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Systematic Review

Changes in Sustainable Development in Manufacturing in Cases of Unexpected Occurrences—A Systematic Review

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Abstract: Nowadays, managers are facing the challenge of operating in situations of high uncertainty: delayed deliveries, lack of energy or rising energy and gas costs, the need to replace energy sources, and changing supply and sales markets. In the literature, two dominant trends in the activities of enterprises in the face of crises can be distinguished: (I) changes in supply chain management (increased flexibility by searching for local suppliers); and (II) transition to digital production and investment in technologies in the concept of Industry 4.0 or even Industry 5.0, such as artificial intelligence, 3D printing, robots, cyber-physical systems, digital manufacturing, and blockchain. A gap in the research has been observed in examining the impacts of these actions on the implementation of sustainable solutions and designating organizational changes in manufacturing. The main goal of this study is to review the literature using the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) for data collection and, secondly, the methodology of Systematic Literature Review (SLR) and Mapping in Literature Reviews (MLR). Our literature review of the selected databases is based on 566 published articles in 2020–2022. The achieved results indicate the main organizational changes in the context of sustainable development in manufacturing, namely in the business management area (adopting Sustainable Project Management (SPM), Sustainable Supply Chain Management practices, Sustainable Supplier Selection (SSS), and Resilient Manufacturing Strategy (RMS)) and in the production area (adopting Internet of Things (IoT)-enabled Additive Manufacturing assists, simulation software, and Life Cycle Assessment. The findings of our study revealed key relationships between the adoption of fifth-generation industrial technologies and the sustainable development of manufacturing.

Keywords: sustainable development of manufacturing; unexpected occurrence; technologies according to the concept of Industry 5.0; systematic review

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1. Introduction

Unexpected occurrences from the last five years, e.g., the deterioration of US–China relations, Brexit, COVID-19, and, nowadays, the current wars in Ukraine and Israel and the tense situation between China and Taiwan, are forcing managers to have solutions that will guarantee the stable functioning of the company in such a difficult-to-predict reality. In such an unexpected environment, the implementation of Sustainable Development Goals (SDGs) may be a huge challenge for companies. SDGs are the basis for the 2030 Agenda for Sustainable Development, and they can be defined as "an urgent call for action by all countries-developed and developing-in a global partnership" [1] and as an 'indivisible whole'—a system of interlinked goals that can only be achieved together [2]. Managers are now facing the challenge of operating in situations of high uncertainty: delayed deliveries, lack of energy or rising energy and gas costs, the need to replace energy sources, and changing supply and sales markets. Moreover, they are struggling to align their activities with SDGs, in particular in terms of sustainable production [3].

Therefore, an important part of the changes to the business model is to identify the relationship between sustainability and the company's performance. Research findings presented in [4] indicate that both innovative solutions and green technologies have an impact on sustainable performance. Implementing innovation requires improvements in both products and business processes [5]. The authors of [6] indicated that the association between environmental safety and corporate strategy has been seen as a trade-off between green practices and productivity performance. Companies should therefore strive for a sustainable business that uses and continuously improves green innovation, green intellectual capital, and green supply chain management practices [7]. Organizations should therefore formulate and integrate environmental challenges across sub-business functions, including production, finance, marketing, human resource management, and the supply chain. [8]. The implications of environmental challenges in business operations will allow for financial growth and the reverse of ecological devastation [9,10].

In the literature [11–13], two dominant trends in the activities of enterprises in the face of crises can be distinguished: (I) changes in supply chain management (increased flexibility by searching for local suppliers); and (II) transition to digital production and investment in technologies in the concept of Industry 5.0, such as artificial intelligence, 3D printing, robots, cyber-physical systems, digital manufacturing, and blockchain.

Digital technologies have revolutionized manufacturing and allowed it to move to the next stage of the industrial revolution, which is Industry 5.0. The new era is the integration of manufacturing and digitization through the use of new technologies, the implementation of which in industry will increase production and deliver products faster [14]. An important aspect of Industry 5.0 is its integrity with the concept of sustainability, where worker well-being and respect for the environment are at the center of the production process [15]. Industry 5.0 is therefore strongly linked to digital manufacturing, which aims to improve manufacturing processes, supply chains, products, and services by applying digital information from multiple sources [16]. The paradigm of digital manufacturing is the strong integration of systems and technologies in the enterprise, including blockchain, cyber-physical systems (CPSs), and artificial intelligence (AI). Blockchain technology is presented as "essentially a distributed database architecture based on cryptographically linked blocks of information containing consensus-checked datasets" [17]. In addition, the implementation of blockchain technology allows for an increase in data's integrity, privacy, and openness, thus bringing benefits to businesses of all sizes [18]. This aspect is particularly relevant in the era of ubiquitous technology, cyber-physical systems (CPSs), or hardware–software systems (CPSs), which allow the virtual world to be closely connected to the physical world [19]. AI, in turn, is a promising technology in terms of improving industrial systems productivity, reliability, and speed of response, which has taken on new importance in the era of the COVID-19 pandemic [20]. AI is a field that embraces a wide variety of methods, including Machine Learning (ML) algorithms, Natural Language Processing, speech recognition, expert systems, and image/video recognition.

The application of technology in Industry 5.0 based on a constant flow of information provides an increase in opportunities for process efficiency as well as improved products already at the design stage. Therefore, it seems reasonable to review the literature to examine the impacts of these actions on the implementation of sustainable solutions and designating organizational changes in manufacturing. Filtering and then analyzing the related literature allows us to reveal any inconsistencies and contradictions in previous scientific achievements.

As mentioned above and in [21–23], the existing literature lacks a systematic literature review study regarding the motivations in manufacturing for the implementation of sustainable solutions when investments in new technologies according to Industry 5.0 are carried out. In response to these research gaps, this study identifies the main organizational changes in the context of sustainable development that have an impact on increasing the level of sustainable development in manufacturing. Therefore, the following research questions (RQs) are formulated:

- RQ1: What are the key variables that describe sustainable solutions?
- RQ2: What are the motivations for implementing solutions affecting the level of substantiable development in manufacturing companies in cases of unexpected occurrences, based on the example of the COVID-19 pandemic?
- RQ3: What type of new technologies, according to the concept of Industry 5.0, were dominant in publications regarding the impact of the COVID-19 pandemic and the sustainable solutions implemented in manufacturing companies?
- RQ4: When do the main organizational changes in the context of the implementation of new technologies regarding the main variables that describe sustainable solutions occur?
- RQ5: What are the challenges and directions for implementing sustainable solutions in the era of Industry 5.0?

This article follows the principles of the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) and uses the Systematic Literature Review (SLR) and Mapping in Literature Reviews (MLR) methodologies for the systematic review of the existing literature on changes in sustainable development in manufacturing in cases of unexpected occurrences. This systematic review highlights the main organizational changes in the context of sustainable development. Second, the key relationships between the adoption of fifth-generation industrial technologies and the sustainable development of manufacturing are clarified. Third, in this systematic review, we synthesize findings from the analyzed studies to help identify areas where further research is required.

2. Materials and Methods

This literature review uses the PRISMA 2020 guidelines [24] and fulfills the PRISMA Checklist (Supplementary Material). These PRISMA principles reflect current advances in methods of identifying, selecting, evaluating, and synthesizing studies used in the scientific literature.

SLR and MLR were used to analyze the literature. SLR is an independent academic method, the application of which allows the identification and evaluation of all the relevant literature in a given subject area in order to draw conclusions about the issue under consideration. SLR can be treated as the method for collecting and analyzing data in a systematic way [25]. MLR techniques are useful at the very beginning of the literature review as a brainstorming and scoping tool [15]. MLR is broadly used to complement SLR. The use of SLR and MLR allows for better results from the literature review while identifying gaps and areas for further research. This methodology is based on 6 steps (Figure 1) and was followed to minimize risks and biases in the selection of the eligible articles for literature analysis.

Figure 1. SLR and MLR.

An important element of the SLR and MLR methods is the definition of the research objective (research questions), as well as the definition of inclusion and exclusion criteria. The criteria adopted directly indicate what to include in further analyses and what to exclude.

The use of formal SLR and MLR approaches (Figure 1) reduces the distortion caused by an overly restrictive selection of the available literature and increases the reliability of the selected literature [26].

2.1. Research Questions

SD is defined as a combination of social, economic, and environmental aspects in the industrial digital transformation [27]. The concept of SD is therefore based on "the creation of manufactured products that uses processes that minimize negative environmental impacts, conserve energy and natural resources, are safe for employees, communities and consumers, and are economically sound" [28].

SP can be treated as the "creation of discrete manufactured products that in fulfilling their functionality over their entire life cycle cause a manageable number of impacts on the environment (nature and society) while delivering economic and societal value" [29].

Sustainable solutions get broken down into controllable elements within an overall system network: products with their functions and behaviors, material selections, production systems, factories, enterprises, logistic elements, value creation networks, patterns of use behaviors, labor and payroll systems, welfare, health, and so forth [29]. In accordance with the SLR and MLR methods adopted in this study, the research questions posed were specified as follows:

- MLR: RQ1, RQ2, and RQ3;
- SLR: RQ4 and RQ5.

2.2. Criteria

The following inclusion criteria were considered in this paper:

- IC1—The article indicates changes affecting the level of sustainable development in manufacturing companies;

and/or

- IC2—The article indicates organizational solutions affecting the level of sustainable development in manufacturing companies;

and/or

- IC3—The article indicates the impact of the COVID-19 pandemic on manufacturing companies.

The following exclusion criteria were considered in this paper:

- EC1—The article does not indicate changes affecting the level of sustainable development in manufacturing companies;

and/or

- EC2—The article does not indicate organizational solutions affecting the level of sustainable development in manufacturing companies;

and/or

- EC3—The article does not indicate the impact of the COVID-19 pandemic on manufacturing companies.

According to SLR and MLR, this step is based on inclusions and exclusions according to the accepted IC and EC. Selection is carried out in the first step primarily based on the title, abstract, subject headings of databases, and keywords.

2.3. Databases and Queries

The review of articles is based on three scientific databases of publishers:

(1) Science Direct—ELSEVIER.
(2) Wiley Online Library.
(3) Springer.

The Science Direct—ELSEVIER, Wiley Online Library, and Springer databases constitute the most popular credible database sources for peer-reviewed articles. A G-suite tool was used to minimize risk and bias in the data analysis process.

After selecting the databases, we define the search terms. "The queries between the different databases where the researcher searches for results should be the same or equivalent (if not, the results gathered would not be comparable) [30]". The goal is to identify as many different synonyms of partial terms as possible. This article compares content in selected databases based on combinations: “change before COVID-19” or/and “impact of the COVID-19 pandemic” or/and “effect of COVID-19” or/and “consequences of COVID-19” or “COVID-19” or “pandemic COVID-19” and “sustainable production” and/or “sustainable industry” and/or “sustainable manufacturing”.

Once the queries are determined, the search is started in the selected databases. It is recommended to enter each combination separately into the selected databases to obtain a good overview of the number of hits per word.

2.4. Review Phases

I. Typical steps:
- Execute a query in the selected database and search the defined query.
- Remove duplicates in the database search.
- Review by regarding titles and abstracts (applying IC and EC).
- Review the full text and assess quality (also applying IC and EC).
- Include (if necessary) the papers cited in your results and repeat.
- Final result: statistics on the number of articles.

II. Quality assessment checklist:
- Preparation of checklists.
- Evaluation of aspects relevant to SLR in each article based on checklists.
- Set a rating threshold to allow the article to be included or excluded.

III. Write results:
- Separate sections for MLR and SLR.
- In each section, answer research questions.
- Use graphics, charts, and tables to make the results readable.

3. Results

3.1. PRISMA Flow Diagram and Study Characteristics

The flow of information during all phases of the systematic literature review conducted is depicted using a PRISMA flow diagram (Figure 2). The flow diagram presents the number of records identified (Appendix A), included, and excluded, as well as the reasons for exclusions.

3.2. Quantitative Analysis of Publications

Our analysis used a structured process of selecting articles, which allowed us to exclude articles that did not meet the criteria. Two sets of keywords were adopted. The first set of keywords was related to COVID-19 and included combinations such as “change before COVID-19”, “impact of the COVID-19 pandemic”, “effect of COVID-19”, “consequences of COVID-19”, and “COVID-19”. The second set of keywords adopted in the work was related to sustainable production, where combinations such as “sustainable production”, “sustainable industry”, and “sustainable manufacturing” were adopted. For the construction of the initial database, the above combinations were used, and the publication date was set for 2020–2022 in three selected databases. Only publications in journals were analyzed. The initial database created allowed for the selection of 566 works without duplicates in the three selected databases. Identification is the first two steps in the review phases: execute a query and remove duplicates.

As a result of searching according to the accepted combinations, 566 published articles were found in the selected databases in the years 2020–2022. As indicated in Figure 3, the majority of articles in the first phase of the analysis were found in the Springer database (274, 48.41%), followed by Science Direct (213, 37.63%); the fewest articles were found in the Wiley Online Library database (79, 13.96%).

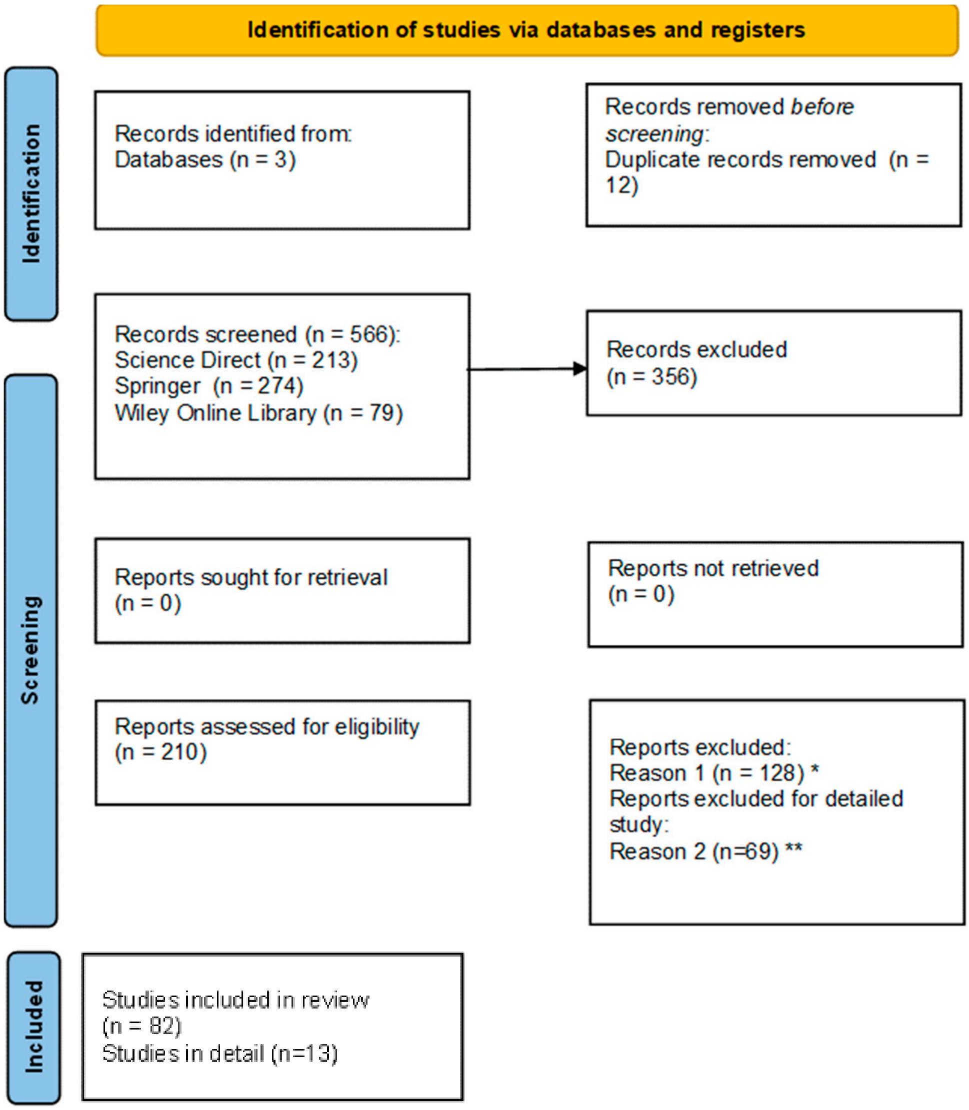

Figure 2. PRISMA flow diagram, where: *—a field of research not included in the scope of the systematic review; **— exclusion on the basis of scores according to the developed checklist.

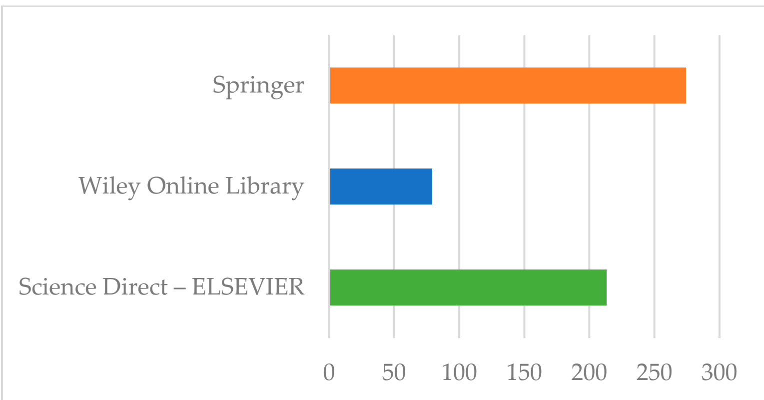

Figure 3. Number of articles in selected databases published between 2020 and 2022.

The analysis covered articles published in journals in 2020–2022. As indicated in Figure 2, the largest number of articles was created in 2022 (312 articles), followed by 2021 (213), and the smallest number in 2020 (41). The results obtained seem justified due to the set of defined combinations, in which the first set focuses on the effects of the COVID-19 pandemic in manufacturing companies, while the second set focuses on the solutions/changes implemented in connection with the pandemic towards sustainable development. In 2020, strict restrictions were in place, and the industry was going through a global crisis. The Polish industry recorded a decline in 2020 for the sold production of industry by 4.8% in March compared to March 2019 and by 7.2% in February compared to February 2019. The crisis affected as many as 16 areas of industry, including the production of cars, trailers and semi-trailers, coal mining, and furniture production. At the end of the first quarter, due to the growing number of COVID-19 cases, the largest automotive companies, including Toyota, Volkswagen, and Fiat, stopped their activities.

The number of publications in the selected databases in 2020–2022 is shown graphically in Figure 4.

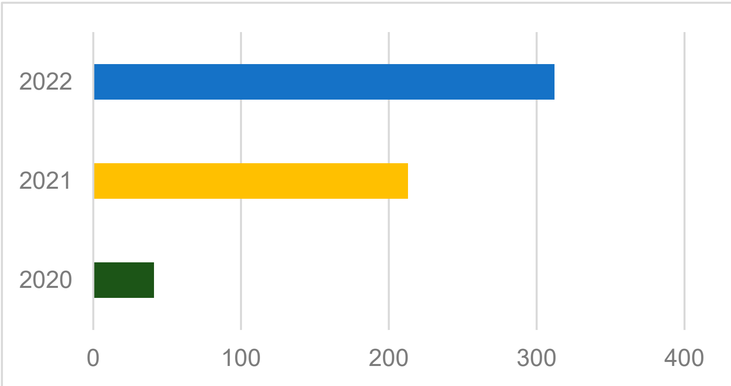

Figure 4. Number of publications in selected databases in 2020–2022.

The next step was to prepare a review by considering titles and abstracts (applying IC and EC; Figure 5). In the next part of the analysis, only. At this stage of the analysis, 484 (85.5%) publications were excluded, which to a large extent concerned publications in areas such as pharmacology, microbiology, or public health.

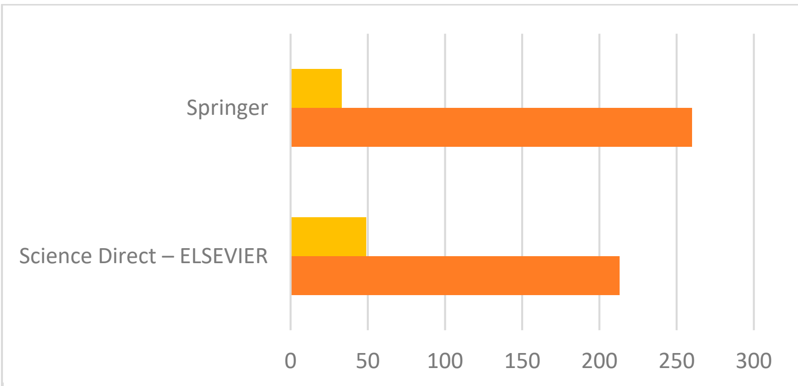

Figure 5. Review of titles and abstracts by using IC and EC in selected databases, where: orange: for all articles indicating the impact of the COVID-19 pandemic on production companies including changes or proposed solutions in the context of sustainable production in the selected databases; yellow: for articles selected scientific databases according to the title and/or abstract.

The total number of articles in the selected scientific databases compliant with title and/or abstract was 82, which is 14.5% of the initial results (Figure 5).

At this stage, the Science Direct database identified 31 journals (Figure 6) in which articles compliant with title and/or abstract were published. The highest number of articles in the Elsevier database was found in *Sustainable Production and Consumption* (12.25%), followed by *Science of The Total Environment* (8.2%), *Computers & Industrial Engineering* (8.2%), and *Journal of Cleaner Production* (8.2%).

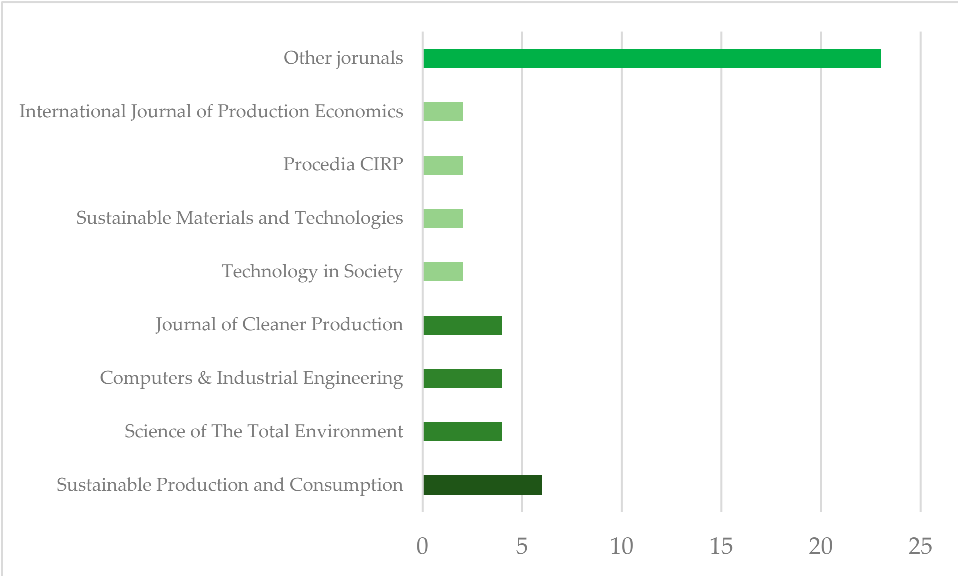

Figure 6. Review of journals in the Science Direct database—compatibility of articles based on title and/or abstract.

In the Springer scientific database, 18 journals (Figure 7) were distinguished in which articles compliant with title and/or abstract were published. The highest number of articles in the Springer database was found in the journals *Operations Management Research* (27.3%), *Environment*, *Development and Sustainability* (15.5%), *and Environmental Science and Pollution Research* (9.1%).

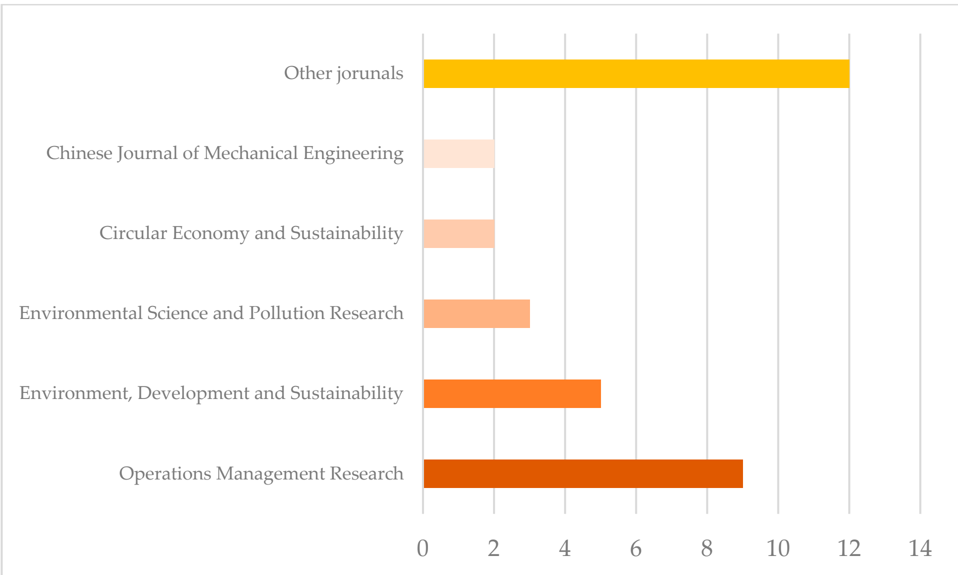

Figure 7. Review of journals in the Springer database—compatibility of articles based on title and/or abstract.

3.3. Review the Full Text and Assess Quality

The next stage is to analyze the content of the articles in terms of their content. Quality assessment in terms of relevance and quality of the analyzed issue is carried out according to certain criteria. For the purposes of this article, assumptions were made about the content of the articles. The assumptions were made in the form of a checklist (Table 1). A scoring scale from 0 to 1 was adopted for each assumption, where:

- 0 points were assigned if the content did not comply with the assumptions.
- 1 point was assigned in the case of compliance of the content with the assumptions.

Table 1. Checklist.

Content Assumptions	Answer Yes	Answer No
1. The article presents the key variables that describe the sustainable solutions.		
2. The article presents solutions affecting the increase in the level of sustainable development in manufacturing companies.		
3. The article presents the impact of COVID-19 on manufacturing companies.		

In the process of evaluating articles according to the checklist (Table 1), 1 point was assigned to references [31–35], while 0 points were assigned to references [36–38].

The next stage in the selection of key articles was a review of the full text and a quality assessment (also applying IC and EC). Therefore, 82 publications were read in full and scored according to the developed checklist. In the next part of the analysis, only articles that received at least 2 points according to the checklist were included.

In the final stage of selection, 13 articles were selected, which allowed us to answer the research questions posed in this work (MLR and SLR) (Table 2).

Table 2. Review the full text and assess quality based on checklist (Table 1).

No	Source	Impact of COVID-19	Sustainable Solutions	Changes	Method/Technique
1	[39]	stringent restrictions and lockdowns; reduced demand for products and services	adoption of environmental innovations, e.g., eco-innovation and green innovation	new strategies: strategic responses or proactive strategies	research approach (questionnaire)
2	[40]	vulnerabilities in lead times and order quantities; supply chain changes; structural changes; severe demand fluctuations	Sustainable Supplier Selection (SSS)—selection based on TBL criteria	pandemic response strategies to achieve supply chain sustainability in the COVID-19 pandemic era	methodology
3	[41]	shortage of materials; lockdowns; delayed deliveries; supply chain changes; bankruptcy	a decision framework for assessing suppliers based on their social sustainability initiatives regarding the criteria relevant to the requirements of working conditions during the COVID-19 pandemic	sustainable supply chain management	framework
4	[42]	lockdowns and restricted transportation; interruptions in manufacturing and shipping; supply chain changes; decrease in labor efficiency and productivity	3D printing	manufacturing techniques	review
5	[43]	fluctuating demand and supply chain changes	combination of practices: pandemic emergency plan (PEP) and sustainability	risk management practices and emergency planning	research model; theoretical and managerial implications
6	[44]	loopholes in supply chain systems	Internet of Things-enabled AM assists; simulation software	risk management; internet-based manufacturing businesses	review

Table 2. *Cont.*

No	Source	Impact of COVID-19	Sustainable Solutions	Changes	Method/Technique
7	[45]	supply chain changes	decision-making framework for integrating resilience and sustainability in managing production systems; scheme of a sustainable and resilient production system	production systems management within supply chains	framework
8	[46]	-	adaptive slicing; LCA of LCD 3DP technology	other slicing strategies	strategy
9	[47]	business changes; supply chain changes	Sustainable Project Management (SPM); Sustainable Supply Chain Management practices	the integration of economic, social, and environmental aspects: supply chain	framework
10	[48]	supply chain changes; severe implications for the performance of companies	circular economy (CE)	change from a linear economy to a circular economy	Delphi approach; experts
11	[49]	supply chain changes; trade changes	advanced technologies; circular economy (CE)	remanufacturing and recycling practices	online survey; covariance-based structural equation modeling (CB-SEM)
12	[50]	changes and complex issues in industrial networks; supply chain changes; production changes	intelligent manufacturing (IM) systems	technology; decision-making model	framework
13	[51]	supply chain changes	Resilient Manufacturing Strategy	strategy	framework

The analyzed papers (Table 2) have some limitations. Some studies are limited to a specific time and country; accordingly, ref. [39] is limited to Norwegian manufacturing, ref. [40] to Nigerian manufacturing, ref. [47] to the Thai metals industry sector, and [48,50,51] to China. They can also be limited to the applied new technology; accordingly, ref. [40,41] to the selected method of Multiple-Criteria Decision-Making and [42,44,46] to the technology 3D printing. Finally, they can be limited to a sector of industry; accordingly, refs. [43,45] to food manufacturing companies and [49] to the automobile sector.

The use of appropriate filters in accordance with the SLR and Mapping methodology allowed us to designate 13 articles in which the impact of the COVID-19 pandemic on the manufacturing industry was indicated and changes/solutions affecting the improvement in sustainable development were proposed. According to the adopted assumptions, this was limited to three selected databases: Science Direct—ELSEVIER, Wiley, and Springer (Figure 8).

In the case of the analysis of articles considered in the final results, the answer obtained as to the year in which the largest number of articles were published regarding the impact of the COVID-19 pandemic and changes/solutions in line with the concept of sustainable production in manufacturing companies replicates the answer for articles retrieved in the initial phase (Figure 9). The year 2022 saw the highest number of articles in the analyzed databases.

Table 3 shows the journals dominating publications on the impact of the COVID-19 pandemic and sustainable solutions implemented in manufacturing companies for the Science Direct-ELSEVIER database.

In the Science Direct—ELSEVIER scientific database, two journals prevailed among the selected articles: *Computers & Industrial Engineering* and *Sustainable Production and Consumption* (Figure 10).

Figure 8. Filtering results in selected databases.

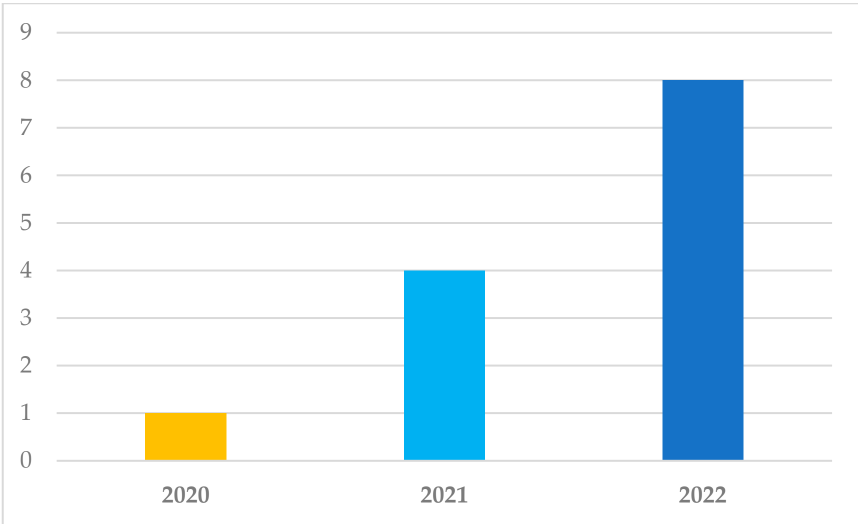

Figure 9. Number of publications in selected databases in 2020–2022 after applying selection according to SLR and Mapping methodology.

Table 3. Journals dominating publications on the impact of the COVID-19 pandemic and sustainable solutions implemented in manufacturing companies: Science Direct database—ELSEVIER.

	Science Direct—ELSEVIER	
No	**Journal**	**Number of Articles**
1	*Computers & Industrial Engineering*	2
2	*Sustainable Production and Consumption*	2
3	*Journal of Manufacturing Systems*	1
4	*International Journal of Production Economics*	1
5	*Advanced Industrial and Engineering Polymer Research*	1
6	*Technology in Society*	1

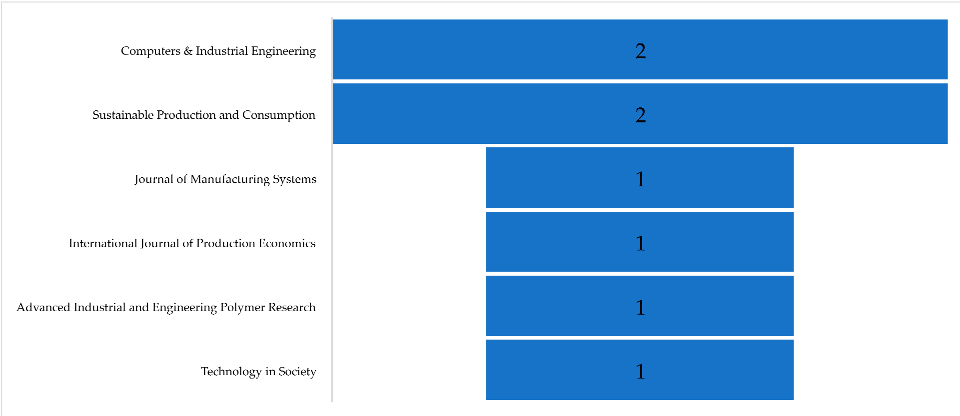

Figure 10. Journals dominating publications on the impact of the COVID-19 pandemic and sustainable solutions implemented in manufacturing companies: Science Direct database—ELSEVIER.

On the other hand, in the Springer scientific database, the largest number of selected articles was published in the journal *Operations Management Research* (Figure 11).

Figure 11. Journals dominating publications on the impact of the COVID-19 pandemic and sustainable solutions implemented in manufacturing companies: SPRINGER database.

3.4. *Qualitative Analysis of Publications*

Then, research was carried out to find answers to the research questions. For addressing RQ1, the analysis was performed using the VOSviewer version 1.6.19 program. VOSviewer is a software tool for constructing and visualizing bibliometric networks. The selected articles were implanted into VOSviewer. The text mining function enabled the generation of a network that determined key variables describing sustainable solutions (Figures 12 and 13).

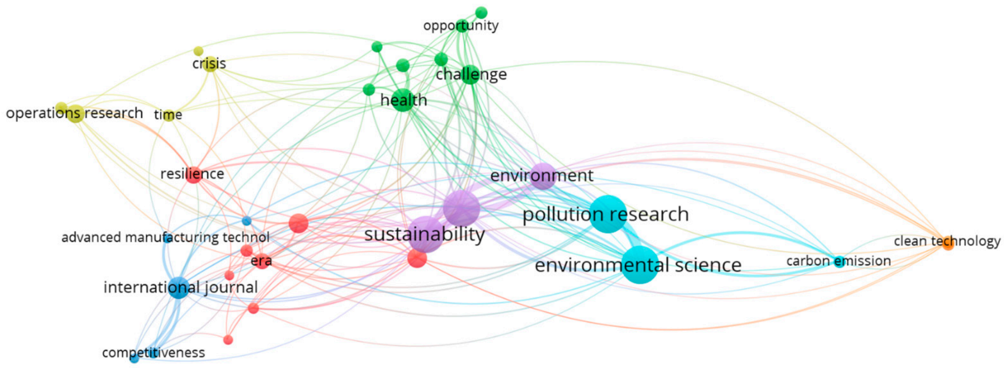

Figure 12. Springer database.

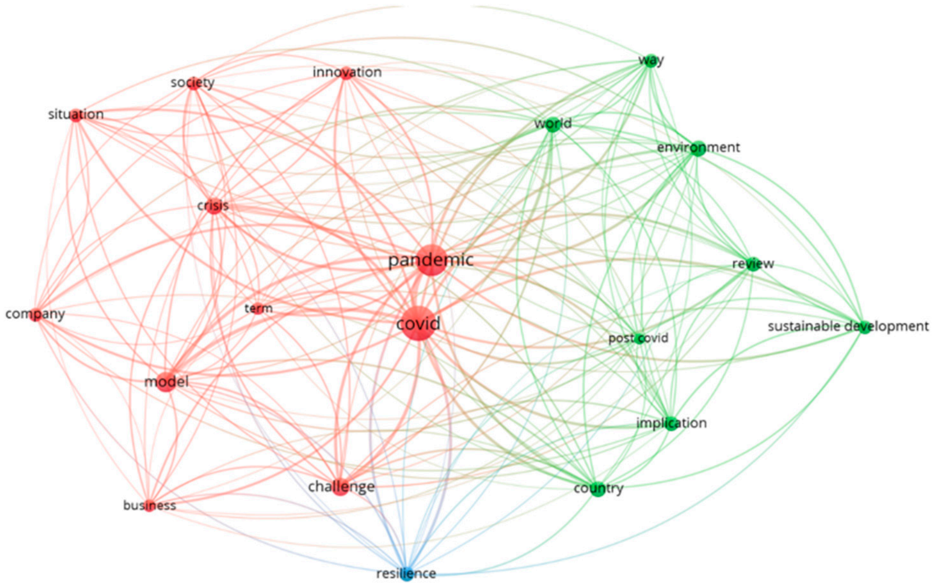

Figure 13. Elsevier database.

Based on the research results, the common key variables that describe sustainable solutions were selected for the two analyzed databases: environment, resilience, challenge, crisis, business (competitiveness), and opportunity (way). Answering the next research question (RQ2), the most frequently cited factor motivating pre-enterprises to implement changes as a result of an unexpected event (using the example of the COVID-19 pandemic) is supply chain change. Supply chain change is cited as a motivating factor for action in 11 of the 13 articles analyzed, with motivating factors not cited in one article. Other frequently cited motivating factors for implementing solutions as a result of the pandemic are lockdowns (3) and fluctuations in demand (3).

Next, the following new technologies, according to the concept of Industry 5.0 regarding the impact of the COVID-19 pandemic and the sustainable solutions implemented in manufacturing companies, were defined (RQ3): 3D printing, Internet of Things-enabled Additive Manufacturing assists, simulation software, and Life Cycle Management of Liquid-Crystal Display 3D printing (LCD 3DP) technology. Finally, the main organizational changes in the context of sustainable development in manufacturing were defined (RQ4):

- In the business management area: adopting Sustainable Project Management (SPM), Sustainable Supply Chain Management practices, Sustainable Supplier Selection (SSS), and Resilient Manufacturing Strategy (RMS).
- In the production area: adopting Internet of Things-enabled Additive Manufacturing assists, simulation software, and Life Cycle Assessment.

The VOSviewer program was also used to analyze the challenges and directions for implementing sustainable solutions in the era of Industry 5.0 (RQ5). Based on a collection of articles in the Elsevier and Springer databases (Figures 14 and 15), the following challenges for industry were discovered:

- Lockdown;
- Globalization;
- Minimization of carbon emissions;
- Climate change;
- Recovery/health;
- Increased competitiveness.

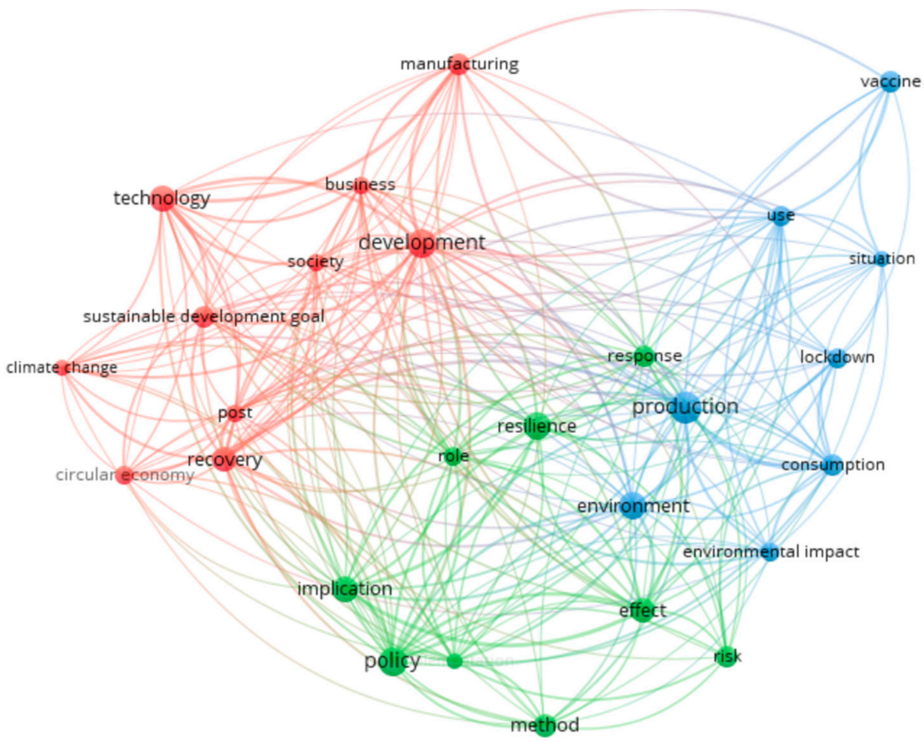

Figure 14. Challenges for implementing sustainable solutions in the era of Industry 5.0—Elsevier database.

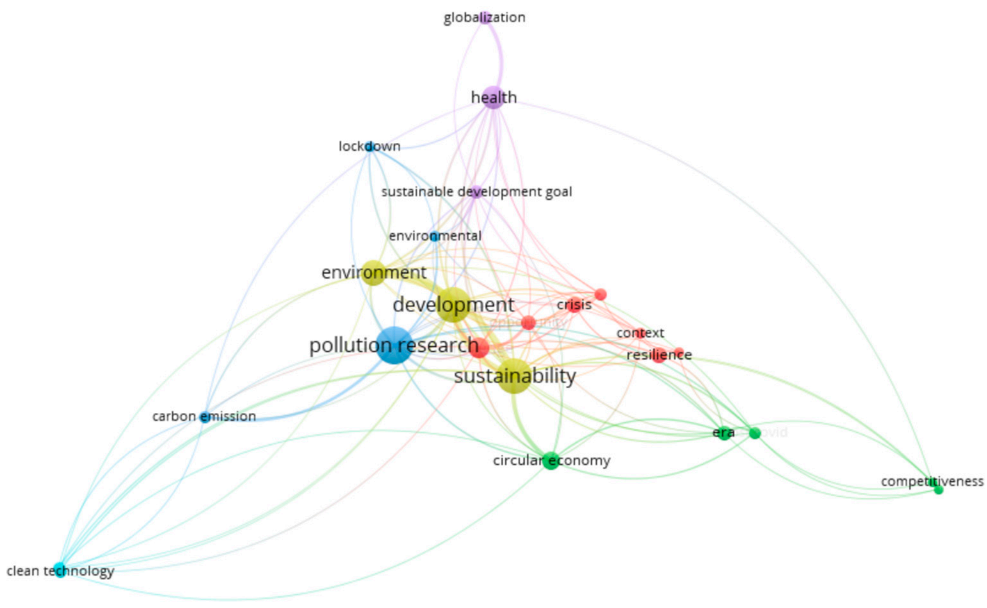

Figure 15. Challenges for implementing sustainable solutions in the era of Industry 5.0—Springer database.

In turn, the following were identified as directions for implementing sustainable solutions in the era of Industry 5.0 based on the results from the Elsevier (Figure 16) and Springer (Figure 17) databases:

- Blockchain;
- Circular economy;
- Big data;
- Supply chain;

- Clean technology;
- Pollution research;
- Innovation.

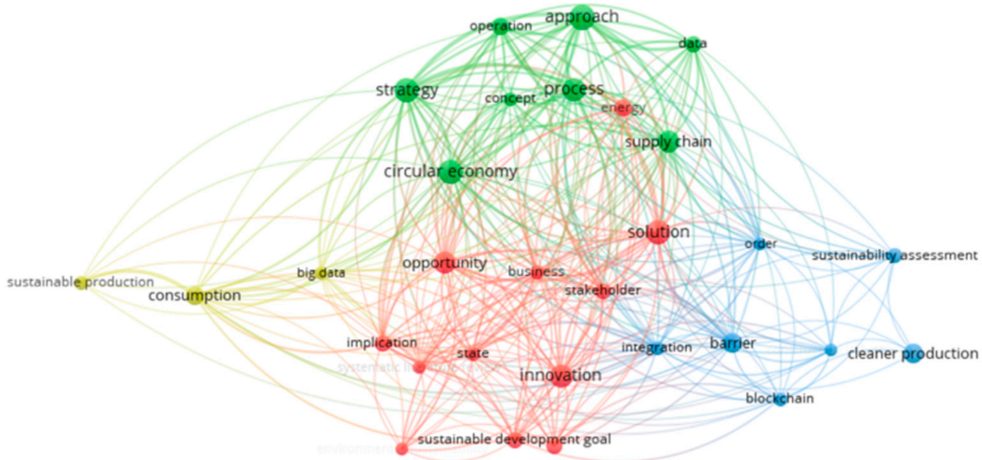

Figure 16. Directions for implementing sustainable solutions in the era of Industry 5.0—Elsevier database.

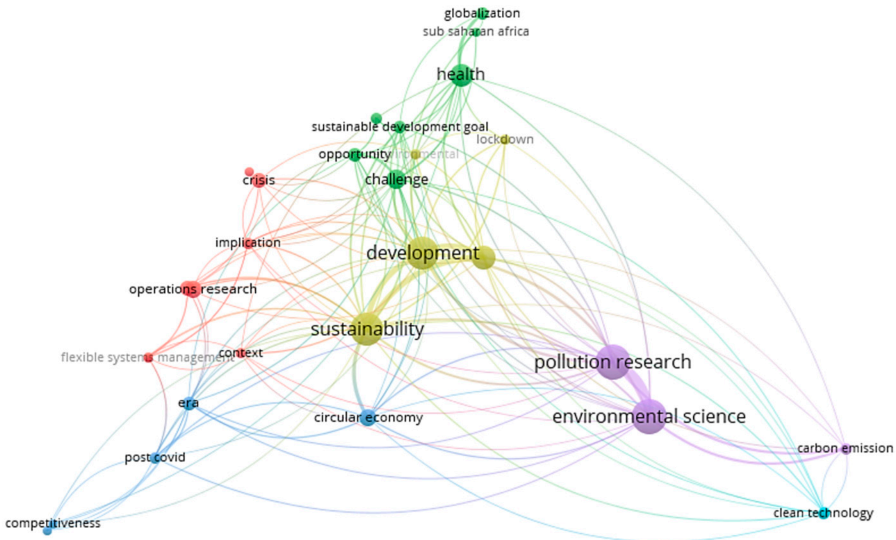

Figure 17. Directions for implementing sustainable solutions in the era of Industry 5.0—Springer database.

Based on the provided analysis, it can be stated that the main challenges for implementing sustainable solutions in the era of Industry 5.0 are the risk of renewed lockdown, globalization, and the need to adapt to climate change. And next, we assume that the direction for further research on this subject should be the relationship between the implementation of Industry 5.0 technologies and increasing the level of sustainable production.

4. Discussion

This analysis of the literature on the subject in the selected databases is based on 566 published articles in 2020–2022. Our research allowed us to find answers to the research questions. Firstly, the key variables that describe sustainable solutions were defined, namely: environment, resilience, challenge, crisis, business (competitiveness), and opportunity (way). These results already show that it is important to provide research on finding solutions that enable the self-healing and self-adaptation of manufacturing companies in cases of crises in the environment or a close competitive environment. The importance of building solutions for manufacturing companies that are resistant to emerging disruptions should be emphasized. Hence, their adaptation allows for gaining a competitive advantage and achieving the goals of sustainable production. SLR confirmed that the COVID-19 pandemic was a factor influencing the implementation of changes in manufacturing companies at various levels. The results obtained indicate that sustainable solutions support the company not only in terms of meeting regulations in the environmental context but also in terms of competitiveness, innovation, and resilience to change. Such results can be a motivating factor for companies to implement changes in this regard. The research results also confirmed that the introduction of new technologies, e.g., 3D printing, Internet of Things-enabled Additive Manufacturing assists, simulation software, and Life Cycle Management of LCD 3DP technology (according to the concept of Industry 5.0), helps to increase the level of adaptation of sustainable solutions. The achieved research results also indicate the main organizational changes in the context of sustainable development in manufacturing, namely in the business management area (adopting Sustainable Project Management (SPM), Sustainable Supply Chain Management practices, Sustainable Supplier Selection (SSS), and Resilient Manufacturing Strategy (RMS)) and the production area (adopting Internet of Things (IoT)-enabled Additive Manufacturing assists, simulation software, and Life Cycle Assessment).

In [52], the relevance of examining the phenomenon of change in the context of COVID-19 is indicated, which emphasizes that understanding these changes will allow companies to prepare for similar situations in the future and adapt to the needs of consumers more easily. Our research results also indicate the main challenges for increasing the level of SD of manufacturing companies in cases of unexpected occurrences, namely globalization, climate change, recovery/health, the need for the minimization of carbon emissions, and increasing competitiveness. To meet these challenges, there is a need to implement new technologies, such as blockchain and big data, clean technology, and organizational changes in the management of supply chains. According to [53], investment in technological progress is essential to achieving the competitiveness of the industrial sector. Analyzing how the implementation of available Industry 4.0 or even Industry 5.0 technologies affects the increase in the level of SD in manufacturing companies should be recommended as the subject of further research.

The limitations of this research are, firstly, a limited number of searched databases and a limited number of keywords, and, secondly, the limitation of research to an unplanned situation such as COVID-19. The current wars in Ukraine and Israel and the tense situation between China and Taiwan indicate the need for further analysis in the face of other unexpected situations. In our future work, we will continue our research in the context of finding the main relationships between the implementation of modern Industry 4.0 or even Industry 5.0 technologies in manufacturing companies and increasing the level of SD. As indicated in the literature [54], the concept of Industry 4.0 allows companies to transform in terms of their flexibility and generate more value, which seems especially important in an era of change. The convergence of various technologies in the Industry 4.0 and Industry 5.0 eras can bring us closer to a more comprehensive understanding of sustainable practices and their impact [55]. Therefore, it is also planned to conduct empirical research in this area that will discover these relationships in economic practice.

Directions for Further Research on Sustainable Manufacturing Development

The research results present the outlook for further scientific work on sustainable manufacturing development:

- Research on solutions ensuring the resilience of sustainable production in case of crises in the environment or a close competitive environment. The COVID-19 crisis has shown that there is no need to return to 'business as usual', which is not immune to change and has also contributed significantly to climate change. Efforts should be made to develop sustainable and change-resilient business models that focus on

common priorities for action, including identifying the role of technology in the organization's operations, changing behaviors, and strengthening the supply chain.
- Research on the relationship between the implementation of Industry 5.0 technologies and increasing the level of sustainable production. Economic and ecological crises are forcing the implementation of changes in production. The foundation of Industry 5.0 is based on manufacturing processes, human-centeredness that aligns with environmental goals, and resilience. Industry 5.0 technologies support tracking anomalies in production processes, analyzing customer behavior, and increasing company efficiency. Studying the relationship between Industry 5.0 and sustainable production can be the basis for developing a framework for innovative green business models.
- Research on strategies combining the implementation of organizational changes with the activities undertaken for sustainable production. Research is assumed to continue in the area of applying the effects of the following strategies in manufacturing: Sustainable Project Management (SPM), Sustainable Supply Chain Management practices, Sustainable Supplier Selection (SSS), and Resilient Manufacturing Strategy (RMS).

5. Conclusions

This study conducted a systematic literature review based on PRISMA guidelines and the SLR and MLR methodologies. Employing the PRISMA approach increased the confidence level in the research outcomes. The research results aimed to determine the key characteristics of examining the impacts of crisis (unexpected) situations on the implementation of sustainable solutions in a manufacturing company and designing organizational changes in manufacturing. The findings of this study revealed key relationships between the adoption of fifth-generation industrial technologies and the sustainable development of manufacturing.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su16020717/s1: PRISMA Checklist.

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Appendix A

Table A1. Full list of analyzed papers.

No.	URL	Title	Year	Reference No.
1	https://doi.org/10.1016/j.techsoc.2022.101918 (accessed on 14 July 2023)	Analyzing the impact of COVID-19 on environmental innovations in manufacturing firms	2022	[29]
2	https://doi.org/10.1016/j.cie.2021.107588 (accessed on 14 July 2023)	Investigating the COVID-19 pandemic's impact on sustainable supplier selection in the Nigerian manufacturing sector	2021	[30]
3	https://doi.org/10.1016/j.spc.2021.04.026 (accessed on 14 July 2023)	Assessing suppliers considering social sustainability innovation factors during COVID-19 disaster	2021	[31]
4	https://doi.org/10.1016/j.techfore.2021.121361 (accessed on 14 July 2023)	Capabilities of digital servitization: Evidence from the socio-technical systems theory	2022	-

Table A1. *Cont.*

No.	URL	Title	Year	Reference No.
5	https://doi.org/10.1016/j.jmsy.2021.07.023 (accessed on 14 July 2023)	Applications of additive manufacturing (AM) in sustainable energy generation and battle against COVID-19 pandemic: The knowledge evolution of 3D printing	2021	[32]
6	https://doi.org/10.1016/j.procir.2021.01.147 (accessed on 14 July 2023)	Business Sustainability in Post COVID-19 Era by Integrated LSS-AM Model in Manufacturing: A Structural Equation Modeling	2021	-
7	https://doi.org/10.1016/j.jik.2022.100181 (accessed on 14 July 2023)	Networking and knowledge creation: Social capital and collaborative innovation in responding to the COVID-19 crisis	2022	-
8	https://doi.org/10.1016/j.seta.2022.102622 (accessed on 15 July 2023)	Covid-19′s fear-uncertainty effect on renewable energy supply chain management and ecological sustainability performance; the moderate effect of big-data analytics	2022	-
9	https://doi.org/10.1016/j.ijpe.2022.108419 (accessed on 15 July 2023)	Pandemic planning, sustainability practices, and organizational performance: An empirical investigation of global manufacturing firms	2022	[33]
10	https://doi.org/10.1016/j.strueco.2022.02.018 (accessed on 15 July 2023)	COVID-19 and the Brazilian manufacturing sector: Roads to reindustrialization within societal purposes	2022	-
11	https://doi.org/10.1016/j.rico.2021.100066 (accessed on 15 July 2023)	Impacts of additive manufacturing to sustainable urban–rural interdependence through strategic control	2021	-
12	https://doi.org/10.1016/j.spc.2020.07.001 (accessed on 15 July 2023)	COVID-19 debunks the myth of socially sustainable supply chain: A case of the clothing industry in South Asian countries Workforce and supply chain disruption as a digital and technological innovation opportunity for resilient manufacturing systems in the COVID-19 pandemic	2020	-
13	https://doi.org/10.1016/j.cie.2022.108158 (accessed on 15 July 2023)	Workforce and supply chain disruption as a digital and technological innovation opportunity for resilient manufacturing systems in the COVID-19 pandemic	2022	-
14	https://doi.org/10.1016/j.aiepr.2021.12.001 (accessed on 15 July 2023)	Understanding the role and capabilities of Internet of Things-enabled Additive Manufacturing through its application areas	2022	[34]
15	https://doi.org/10.1016/j.jobe.2021.103935 (accessed on 15 July 2023)	The challenges confronting the growth of sustainable prefabricated building construction in Australia: Construction industry views	2022	-
16	https://doi.org/10.1016/j.pnsc.2022.01.001 (accessed on 15 July 2023)	Green economy and waste management: An inevitable plan for materials science	2022	-
17	https://doi.org/10.1016/j.ijpe.2021.108193 (accessed on 15 July 2023)	Challenges to COVID-19 vaccine supply chain: Implications for sustainable development goals	2021	-
18	https://doi.org/10.1016/j.jclepro.2021.127278 (accessed on 15 July 2023)	Digital twins-based remote semi-physical commissioning of flow-type smart manufacturing systems	2021	-
19	https://doi.org/10.1016/j.scitotenv.2020.141362 (accessed on 15 July 2023)	Unlocking challenges and opportunities presented by COVID-19 pandemic for cross-cutting disruption in agri-food and green deal innovations: Quo Vadis?	2020	-
20	https://doi.org/10.1016/j.energy.2021.121315 (accessed on 15 July 2023)	Energy, environmental, economic and social equity (4E) pressures of COVID-19 vaccination mismanagement: A global perspective	2021	-
21	https://doi.org/10.1016/j.susmat.2022.e00481 (accessed on 15 July 2023)	Critical appraisal and systematic review of 3D & 4D printing in sustainable and environment-friendly smart manufacturing technologies	2022	-
22	https://doi.org/10.1016/j.marpol.2022.105313 (accessed on 15 July 2023)	Financial and economic impacts of the COVID-19 pandemic on aquaculture in Türkiye and financial policy recommendations	2022	-
23	https://doi.org/10.1016/j.cep.2022.108883 (accessed on 15 July 2023)	Modular and intensified—Reimagining manufacturing at the energy-chemistry nexus and beyond	2022	-

Table A1. *Cont.*

No.	URL	Title	Year	Reference No.
24	https://doi.org/10.1016/j.jbusres.2022.01.032 (accessed on 15 July 2023)	Frugal innovations: A multidisciplinary review & agenda for future research	2022	-
25	https://doi.org/10.1016/j.jafr.2021.100225 (accessed on 15 July 2023)	Farm mechanization in Bangladesh: A review of the status, roles, policy, and potentials	2021	-
26	https://doi.org/10.1016/j.chemosphere.2021.132248 (accessed on 15 July 2023)	Integration of various technology-based approaches for enhancing the performance of microbial fuel cell technology: A review	2022	-
27	https://doi.org/10.1016/j.resconrec.2022.106571 (accessed on 15 July 2023)	Environment-Social-Governance Disclosures nexus between Financial Performance: A Sustainable Value Chain Approach	2022	-
28	https://doi.org/10.1016/j.technovation.2021.102221 (accessed on 15 July 2023)	Open innovation in the manufacturing industry: A review and research agenda	2021	-
29	https://doi.org/10.1016/j.susmat.2022.e00475 (accessed on 15 July 2023)	Using the concept of circular economy to reduce the environmental impact of COVID-19 face mask waste	2022	-
30	https://doi.org/10.1016/j.resconrec.2020.105169 (accessed on 15 July 2023)	A critical analysis of the impacts of COVID-19 on the global economy and ecosystems and opportunities for circular economy strategies	2021	-
31	https://doi.org/10.1016/j.scitotenv.2022.154416 (accessed on 15 July 2023)	Principal of environmental life cycle assessment for medical waste during COVID-19 outbreak to support sustainable development goals	2022	-
32	https://doi.org/10.1016/j.vaccine.2021.12.038 (accessed on 15 July 2023)	How to accelerate the supply of vaccines to all populations worldwide? Part II: Initial industry lessons learned and detailed technical reflections leveraging the COVID-19 situation	2022	-
33	https://doi.org/10.1016/j.spc.2022.01.023 (accessed on 15 July 2023)	Opportunities for single-use plastic reduction in the food service sector during COVID-19	2022	-
34	https://doi.org/10.1016/j.jclepro.2021.127464 (accessed on 17 July 2023)	Research advances in the fabrication of biosafety and functional leather: A way-forward for effective management of COVID-19 outbreak	2021	-
35	https://doi.org/10.1016/j.matpr.2021.10.292 (accessed on 17 July 2023)	Sustainable supply chain practices with reverse innovation in healthcare start-ups—A Structural Equation Model (SEM) approach	2022	-
36	https://doi.org/10.1016/j.cesys.2021.100040 (accessed on 17 July 2023)	The impact of buying power on corporate sustainability—The mediating role of suppliers' traceability data	2021	-
37	https://doi.org/10.1016/j.biortech.2020.124222 (accessed on 17 July 2023)	Biosurfactants: The green generation of speciality chemicals and potential production using Solid-State fermentation (SSF) technology	2021	-
38	https://doi.org/10.1016/j.scs.2021.103310 (accessed on 17 July 2023)	Last-mile-as-a-service (LMaaS): An innovative concept for the disruption of the supply chain	2021	-
39	https://doi.org/10.1016/j.elerap.2020.101004 (accessed on 17 July 2023)	How should we understand the digital economy in Asia? Critical assessment and research agenda	2020	-
40	https://doi.org/10.1016/j.xphs.2022.07.011 (accessed on 17 July 2023)	Analysis of the renewed European Medical Device Regulations in the frame of the non–EU regulatory landscape during the COVID facilitated change	2022	-
41	https://doi.org/10.1016/j.scitotenv.2021.149605 (accessed on 17 July 2023)	Circular economy approach in solid waste management system to achieve UN-SDGs: Solutions for post-COVID recovery	2021	-
42	https://doi.org/10.1016/j.rser.2021.111400 (accessed on 17 July 2023)	COVID-19 pandemics Stage II—Energy and environmental impacts of vaccination	2021	-
43	https://doi.org/10.1016/j.spc.2021.12.024 (accessed on 17 July 2023)	Advancing towards sustainability in liquid crystal display 3D printing via adaptive slicing	2022	[36]
44	https://doi.org/10.1016/j.jestch.2021.09.006 (accessed on 17 July 2023)	A sustainable approach for the utilization of PPE biomedical waste in the construction sector	2022	-
45	https://doi.org/10.1016/j.sftr.2022.100093 (accessed on 17 July 2023)	Re-engineering of a food oven for thermal sanitization of Personal Protective Equipment against Sars-CoV-2 virus	2022	-

Table A1. *Cont.*

No.	URL	Title	Year	Reference No.
46	https://doi.org/10.1016/j.spc.2021.05.018 (accessed on 17 July 2023)	Do responses to the COVID-19 pandemic anticipate a long-lasting shift towards peer-to-peer production or degrowth?	2021	-
47	https://doi.org/10.1016/j.jclepro.2022.132608 (accessed on 17 July 2023)	An adoption-implementation framework of digital green knowledge to improve the performance of digital green innovation practices for industry 5.0	2022	-
48	https://doi.org/10.1016/j.procir.2021.01.077 (accessed on 17 July 2023)	Industry 4.0: Challenges and opportunities for Kazakhstan SMEs	2021	-
49	https://doi.org/10.1016/j.jenvman.2021.111966 (accessed on 17 July 2023)	Incineration of sewage sludge and recovery of residue ash as building material: A valuable option as a consequence of the COVID-19 pandemic	2021	-
50	https://doi.org/10.1016/j.heliyon.2022.e09859 (accessed on 17 July 2023)	Inapt management of menstrual hygiene waste (MHW): An urgent global environmental and public health challenge in developed and developing countries	2022	-
51	https://doi.org/10.1016/j.chom.2021.08.002 (accessed on 17 July 2023)	An AAV-based, room-temperature-stable, single-dose COVID-19 vaccine provides durable immunogenicity and protection in non-human primates	2021	-
52	https://doi.org/10.1016/j.tifs.2022.04.016 (accessed on 17 July 2023)	Trends and challenges on fruit and vegetable processing: Insights into sustainable, traceable, precise, healthy, intelligent, personalized and local innovative food products	2022	-
53	https://doi.org/10.1016/j.seps.2021.101095 (accessed on 17 July 2023)	Has the COVID-19 pandemic changed food waste perception and behavior? Evidence from Italian consumers	2022	-
54	https://doi.org/10.1016/j.techfore.2022.121548 (accessed on 17 July 2023)	Business networks and organizational resilience capacity in the digital age during COVID-19: A perspective utilizing organizational information processing theory	2022	-
55	https://doi.org/10.1016/j.rser.2021.111750 (accessed on 18 July 2023)	Evolving from a hydrocarbon-based to a sustainable economy: Starting with a case study for Iran	2022	-
56	https://doi.org/10.1016/j.jclepro.2022.135153 (accessed on 18 July 2023)	How sustainable are the biodegradable medical gowns via environmental and social life cycle assessment?	2022	-
57	https://doi.org/10.1016/j.checat.2022.03.027 (accessed on 18 July 2023)	C–H activation: A strategic approach toward lactams using transition metals	2022	-
58	https://doi.org/10.1016/j.procir.2021.10.021 (accessed on 18 July 2023)	Four Independent Knowledge Domains to Enable an Agile, Distributed Development of User-Centred Engineering Configurators	2021	-
59	https://doi.org/10.1016/j.actaastro.2022.06.005 (accessed on 18 July 2023)	Space as an enabler for sustainable digital transformation: The new space race and benefits for newcommers	2022	-
60	https://doi.org/10.1016/j.watres.2022.118824 (accessed on 18 July 2023)	Identification and quantification of bioactive compounds suppressing SARS-CoV-2 signals in wastewater-based epidemiology surveillance	2022	-
61	https://doi.org/10.1016/j.vaccine.2020.12.018 (accessed on 18 July 2023)	Global production capacity of seasonal and pandemic influenza vaccines in 2019	2021	-
62	https://doi.org/10.1016/j.amjsurg.2022.02.064 (accessed on 18 July 2023)	CRISIS ventilator: A 3D printed option for ventilator surge in mass respiratory pandemics	2022	-
63	https://doi.org/10.1016/s0140-6736(21)00503-1 (accessed on 18 July 2023)	Urgent lessons from COVID 19: why the world needs a standing, coordinated system and sustainable financing for global research and development	2021	-
64	https://doi.org/10.1016/j.ifacol.2021.10.492 (accessed on 18 July 2023)	A Critical Historical and Scientific Overview of all Industrial Revolutions	2021	-
65	https://doi.org/10.1016/j.matpr.2020.11.819 (accessed on 18 July 2023)	Critical success factors for new horizons in the supply chain of 3-D printed products—A review	2021	-
66	https://doi.org/10.1016/j.mattod.2022.08.019 (accessed on 18 July 2023)	Internet-of-nano-things (IoNT) driven intelligent face masks to combat airborne health hazard	2022	-

Table A1. *Cont.*

No.	URL	Title	Year	Reference No.
67	https://doi.org/10.1016/j.resconrec.2020.105248 (accessed on 18 July 2023)	Disruption risks to material supply chains in the electronics sector	2021	-
68	https://doi.org/10.1016/j.envint.2022.107272 (18.08.2023)	A new laser device for ultra-rapid and sustainable aerosol sterilization	2022	-
69	https://doi.org/10.1016/j.jbusres.2020.05.035 (accessed on 18 July 2023)	COVID-19's impact on supply chain decisions: Strategic insights from NASDAQ 100 firms using Twitter data	2020	-
70	https://doi.org/10.1016/j.fufo.2022.100123 (accessed on 18 July 2023)	Water kefir, a fermented beverage containing probiotic microorganisms: From ancient and artisanal manufacture to industrialized and regulated commercialization	2022	-
71	https://doi.org/10.1016/j.biologicals.2022.02.003 (accessed on 18 July 2023)	A gaps-and-needs analysis of vaccine R&D in Europe: Recommendations to improve the research infrastructure	2022	-
72	https://doi.org/10.1016/j.coesh.2021.100290 (17.08.2023)	Efficacy of frontline chemical biocides and disinfection approaches for inactivating SARS-CoV-2 variants of concern that cause coronavirus disease with the emergence of opportunities for green eco-solutions	2021	-
73	https://doi.org/10.1016/j.cie.2021.107905 (accessed on 18 July 2023)	Decision-making framework for a resilient sustainable production system during COVID-19: An evidence-based research	2022	[35]
74	https://doi.org/10.1007/s12063-022-00283-7 (accessed on 18 July 2023)	Role of project management on Sustainable Supply Chain development through Industry 4.0 technologies and Circular Economy during the COVID-19 pandemic: A multiple case study of Thai metals industry	2022	[37]
75	https://doi.org/10.1007/s12063-021-00220-0 (accessed on 18 July 2023)	The future of industry 4.0 and the circular economy in Chinese supply chain: In the Era of post-COVID-19 pandemic	2022	[38]
76	https://doi.org/10.1007/s12063-022-00263-x (accessed on 18 July 2023)	Adoption of technological innovation and recycling practices in automobile sector: under the Covid-19 pandemic	2022	[39]
77	https://doi.org/10.1186/s10033-020-00476-w (accessed on 18 July 2023)	Intelligent Manufacturing Systems in COVID-19 Pandemic and Beyond: Framework and Impact Assessment	2020	[40]
78	https://doi.org/10.1186/s10033-021-00573-4 (accessed on 18 July 2023)	Industrial Internet-enabled Resilient Manufacturing Strategy in the Wake of COVID-19 Pandemic: A Conceptual Framework and Implementations in China	2021	[41]
79	https://doi.org/10.1007/s12063-021-00179-y (accessed on 18 July 2023)	Disruption in global supply chain and socio-economic shocks: a lesson from COVID-19 for sustainable production and consumption	2021	-
80	https://doi.org/10.1016/j.cie.2021.107381 (accessed on 18 July 2023)	Sustainable production and waste management policies for COVID-19 medical equipment under uncertainty: A case study analysis	2021	-
81	https://doi.org/10.1016/j.jclepro.2021.129216 (accessed on 18 July 2023)	The drivers of industry 4.0 in a circular economy: The palm oil industry in Malaysia	2021	-
82	https://doi.org/10.1016/j.worlddev.2020.105215 (accessed on 18 July 2023)	Industrial policy for sustainable human development in the post-Covid19 era	2021	-

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