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**Matija Kovačić**[1]

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# IMPACT OF INDUSTRY 4.0. ON SUPPLY CHAIN SUSTAINABILITY: A SYSTEMATIC LITERATURE REVIEW

***Abstract:*** *This article is based on a systematic research of the literature related to influence of Industry 4.0 and its technologies on achieving sustainability in supply chain, which is becoming increasingly significant topic as demand for supply chain sustainability increases.Based on the research findings, this article highlights scholars that mainly discuss the influence of Industry 4.0 on supply chain sustainability, as well as the most relevant articles that might form a basis for other scholars when conducting research. The findings reveal a trend toward studying the supply chain from the perspective of the circular economy, i.e. the importance of building the supply chain using circular economy concepts. The study has limitations due to the analysis of only Englishlanguage articles without including books, as well as a concentration on the Scopus database only.*

***Keywords:*** *Industry 4.0, supply chain, sustainability of supply chain, circular economy*.

## 1. Introduction

The supply chain is a set of mutually connected organizations with the main goal of ensuring enough raw materials, products, and services that are necessary for the fulfilment of customer specifications (Islam et al., 2013). The supply chain is a critical aspect for the normal functioning of today's economy, as well as for the normal functioning of organizations because it provides all the resources necessary for the normal functioning of processes (Sombultawee et.al., 2022). Accordingly, organizations in the supply chain might have a negative impact on sustainability components when assuring necessary resources. For example, a study conducted in China shows that the supply chain process in China has an average annual growth rate of carbon dioxide emissions of 1.73% (Ma et al., 2022). The concentration of carbon dioxide emissions in various firms in the supply chain can be much higher depending on the characteristics of supply chain manufacturing processes. As a result, the supply chain's potential negative impact on sustainability must be carefully evaluated at all stages of the product life cycle (product creation, the phase of production and distribution of products, and the phase of disposal or recycling of products) (Linton, Klassen and Jayaraman, 2007). Given growing concerns about CO2 emissions and the negative impact that rising CO2 emissions have on supply chain sustainability in general, stakeholders are emphasizing the importance of sustainability and reducing the negative impact of CO2 on the supply chain. Solutions for reducing negative impact must be developed and implemented in every organization that is

[1] Corresponding author: Matija Kovačić
Email: matkovacic@unin.hr

incorporated into the supply chain and has a negative impact on sustainability components (Saeed and Kersten, 2019). Developed solutions must address all components of sustainability, i.e., economic, social, and environmental component. Furthermore, such solutions must consider the requirements defined by positive legislation related to greenhouse gas emissions, measures against labour exploitation, anticorruption measures, measures to increase the safety of financial transactions, etc. (Hsu et al., 2013, Arovski 2023, Lazic et al. 2023). Considering all of the needs of stakeholders with the need to fully comply with laws and other normative documents connected to sustainability, implementing sustainable solutions in the supply chain is becoming increasingly important (Chin, Tat and Sulaiman, 2015). Industry 4.0 technologies are among the mehanisms that might increase the supply chain's sustainability as part of the development of the idea of green supply chains. Industry 4.0 solutions can improve the efficiency and efficacy of supply chain processes, as well as making supply chain activities more sustainable.

Because of the rising significance of examination of the prospects of Industry 4.0, an increasing number of scientists are starting to explore the role of Industry 4.0 technologies on sustainabilityand supply chain sustainability. The opportunities that Industry 4.0 technology has on the ability to construct an integrated supply chain are described in professional and scientific articles dealing with: the impact of Industry 4.0 on the supply chain(Tiwari, 2020), the impact that Industry 4.0 has on increasing supply chain resilience (Spieske and Birkel, 2021), the impact that Industry 4.0 has on increasing or decreasing risk, as well as general risk management in the supply chain (Zimmermann et al., 2019) that is, the impact that Industry 4.0 has on increasing and developing sustainability (Bai et al., 2020).

Also, the authors research impact of Industry 4.0 on the supply chain through the process of creating a circular economy, which is the basis for creating a sustainable supply chain (Manavalan and Jayakrishna, 2019).

The research identified that the authors are focused on recognizing the significance of certain Industry 4.0technologies on sustainability, i.e. the supply chain, and how they see the consequences that the COVID-19 virus pandemic has on the functioning of supply chains.An insufficient number of scholars explore how Industry 4.0 impacts supply chain sustainabilitywhether Industry 4.0 does have an impact on supply chain sustainability.

Existing research papers are describing how Industry 4.0 affects individual pillars of sustainability (Birkel and Müller, 2021),and includes:the sustainability of Industry 4.0 as such and the technologies that occur within Industry 4.0 (Kamble, Gunasekaran and Gawankar, 2018) and the impact that Industry 4.0 has on sustainable production (Ching et al., 2021).

Because there are few articles that examine the impact of Industry 4.0 on supply chain sustainability, this article used bibliometrics to perform a systematic review of the literature. Bibliometrics is a tool for analyzing current studies and its interconnections, as well as determining the connection and potential future research trends (Xu et al., 2020). The results of the analysis can be graphically presented using various parameters such as author productivity, author citations, the evolution of topics, productivity of individual geographical areas, or interconnection of different geographical areas, source analysis, citation analysis, etc. Systematic analysis using bibliometrics is a method that gives more reliable results compared to traditional literature reviews and is used in various branches of science (Ferreira, Fernandes and Ratten, 2016). In addition, this approach eliminates the possible subjectivity of researchers and includes many different

studies conducted by other authors, and the results can serve as a basis for creating new research, i.e., as a basis for other researchers to create and focus on specific topics (Sombultawee et al., 2022). The paper consists of four chapters: an introductory chapter describing the importance of Industry 4.0, supply chain, and sustainability; a second chapter describing the methodology and the way the research was conducted; a third chapter describing the results of the research; a fourth chapter in which the results are discussed; and the last, fifth chapter, in which is described the conclusion of the research.

## 2. Materials and Methods

The research was conducted by searching the Scopus database with the keywords "Industry 4.0" and "Sustainable Supply Chain". The search includes all papers published in the period from 2011 to the 2021 year, which is the period since the beginning of the fourth industrial revolution. Search includes titles of papers, abstracts, and keywords to ensure access to all relevant papers in the field of Industry 4.0 and supply chain sustainability. The initial search yielded 13,808 papers, after which the list was filtered exclusively for articles, while books were excluded from the search. After filtering, the total number of articles included in the research is 10,385. The obtained results were then filtered and focused on the field of green technologies, i.e., technologies that support sustainability, which reduced the results to 3,100 papers, and after filtering papers in English, the number of papers included in the research is 3,093. Furthermore, by reading abstracts, titles, and keywords, i.e., by selecting only papers that are complete, the number of papers included in the research is 300.

### 2.1. Bibliometric Study

Analysis was conducted based on the selected 300 articles, and include an analysis of the authors' productivity, an analysis of papers, i.e., a review of the most cited papers, an analysis of sources in which papers were found, an analysis of journals in which papers were published, and an analysis of coauthorship of papers included in the analysis, the geographical distribution of papers, author citation analysis, thematic map and thematic evolution.

### 2.1. Author productivity

The analysis of authors' productivity considered the number of papers published by authors in the period from the 2015 year to the 2021 year, the country from which the authors come, the number of papers published so far, and the share of each author in the total number of published papers. The calculation the share of published works by the author was calculated according to:

$$Share = \frac{N_a}{N_{ri}}$$

Where is $N_a$the total number of papers by the author and $N_{ri}$ is the total number of papers included in the sample. In addition, in the analysis of the author's productivity, articles fractionalized were also considered, which indicates the contribution of an individual author to the total number of published papers. For the calculation of fractionalized articles is used expression:

$$FracFreq(AU_j) = \sum_{h \in AU_j} \frac{1}{nofCoAuthors\ (h)}$$

Where$AU_j$ is the number of papers co-authored by an author j while h is the work included in $AU_j$.

### 2.2. Analysis of papers

When analyzing the papers, authors consider the number of citations of papers in the period from the 2011 year to the 2021 year, the total number of citations of papers per year in the mentioned period and normalized total citations. Normalized total citations are calculated as the ratio of the actual number of citations to the expected number of citations for papers that are similar in importance and area, i.e., the year of publication. For the calculation of normalized total citations, several terms are used, depending on whether it is paper related to one area or to several areas, as well as whether it counts for a larger number ofgrupedpapers. When calculating the normalized citation impact, it is initially necessary to define and calculate the Relative Citation Rate according to the expression:

$$RCR_{ift} = \frac{c_{ift}}{p_{ift}} / \frac{c_{it}}{p_{ft}}$$

Where *c* is the number of citations and *a* is the number of papers, the notation *i* represents the number of papers of an individual institution, $f$ represents the number of papers in an area, and *t* denotes the number of papers in each period. After that, it is necessary to calculate the weighted mean where the number of publications of the institution from which the author comes is taken as a weight, and then the normalized citation impact is calculated according to:

$$NCL_i = \frac{\sum_f \sum_t \sum_f p_{ift} RCR_{ift}}{\sum_f \sum_t p_{ift}}$$

If the expected citation rate is calculated, then the expression can be written:

$$e_{ft} = \frac{c_{ft}}{p_{ft}}$$

Therefore, the expression can be reduced to:

$$NCL_i = \frac{\sum_f \sum_t \sum_f p_{ift} RCR_{ift}}{\sum_f \sum_t p_{ift}} = \frac{\sum_f \sum_t \sum_f p_{ift} \frac{c_{ift}}{p_{ift}} \frac{1}{e_{ft}}}{\sum_f \sum_t p_{ift}} = \frac{\sum_f \sum_t \frac{c_{ift}}{p_{ift}} \frac{1}{e_{ft}}}{\sum_f \sum_t p_{ift}}$$

The total number of papers that was considered during the analysis is 10 in the context of the largest number of citations, the largest number of citations during the year, and the largest Normalized total citations.

### 2.3. Source analysis

When analyzing the sources, the criteria that were considered was the total number of papers published in the journal. Furthermore, the analysis included the countries in which the journals are located, and the absolute cumulative frequency of publication that was used for ABC analysis, i.e., Pareto analysis. Formula that is used to analyze the Impact Factor journal is:

$$IF = \frac{N_c}{N_{ri}}$$

Where *IF* is the impact factor, $N_c$is the number of citations from the journal under review, and $N_{ri}$ is the number of papers published in the journal in the last year.

### 2.4. Coautorship analysis

The coauthorship network shows collaboration between different authors. Collaboration is presented in relations where the thickness of the line indicates a larger number of papers that the authors have published together. In addition, the larger the circle representing the author, the greater is the number of papers published by the author. Furthermore, the distance between

the circles defines the frequency of cooperation, i.e., the intensity of cooperation between the authors. The smaller the distance between the circles, the greater is the frequency of cooperation between the authors and vice versa. The authors are presented in clusters concerning their collaboration. If there is no link between the clusters, then the authors do not cooperate. The minimum number of papers considered in the coauthorship analysis is two.

### 2.5. Geographical distribution analysis

The geographical distribution shows the countries from which the produced papers originate. The geographical distribution is depicted in the table 2. The table 2 present countries and the number of papers in absolute and relative terms as criteria. Cooperation between countries is shown by relations between circles. Circles represent countries, and relations represent the frequency of cooperation. The thicker the relationship, the higher is the frequency of cooperation. On the other hand, the larger the circles, the greater the number of papers is producted by country.

### 2.6. Citation analysis

Citation is shown by circles and relations between them refers to the number of mutual citations of authors. Circles represent authors, and the size of a circle represents the number of papers that an author produces. The number and thickness of relation lines represent the frequency, i.e., the number of citations of the author. The citation analysis aims to identify authors whose research provides a basis for the papers of other authors, i.e., the most influential groups of authors. The authors are placed in clusters, and within each cluster are circles that represent the authors. In addition to citations within clusters, all clusters and the authors within them are linked by relations that represent citations between clusters.

## 3. Results

If we look at the number of published papers over time, Figure 1 shows the trend in the number of papers in the period from 2013 to 2021 year.

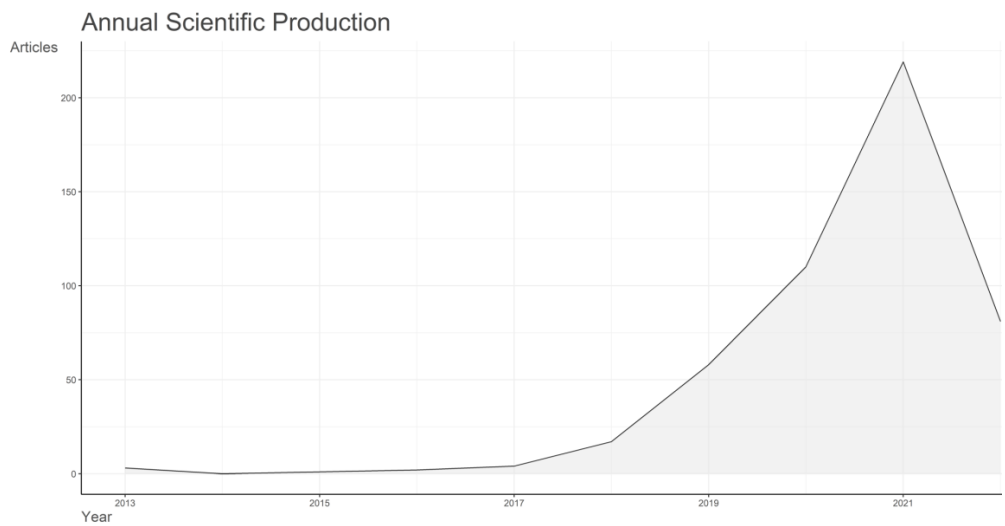


**Figure 1.** Annual scientific production

The interest of researchers in impact of Industry 4.0 on the sustainability of the supply chain is growing. In 2013, only 3 papers were produced on the analyzed topic, while in 2021 year 219 papers were produced, which is an increase of 98%. If we analyze the average increase in papers per year, it was identified that the number of works in the area is growing by 50.98%. A declining trend was observed since the research was conducted in 2022, which means that it does not include the total number of papers that will be produced by the end of 2022 year, but only papers that are produced by the month of 2022.year.

In the observed period, the average citation of papers was 18.86. In other words, if the citation of an individual paper is considered, then the total citation is 5,999. Furthermore, the total number of papers with only one author is 28, while the average number of papers per author is 0.345. If we talk about cooperation between authors, in the observed period, 41.82% of papers were created by the international cooperation of authors.

Figure 2 shows the average citation of papers in this area. It is evident that the number of citations of papers from the field is growing as well as the number of researches is growing, i.e. that trends related to sustainability and the importance of sustainability are changing.

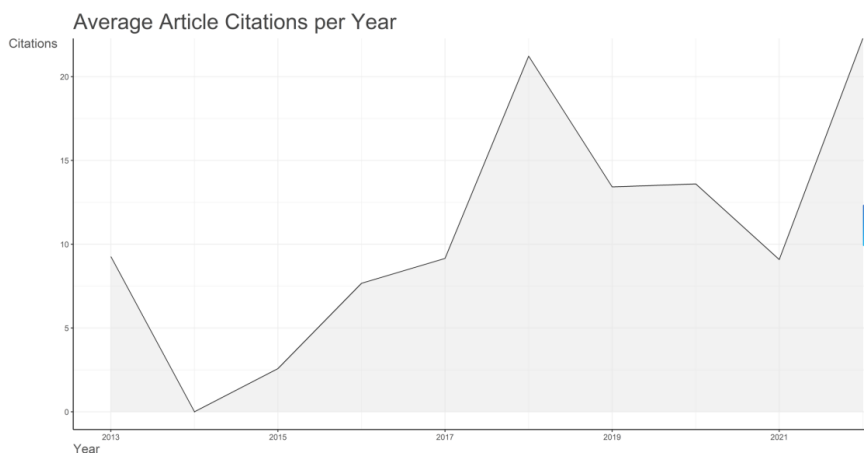


**Figure 2.** Average article citations per year

### 3.1. Author productivity

The analysis of the author's productivity is shown in Table 1. Author with the largest number of produced papers in the observed period was Awanish Kumar from India, who produced 16 papers, which in relative share in the total number of papers 3.2%, with articles fractionalized of 3.64. The second in a row is Sunil Luthra, also from India, who in the observed period produced 15 papers, which is 3% of the total number of papers sampled and with articles fractionalized of 3.64. SachinMangla from England is the third author in terms of the number of published papers with 13 published papers, which is a relative amount of 2.6%, with Articles Fractionalized of 3.30. The fourth and fifth authors in terms of the number of published papers come from Bangladesh. Abdul Moktadir produced 11 papers, which is 2.2% of the total number of works considered, and with articles fractionalized of 2.25. Sumit Paul as the second author from Bangladesh has produced 10 papers which is 2% of the total number of papers sampled with articles fractionalized of 2.08.

**Table 1.** Productivity of the authors

| Rank | Author Name | Country of Author | Number of publications | % | Articles Fractionalized |
|---|---|---|---|---|---|
| 1. | Awanish Kumar | India | 16 | 3.2 | 3.64 |
| 2. | Sunil Luthra | India | 15 | 3 | 3.88 |
| 3. | SachinMangla | England | 13 | 2.6 | 3.30 |
| 4. | Abdul Moktadir | Bangladesh | 11 | 2.2 | 2.25 |
| 5. | Sumit Paul | Bangladesh | 10 | 2 | 2.08 |

### 3.2. Country productivity

Table 2 shows the productivity of countries, which includes the number of produced papers. The table shows that the largest number of papers comes from India, 176, followed by China with a total of 154 papers, and in third place is the United Kingdom with 125 papers.

**Table 2.** Country productivity

| Rank | Country | Number of papers |
|---|---|---|
| 1 | India | 176 |
| 2 | China | 154 |
| 3 | UK | 125 |
| 4 | Italy | 88 |
| 5 | USA | 82 |
| 6 | Brazil | 54 |
| 7 | Iran | 49 |
| 8 | Spain | 44 |
| 9 | Thailand | 41 |
| 10 | France | 40 |

### 3.3. Productivity of institutions

Table 3 shows the productivity of institutions. The largest number of papers comes from India, i.e. the National Institute of Industrial Engineering (NITIE), with 18 of them in a relative amount of 3.63%, followed by Ton Duc Thang University from Vietnam with 13 papers in a relative amount of 2.62% and the University of Technology Sydney from Australia with 13 papers which is a relative amount of 2.62%.

**Table 3.** Productivity of institutions

| Institution | Country | Numberofpapers |
|---|---|---|
| National Institute of Industrial Engineering (NITIE) | India | 18 |
| Ton Duc Thang University | Vietnam | 13 |
| University of Technology Sydney | Australia | 13 |
| University of Dhaka | Bangladesh | 12 |
| Islamic Azad University | Iran | 10 |
| Yasar university | Turkey | 10 |
| London metropolitanuniversity | United Kingdom | 9 |
| University ofplymouth | United Kingdom | 9 |
| Bangladesh University of Engineering and Technology | Bangladesh | 8 |
| University of Southern Denmark | Denmark | 8 |

### 3.4. Analysis of papers

Table 4 shows the analysis of the papers. Of the total number of papers considered, the paper with the largest number of citations is the paper by Saberi, S., Kouhi-zadeh, M., Sarkis, J., & Shen, L. entitled "Blockchain technology and its relationships to sustainable supply chain management" which has a total of 735 citations, i.e. the average citation in a year is 183,750, and the normalized total citations is 18.2570. The second paper by a number of citations is the paper "Smart manufacturing" by Kusiak, A. with a total number of citations of 475, an average number of citations per year of 91,400 and a normalized total citation of 5.3839.

**Table 4.** Paper analysis

| Rank | Name of paper | Authors | Total Citations | Total citations per year | Normalized total citations |
|---|---|---|---|---|---|
| 1. | Blockchain technology and its relationships to sustainable supply chain management | Saberi, S., Kouhizadeh, M., Sarkis, J., & Shen, L. | 735 | 183.750 | 18.2570 |
| 2. | Smart manufacturing | Kusiak, A. | 457 | 91.400 | 5.3839 |
| 3. | Evaluating challenges to Industry 4.0 initiatives for supply chain sustainability in emerging economies | Luthra, S., & Mangla, S. K | 275 | 55.000 | 3.2398 |
| 4. | A review of Internet of Things (IoT) embedded sustainable supply chain for industry 4.0 requirements | Manavalan, E., &Jayakrishna, K. | 256 | 64.000 | 6.3589 |
| 5. | Modeling the blockchain enabled traceability in agriculture supply chain | Kamble, S. S., Gunasekaran, A., & Sharma, R. | 181 | 60.333 | 6.6566 |
| 6. | Drivers to sustainable manufacturing practices and circular economy: A perspective of leather industries in Bangladesh | Moktadir, M. A., Rahman, T., Rahman, M. H., Ali, S. M., & Paul, S. K. | 165 | 33.000 | 1.9439 |
| 7. | Blockchain technology and the sustainable supply chain: Theoretically exploring adoption barriers | Kouhizadeh, M., Saberi, S., & Sarkis, J | 136 | 68.000 | 14.9744 |
| 8. | A framework to overcome sustainable supply chain challenges through solution measures of industry 4.0 and circular economy: An automotive case | Yadav, G., Luthra, S., Jakhar, S. K., Mangla, S. K., & Rai, D. P. | 130 | 43.333 | 4.7810 |
| 9. | Time to seize the digital evolution: Adoption of blockchain in operations and supply chain management among Malaysian SMEs | Wong, L. W., Leong, L. Y., Hew, J. J., Tan, G. W. H., &Ooi, K. B. | 128 | 42.667 | 4.7075 |
| 10. | Developing green management standards for restaurants: An application of green supply chain management | Wang, Y. F., Chen, S. P., Lee, Y. C., & Tsai, C. T. S | 128 | 12.800 | 1.5360 |

If we analyze the topics contained in the papers shown in Table 4, the topics cover the impact of certain technologies such as blockchain or the Internet of Things on increasing the sustainability of the supply chain, or sustainability in general. On the other hand, if we analyze the productivity of authors and compare it with the papers that have the largest number of citations, we see that the third most productive authors Sunil L., and Mangla, S. and their work "Evaluating challenges to Industry 4.0 initiatives for supply chain sustainability in emerging economies" is the third most cited paper. Mentioned authors also appear in the paper:"A framework to overcome sustainable supply chain challenges through solution measures of industry 4.0 and circular economy: An automotive case" as coauthors, which is in line with their position as the most productive authors in the field of Industry 4.0 impact on supply chain sustainability.

### 3.5. Source analysis

Table 5 shows the sources with most published papers related to the topic. The table shows that the largest number of papers were published in the journal "Sustainability" (Switzerland), 106 of them, which represents 21.41% of all published papers. The second journal is the "Journal of cleaner production" (United Kingdom) with a total number of published papers 46 which represents 9.29% of all published papers.

**Table 5**. Source analysis

| Rank | Source | Freq | H-index | Total citations | Impact Factor |
|---|---|---|---|---|---|
| 1. | Sustainability | 106 | 85 | 799 | 3.251 |
| 2. | Journal of cleaner production | 46 | 200 | 1280 | 9.297 |
| 3. | Business strategy and the environment | 15 | 105 | 309 | 10.302 |
| 4. | International journal of supply chain management | 14 | 17 | 13 | 3,7 |
| 5. | Resources conservation and recycling | 14 | 130 | 763 | 10.204 |
| 6. | Computers and industrial engineering | 13 | 128 | 341 | 5.431 |
| 7. | International journal of production research | 12 | 142 | 1508 | 8.568 |
| 8. | Sustainable production and consumption | 12 | 26 | 129 | 5.032 |
| 9. | Technological forecasting and social change | 12 | 117 | 183 | 8.593 |
| 10. | International journal of production economics | 11 | 185 | 274 | 7.885 |

If the number of citations is considered, the journal with the highest number of citations is the "International journal of production research" (United Kingdom), 1508, followed by the "Journal of cleaner production" 1280. If we analyze the Impact Factor, the journal with the largest impact factor is the "Business strategy and the environment" (United Kingdom) with an impact factor of 10,302 followed by "Resources conservation and recycling" (Netherlands) with an impact Factor 10,204.

### 3.6. Co-authorship analysis

Figure 3 shows the coauthorship analysis. The authors with the highest productivity are also the authors who collaborate the most, and this primarily refers to Mangala S, Kumar A and Lutrha S. The mentioned authors, Red Cluster, collaborate with the authors Rakesh D. Raut, Pranjali Priyadarshini and Balkrishna Eknath Narkhede. In addition to the mentioned authors, the authors in the Red Cluster collaborate with the authors from the Blue claster, especially Abdul Moktadir. It should be emphasized that the analysis of the cluster of authors shows that there are a number of authors who are not interconnected and do not collaborate with other authors, but also that at least two authors who collaborate with each other within the cluster.

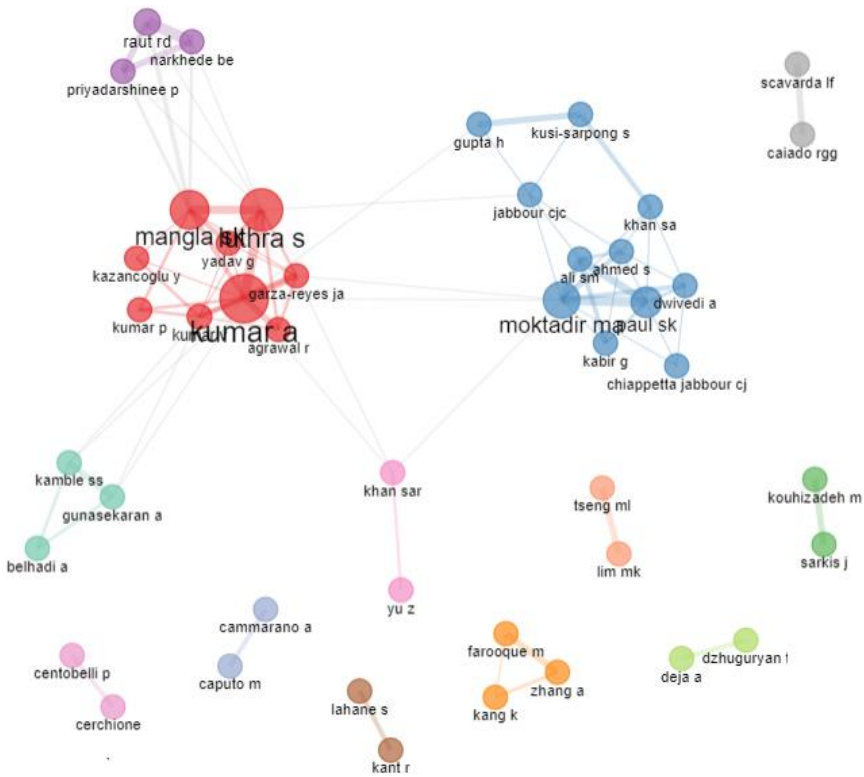


**Figure 3.** Co-authorship clasters

It is evident that the red cluster has the most impact on the other autors, i.e. it cooperates the most with all other clusters, which is also visible in the number of papers that autorsfrom the red cluster produce. Furthermore, most of authors come from India and China, and the most of authors deal themes related to the supply chain and supply chain management.

### 3.7. Mutual citation analysis

Figure 4 shows the mutual citation of authors. The authors are grouped into four clusters, red cluster, green cluster, purple cluster and blue cluster. Authors within all clusters are interconnected and collaborate with each other. Stefan A. Seuring stands out as the author of the article that is most cited in the red group of the cluster, which almost all other authors from the red cluster used as the foundation for their papers. Stefan A. Seuring in his paper entitled "From a literature review to a conceptual framework for sustainable supply chain management" (6195 citations) shows an insight of all studies between 1994 to 2007, as well as a methodology for summarizing studies in supply chain management through lens of safety and sustainable development (Seuring and Müller, 2008). His research became the foundation for research later research that is conducted by Craig R. Carter (4348 citations).Seuring later in his research also defined a new framework that could be used for sustainable supply chain management (Carter and Rogers, 2008).

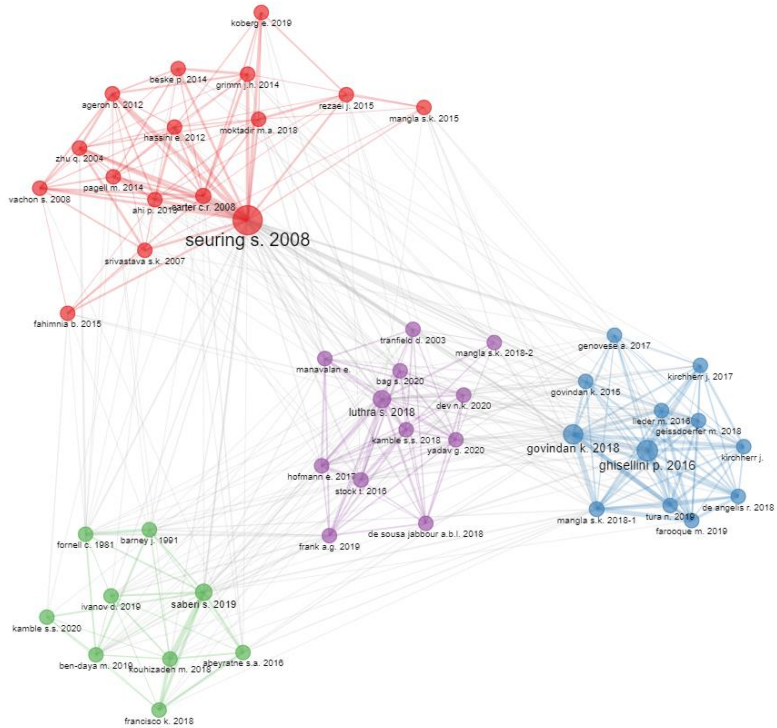


**Figure 4.**Mutual citation analysis

Qinghua Zhu (2939 citations) is also another notable researcher from the red cluster, that focuses on supply chain integration research to improve the industry's productivity and sustainability, i.e. investigates the performance of companies that have integrated or altered their supply chain towards becoming sustainable (477 citations) (Zhu and Sarkis, 2004). In addition, it is essential to mention Payman Ahi (1438 citations) who looks at the conceptual definitions of a green and a sustainable supply chain i.e. defines the key characteristics of a sustainable and a green supply chain. There is a conclusion that the green supply chain is a significantly narrower area compared to a sustainable supply chain (Ahi and Searcy, 2013). Stefan A. Seuring is the link between the red cluster and all other clusters, especially the purple cluster. Within the purple cluster, the most prominent author is Sunil Luthra with his paper "Evaluating challenges to Industry 4.0 initiatives for supply chain sustainability in emerging economies" (455 citations) in which he outlines the growth of Industry 4.0 technology across all industries. Furthermore, SunilLuthra examines the prospects of implementing Industry 4.0 technology, as well as the obstacles that come from using automation technology arising from Industry 4.0 in the supply chain to improve its sustainable business practices. Based on an analysis that involves 96 firms in the Indian manufacturing sector, Sunil Luthra's research found a total of 18 difficulties associated with the integration of Industry 4.0 innovations. (Ahi and Searcy, 2013).

Another author within the purple cluster is Tim Stock (1695 citations) who in his paper "Opportunities of Sustainable Manufacturing in Industry 4.0"examines the issues of globalization and rising product and service demand.The article outlines how new technological advancements should be

designed with minimal environmental impact, as well as the possibilities of Industry 4.0 technologies in the context of boosting industrial sustainability, i.e. the establishment of a green production paradigm. (Luthra and Mangla, 2018). SachinKamble is the third most important researcher in the purple cluster, who in his work "Sustainable Industry 4.0 framework: A systematic literature review identifying current trends and future perspectives" (671 citations) examines how scientists' approach when conducting researching of Industry 4.0 technologies.Industry 4.0 technologies are related to sustainable development, according to SachinKamble, because they can be used to improve sustainability by increasing effectives and efficiency of processes (Stock and Seliger, 2016). Sunil Luthra (198 citations) and Gunjan Yadav (198 citations) stand out as the author who represents the link between the purple cluster and other clusters, especially the blue cluster (Kamble, Gunasekaran and Gawankar, 2018). Sara Saberi is by far the most quoted researcher in the green cluster, where she discusses the application of blockchain technology as well as the prospects of using it to improve supply chain sustainability.In his article, he examines the blockchain as well as its possibility of becoming a disruptive technology capable of overcoming supply chain concerns such as transparency and security (Yadav et al., 2020). Sara Saberi (1246 citations) is also the author who is the link between the green cluster and other clusters, and most of all the purple cluster. In addition to Sara Saberi, KouhizadehMahtab (268 citations) appears out from the green cluster as the significant author, that looks into the prospects of using blockchain technology to improve supply chain sustainability.Throughout his paper, Kouhizadeh Mahtab explains what blockchain technology is and what the possibilities of using it in the supply chain are, as well as future problems that may occur as a result of its deployment (Saberi et al., 2019). Among other authors in the green cluster, Dmitry Ivanov (745 citations) stands out, researching the influence of Industry 4.0 innovations on the developing risks in the supply chain. Ivanov states that the he is one of the first researches that connects business, engineering and digitalization of business with the risks in the supply chain (Kouhizadeh and Sarkis, 2018). If we analyze the citations of authors from the blue cluster, the two most prominent authors are PatriziaGhisellini (citation number 3625) and Kannan Govindan. PatriziaGhisellini examines the circular economy and the prospects it presents in terms of increasing sustainability.

Furthermore, authors research governance policies in different countries around the world and how different governance policies affect sustainability, i.e. the creation of a circular economy (Ivanov, Dolgui and Sokolov, 2019). Moreover, Kannan Govindan (507 citations) in his work gives a systematic overview of the drivers, barriers and practices that lead to the creation of a circular economy from the standpoint of supply chain.

### 3.8. Co-occurrence network

Co-occurrence analysis allows a simpler and easier understanding of keywords as well as the interrelationship of keywords. Figure 5 shows the keywords classified into clusters related to the Industry 4.0 and supply chain sustainability.

As can be seen in Figure 5, the analysis identified a total of 5 keyword clusters, and each of the clusters is described in Table 6.

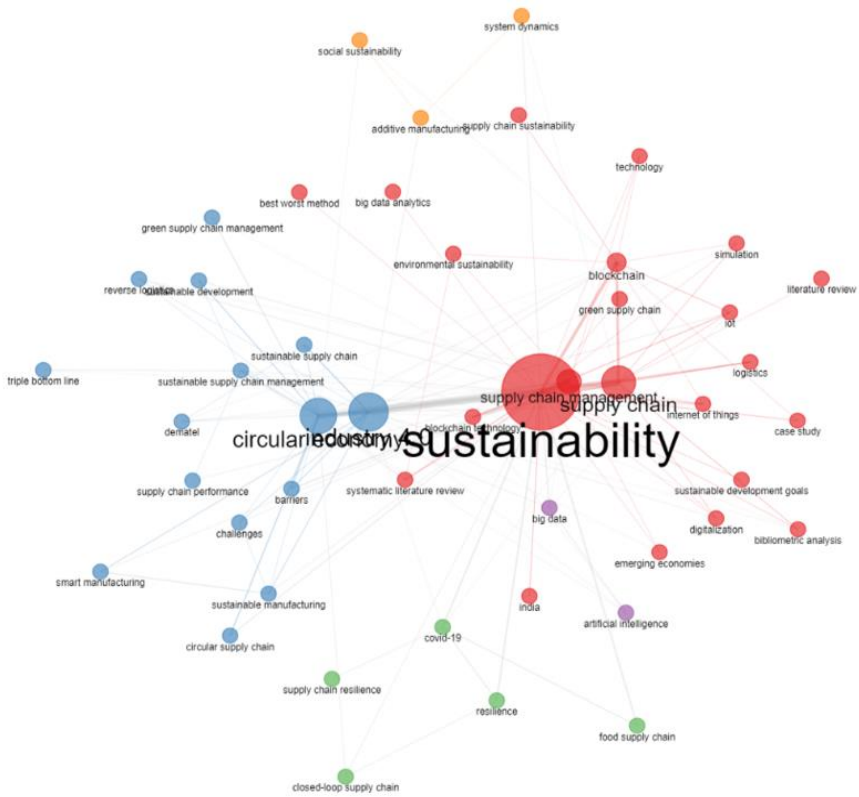


**Figure 5.**Co-occurrence network in clusters

Two subtopics, elements of sustainable development and their impact on sustainability, i.e. Industry 4.0 Technology and the supply chain, have been highlighted in Cluster 1.When it comes to the themes' interconnection, it was discovered that there is a very strong link among sustainability and supply chain, as shown in Figure 5.Sustainability and development of sustainable supply chains are particularly important for organizations given the requirements that stakeholders place on the supply chain, such as requirements for reduced negative environmental impact, improved attitudes towards the economic and social segment of sustainability due to global supply chain distribution and different conditions which predominate in different organizations in different countries of the world (Koberg and Longoni, 2019). Given the imperative to increase the sustainability of supply chains there is need for the development of new theories and concepts that can increase sustainability (Allen, Zhu and Sarkis, 2021). For the development of new theories and approaches related to increasing the sustainability of the supply chain, there are several technologies that are based on Industry 4.0, such as the Internet of Things (Mastos et al., 2020) big data or blockchain applications, primarily in the context of increasing transparency and security (Esmaeilian et al., 2020) of cooperation between stakeholders involved in the supply chain and reducing the cost of processes in the supply chain. Therefore, implementing Industry 4.0 technology in the supply chain necessitates the adoption of digitalization, or supply chain digital transformation (Nasiri, 2020).

**Table 6**. Co-occurrence network analysis

| Theme | Sub-topic | Keywords |
|---|---|---|
| Cluster 1 (red color)<br>Sustainable development, impact of sustainable development on Industry 4.0 technologies and supply chains sustainability | The impact of sustainable development on the supply chain | Systematic literature review<br>Big dana analytic<br>Environmental sustainability<br>Supply chain sustainability<br>Technology<br>Supply Chain management<br>Blockchain<br>Logistic<br>Iot<br>Digitalization<br>Sustainability |
| | Industry Technologies 4.0 and Supply Chain Sustainability | |
| Cluster 2 (green color)<br>Supply chain and food supply chain resistance | COVID-19 and supply chain | Supply chain resilience<br>Resilience<br>COVID-19<br>Food supply chain<br>Closed loop supply chain<br>Food supply chain |
| | Resistance in the supply chain | |
| Cluster 3 (blue color)<br>Circular Economy and Industry 4.0 | The influence of Industry 4.0 on the circular economy's development | Smart manufacturing<br>Sustainable manufacturing<br>Circular supply chain<br>Sustainable development<br>Green supply chain<br>Challenges<br>Sustainable supply chain<br>Reverse Logistics<br>Supply chain performance<br>Sustainable supply chain |
| | Supply chain and circular economy | |
| Cluster 4 (Purple color)<br>Industry Technologies 4.0 | Application of big data and artificial intelligence | Artificial intelligence<br>Big data |
| Cluster 5 (Orange)<br>Production and sustainability | Potentials of Industry 4.0 in increasing social sustainbiltiy | Additive manufacturing<br>Social sustainability<br>System dynamic |

So, the Cluster 1 is focused on the prospects presented by technical solutions of Industry 4.0 in strengthening the supply chain's sustainability, according to the analysis of the cluster. The use of Industry 4.0 technologies can increase the efficiency and effectiveness of processes in supply chains, but it can also bring with it risks associated primarily with cybersecurity in the chain.

If the research from Cluster 1 relate to other clusters, the link is visible with cluster 3, thatdescribes sustainability and the circular economy. The circular economy impliesrecycling which addresses the environmental component of sustainability, i.e. has an impact on increasing the supply chain's sustainability. To establish a circular economy, it is possible to use technological advances that are being developed within Industry 4.0. (Manavalan and Jayakrishna, 2019).

In cluster 2, the dominant themes relate to the resistance of the supply chain that has importance due to changes in the business environment caused by disturbances of the COVID-19 virus, but also war and political crises in Eastern Europe. The COVID-19 pandemic has brought to light the importance of global supply chains, leading to the need to develop recovery plans to respond to recovery challenges once the COVID-19 pandemic ends (Paul, 2021). Given the need to develop supply chain resilience, researchers in this field are

beginning to look at possible ways to increase supply chain resilience, which turn out to be primarily innovation (Konstantinou, Chatzoudes and Chatzoglou 2021), increasing the number of suppliers involved in the supply chain thus reducing dependence on one supplier (Lahyani et al., 2021) and especially the digitalization. In addition, the disruptions caused by the COVID-19 pandemic have particularly affected the food supply chain, which is why the food supply chain must adapt to the new conditions, i.e. it must develop mechanisms to increase its resilience (Ali et al., 2022). The development of mechanisms involves primarily risk management in terms of identifying risks that may result in disruptions, followed by analyzing identified risks and defining mitigation plans to reduce or eliminate identified risks (Bret et al., 2021). In addition, increasing the resilience of the supply chain, and the food supply chain can be achieved by shortening the chain, which means that the chain is no longer globally distributed but reduced to local suppliers reducing the risk that global suppliers cannot meet the defined resource needs they need to provide (Marusak et al., 2021).

Disruptions caused by the necessity for self-isolation of truck drivers and in general closure of nations to avoid the transmission of COVID-19 infection, or shutdown of businesses to decrease human interaction and risk from the virus's transmission, reveal the need to strengthen and shorten the food supply chain. The closure caused financial problems for the organizations, which put them at risk of bankruptcy. Furthermore, closure and potential bankruptcyhas reduced the number of able stakeholders in the supply chain to supply the necessary resources, leading to strains in the supply chain but also the need for states to define different support policies in such cases (Fan et al., 2021).

If we analyze the connection of cluster 2 with other clusters, the link is visible between Cluster 1, i.e. the cluster whose main topic is the impact of Industry 4.0 on the sustainability of the supply chain and cluster 3 whose main topic is sustainability and the circular economy. The reason for this can be found through the impact that the circular economy has on sustainability i.e. on the development of supply chain resilience as well as the impact of technological innovation in Industry 4.0 on supply chain sustainability.

Three main themes were identified within Cluster 3: the influence of Industry 4.0 on the creation of the circular economy, the supply chain and the circular economy, and the supply chain's sustainability. With the growing need related to sustainability, which is especially significant for businesses located worldwide, the subject of the influence of Industry 4.0 on the establishment of the circular economy is becoming increasingly importan. Given this, as well as the potential provided by Industry 4.0 technologies, scientists are concentrating on the prospects of implementing Industry 4.0 technical breakthroughs (Dwivedi et al., 2021) such as the big data, the development of a circular economy, artificial intelligence, the Internet of Things but also other technologies (Abdul-Hamid et al., 2021). Industry 4.0 technological advancements could be applied in the design of the circular economy in a wide range of sectors, particularly those with a major negative impact on sustainability.The palm oil business is an example of such industry, where the negative environmental impact of the production process can be decreased through upgrading of the production process using Industry 4.0 technical innovations(Acerbi et al., 2021). The so-called SMART solutions, which use Industry 4.0 technologies, include the possibility of achieving system autonomy as well as boosting the efficiency and effectiveness of production processes, which lowers negative environmental impact and thus promotes sustainability.

Within Cluster 4, the topic of Industry 4.0 technologies was identified, primarily

artificial intelligence and big data. Artificial intelligence finds application in various industries and can primarily be used to help in decisionmaking (Duan, Edwards and Dwivedi, 2019) or can be used as an aid in shaping decisions made by the management of organizations that may be related to forecasting future trends, i.e. demand (Khan and Al-Badi, 2020), which is especially important in the supply chain. On the other hand, if we are talking about big data, big data is created by collecting data from sensors located on various machines and devices which is especially useful if we are talking about the supply chain. Big data analysis can lead to insights into supply chain trends. In this context, the application and combination of big data with other technologies in the supply chain may result in increased revenue due to better customer information collected and contained in big data (Sundarakani, Ajaykumar and Gunasekaran, 2021). When we discuss the connections between subjects in Cluster 4 and other topics, we can see the link between blockchain technology and supply chain sustainability, which is significant when we discuss supply chain management in the context of lowering the need for traditional supply chain documents. (Černý et al., 2021).

As a result of develpoment of Industry 4.0, new ways to production have emerged and the most prominent is 3D printing, also known as additive manufacturing. The advancement of additive manufacturing has the potential to have a wide range of effects on society, including employee safety and health, quality of life, workplace conditions, and so on(Matos et al., 2019). In addition to the above, additive manufacturing has a significant impact on environmental sustainability as additive manufacturing consumes significantly lower resources, i.e. resources are spent significantly more efficiently compared to the traditional approach to production (Javaid et al., 2021). More efficient use of resources also reduces the need for resources, which means less stress in supply chains to secure resources. On the other hand, organizations involved in the supply chain that use additive manufacturing may become more competitive as additive manufacturing becomes a disruptive technology that affects sustainability (Naghshineh et al., 2021).Furthermore, the emergence of additive manufacturing into the supply chain requires a decentralized supply chain design, where the vendor provides the resources required for additive manufacturing to producers who can produce the required components and deliver them directly to customers' distribution centers(Rinaldi et al., 2021). As a result, additive manufacturing is one of the Industry 4.0 technologies that has an impact on sustainability, particularly the social component of sustainability, owing to the lower risk of accidents occurring during manufacturing per employee involved in production, and then the sustainability components, as it can lead to the development of competitive advantage, i.e. a reduction in the need for resources due to more efficient use of available resources.

## 4. Discussion

The need to develop sustainability is driven by growing societal concerns about climate change resulting in rising global temperatures, disrupting flora and fauna as well as generally negative environmental impacts, excessive and uncontrolled depletion of nonrenewable resources, and differences in standards and quality of life.

Supply chains oversee providing all the necessary resources for the normal functioning of society, i.e. the normal course of processes in business organizations. Moreover, due to the prevalence of global supply chains and the diverse conditions in which supply chain organizations operate, there are challenges to ensuring supply chain sustainability, rational use of natural resources, and improving the efficiency and effectiveness of current supply chain operations. There is a reduction in the

requirement for resources when the efficiency and effectiveness of supply chain processes improves.

Technological advancements that can increase the supply chain's sustainability are emerging as a result of the growth of Industry 4.0. Such technologies are primarily related to big data and sensors, analysis of colected data with, for example, artificial intelligence, aid in the identification of opportunities for improvements that will lead to lower need for resource requirements or reduce negative impact on sustainability components. An example of such technologies, apart from artificial intelligence and big data, is additive manufacturing, which uses resources significantly more efficiently. On the other hand, it is necessary to mention the possibility of using blockchain technology, which can have an indirect effect on increasing sustainability, and then directly on increasing the security of the supply chain.

Many scholars started to evaluate the potentials of Industry 4.0 technologies in boosting supply chain sustainability over the time from 2011 when the phrase first arose, i.e. when its development began, until the end of 2021 and the beginning of 2022, according to the research. As a result, five separate topic clusters were found.

### 4.1. Sustainability and the impact of Industry 4.0 technologies on sustainability and supply chain

Researchers in Cluster 1 generally explain the influence of Industry 4.0 technologies on changing the structure of the supply chain, mainly through digitization of business or the use of based on the internet of Things, blockchain technology, and big data. According to research conducted within this cluster, the use of Industry 4.0 technologies can affect supply chain sustainability, particularly environmental sustainability.The need to improve the supply chain's sustainability, which includes boosting environmental, economic, and social sustainability, is an especially important research topic inside this cluster. It was discovered that business digitalization is becoming increasingly important. Regarding to that, there are risks, primarily related to cybersecurity risks that can have a significant impact on the safety of customer and user information, as well as information relating to the company. Ultimately, despite the possible concerns, it was discovered that Industry 4.0 technologies had a positive impact on the development of sustainability, i.e. boosting the supply chain's sustainability.

### 4.2. Resistance of the supply chain and food supply chain

The COVID-19 virus pandemic has highlighted supply chain vulnerabilities, which are primarily visible through interruptions in the chains created by state closures. Risks of supply chain disruptions pointed to the need to develop plans to address risks that could affect interruptions, which include changing the approach to supply chain design, which involves more organizations that can ensure timely delivery of resources or shorten supply chains. However, research has identified that one of the most important ways to increase supply chain resilience is innovation and development, i.e. the implementation of technological solutions aimed at anticipating and reducing the risk of potential variability that will result in disruption of supply chain functionality. It should be emphasized that the food supply chain is a particularly important area due to the need to ensure enough food, i.e. to ensure efficient and effective production without significant negative environmental impacts.

### 4.3. Circular Economy and Industry 4.0

The circular economy has a direct impact on the supply chain sustainability, which is primarily measured by the reuse of materials and components across the supply chain.

Due to the reuse of previously used resources, recycling greatly reduces the requirement for resources that will be utilized in production. However, the implementation of Industry 4.0 technologies also can lead to the ability to ensure the accomplishment of UN goals, which are primarily related to renewable energy production, workplace risk reduction, and employee burden reduction, as well as the development and implementation of disruptive technology, which affects competitiveness and the like.Similarly, if we consider the impact of Industry 4.0 on, say, metropolitan regions, urban areas become more sustainable, as citizens are encouraged to generate and utilize energy more sensibly, which significantly impacts supply chain relief and promotes sustainability.

### 4.4. Industry 4.0 Technology, Manufacturing and Sustainability

Clusters 4 and 5 in this chapter are combined because they are very similar to each other. Given by the fact that Industry 4.0 was created based on the automation of production processes, and the application of technological innovations that have resulted in more efficient and effective process management, authors createtearmsocalled SMART factories that can also impact the sustainability. On the other hand, this approach enables the reduction of the need for human labor in activities that pose a high risk to humans. Furthermore, technologies such as additive manufacturing affect the more rational use of resources in production, which also increases sustainability.

## 5. Conclusion

The results of a bibliometric review of the influence of Industry 4.0 on supply chain sustainability are presented in this research.
The study identified the most influential scholars on the influence of Industry 4.0 on sustainability, the most productive states in terms of research, the journals with the most articles related to sustainability, Industry 4.0, and the supply chain, and examined the most cited articles and relationships between articles.

While India as a country is the most productive in this discipline, Awanish Kumar from India stood out as a particularly noteworthy author in this topic. It was also discovered that the most important and influential authors are divided into two groups. The most significant journal in this area is Sustainability Journal.

When the major topics are analyzed, the themes can be described as sustainability and a sustainable supply chain, i.e. circular economy, and the impact that Industry 4.0 has on enhancing sustainability.

Furthermore, it was discovered that researchers have a considerable influence and interest in the potential applications of technological 4.0 technology solutions. Also, scholars are dealing with supply chain resilience and opportunities to increase resilience through the application of Industry 4.0 technologies, which proved particularly significant when discussing the COVID-19 virus pandemic, which highlighted the vulnerability of global supply chains, resulting in a reduced ability to meet the needs of stakeholders.

The study discovered that the evolution of Industry 4.0 could be seen in various aspects of social and economic activities, and that new technological advances can improve corporate efficiency and effectiveness while also increasing sustainability.

The supply chain is one of the most important areas affected by Industry 4.0, where the need of guaranteeing sustainability is becoming increasingly highlighted due to increased demands connected to the rational use of resources available, i.e. their consumption.

The result of research showed how supply chain organizations should invest in the adoption and development of their processes utilizing Industry 4.0 technologies, since these technologies might have a beneficial

impact on company or enable easier and more efficient management. When adopting technologies, on the other hand, it is vital to examine the implementation risks that may be related to the lack of security of information kept in databases, or the possibility of third parties accessing or controlling implemented technologies.

This research has limitations. The fundamental limitation is manifested through the focus exclusively on professional and scientific papers, which means that books, monographs, chapters in books and the like are excluded from research. The second limitation concerns the focus exclusively on the SCOPUS database, without including other databases. As a result, future studies in this subject should look into the phenomena of supply chain shortening in order to improve the chain's sustainability, as well as the influence that supply chain shortening, or the potential for Industry 4.0 technologies to shorten the supply chain, has.

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**Matija Kovačić**
University North,
Koprivnica,
Croatia
matkovacic@unin.hr
ORCID 0000-0002-5472-5192