardt et al. (2022), Chabane et al. (2023), Cortés-Leal et al. (2022), Ismail et al. (2024), Sunmola, Baryannis (2024).

Source: Authors' elaboration.