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SUSTAINABLE PRODUCTION: A BIBLIOMETRIC REVIEW

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Abstract

The purpose of this document is to determine the scope of studies on sustainable manufacturing, to identify influential journals, authors and documents, to analyze the intellectual structure of the relevant field, and to reveal emerging themes and research gaps on the subject. In this study, 1264 articles published between 1987-2022 from the Web of Science database about sustainable manufacturing were subjected to bibliometric analysis. The Biblio-metrix package in the R program was used for data analysis and visualization. In the study, both descriptive analyzes for sustainable production literature were used, and keyword analyzes were used to determine current and future trends. The findings reveal that the literature on sustainable manufacturing is quite new. Examining citation analyzes of journals, authors, and documents reveals that the results provide a high level of scientific content for a newly growing literature.

Keywords: Sustainable Manufacturing, Sustainable Production, Literature Review, Bibliometric, Biblioshiny

JEL Codes: L23, L60, M11

SÜRDÜRÜLEBİLİR ÜRETİM: BİBLİYOMETRİK BİR DEĞERLENDİRME

Öz

Çalışmada sürdürülebilir üretim araştırmalarının kapsamını ve gelişimini belgelemek; etkili dergileri, yazarları ve belgeleri belirlemek, ilgili alanının entelektüel yapısını analiz etmek ve konu hakkında ortaya çıkan temaları ve araştırma boşluklarını belirlemek amaçlanmıştır. Bu araştırma sürdürülebilir üretim hakkında Web of Science (WOS) veri tabanından 1987-2022 yılları arasında yayınlanmış 1264 makaleyi bibliyometrik analize tabi tutmuştur. Veri analizi ve görselleştirme için R programı içinde Biblio-metrix paket kullanılmıştır. Çalışmada hem sürdürülebilir üretim literatürü için tanımlayıcı analizler hem de mevcut ve gelecekteki trendleri belirleyebilmek için anahtar kelime analizleri kullanılmıştır. Bulgular, sürdürülebilir üretim ile ilgili literatürün oldukça yeni olduğunu ve her yıl çalışma hacminin arttığını ortaya koymaktadır. Dergilerin, yazarların ve belgelerin alıntı analizleri incelendiğinde, yeni büyüyen bir literatür için sonuçların yüksek düzeyde bilimsel içerik sağladığı görülmektedir.

Anahtar Kelimeler: Sürdürülebilir İmalat, Sürdürülebilir Üretim, Literatür Taraması, Bibliyometrik, Biblioshiny

JEL Kodları: L23, L60, M11

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INTRODUCTION

Increasing environmental pressures with global resource consumption, climate change, water resources and air pollution all over the world bring sustainability issues to the agenda more and more each day (Cevik Aka, 2022). Understanding the importance of sustainability requires examining traditional management approaches in relation to sustainability in many ways. Focusing on "sustainability" in business and society has become one of the important developments (Sarkis, Zhu, and Lai, 2011; Abbasi and Nilsson, 2012). For sustainability in production, the existing production patterns in the industry have to be changed. As a result of increasing pressures, a system developed as sustainable production has emerged (Sanyé et al., 2014; Yip, Zhou, and To, 2022). Sustainable production is defined as the realization of production using methods and processes that will support the reduction of negative environmental impacts caused by energy consumption, greenhouse gas emissions or waste (Bhanot, Rao, and Deshmukh, 2017). Sustainable production aims to increase the efficiency of all products produced throughout their life cycle (Jovane,Westkämper, and Williams, 2018).

Sustainable production is especially seen as one of the sustainable supply chain management practices (Jovane et al., 2018; Xu and Wang, 2018; Yip et al., 2022; Zhou, Yip, Ren, and To, 2022). However, due to the fact that sustainable production has a wide field of study, it was insufficient to examine the subject only within the sustainable supply chain, and the sustainable production literature has developed in particular. These developments have encouraged researchers to research sustainable production from the perspectives of producers (Chai et al., 2007; Pusavec, Krajinik and Kopac 2010; Jimenez-Gonzalez, 2011; Galvis et al., 2012; Moktadir et al., 2018; Marjanovic et al., 2020), consumers (Khor and Hazen, 2016) and society (Rakic, Pavlovic, and Marjanovic, 2021). Different research areas have resulted in the development of a knowledge base for sustainable production.

There have been many literature studies on the sustainable supply chain. Borregan-Alvarado et al. (2020)'s, Zhang et al. (2021)'s, Patidar et al. (2022)'s, Wangsa et al. (2022)'s, Yu et al. (2022)'s and Liu et al. (2023)' studies are important literature review studies on the subject. However, few bibliometric studies on sustainable production have been found. This research was developed to examine the academic and scientific literature on sustainable production. This bibliometric study is important in terms of allowing the characteristics and general trends of publications related to sustainable production to be determined. In addition, it is thought that this study is important in terms of discovering and analyzing the data of all the relevant literature published so far and obtaining insights about the evolution of the subject. This will help the academic community that will specifically study sustainable production, where to start their studies, which studies they should focus on, and which research topics they should focus on.

Bibliometric analysis is a quantitative method that methodically evaluates the characteristics of studies prepared on any subject from various aspects (Yu, Xu, and Wang, 2019). The scarcity of studies that systematically examine the relevant literature in terms of various characteristics necessitated focusing on studies written on sustainable production. For this reason, the use of the bibliometric analysis method was seen as the most appropriate tool in the document. Exploring and analyzing volumetric data on sustainable production, using scientific mapping and bibliometric techniques, and identifying current and future trends of the study are important for the related field. In this study, it was aimed to examine the scientific researches published directly on sustainable production until the end of 2022 and to reveal the conditions for the development of the related field. Five research questions (RQs) are addressed in this study and are listed below.

RQ1: What is the volume of sustainable production literature and its productivity over the years?

RQ2: Which journals, authors and documents have had the greatest impact on sustainable production literature?

RQ3: What is the global distribution of sustainable production literature?

RQ4: What does the main topics, trend topic reveal in the sustainable production literature?

RQ5: What is the intellectual structure of the sustainable production knowledge base?

Related studies were taken from the Web of Science Core Collection, which has a large scientific literature, and the Biblio-metrix package of the R program was used. A total of 1264 documents related to sustainable production were examined in the study.

The study consists of five sections. In the first section, the theoretical background on sustainable production is mentioned and literature studies prepared on the subject are included. The second part is theoretical background. In this section, literature reviews about sustainable production are included. The third part is material and method. This section presents a framework for the method used in the document, research criteria, selection of sources, and data analysis. In the next section, bibliometric analysis results on sustainable production are presented and research questions are answered. While the results of the study are included in the fourth section, the results and limits of the study are emphasized in the last section.

THEORETICAL BACKGROUND

Interest in sustainable production has been growing for the last 15 years and still remains a topic of interest to researchers. The "2030 Agenda for Sustainable Development", which includes 17 sustainable development goals (SDG) approved by the United Nations in 2015, triggered the growth in its publications on sustainable supply chain exponentially (Nimsai, Yoopetch, and Lai, 2020). The fact that one of the seventeen goals of sustainable development is directly related to sustainable production has also been influential in the development of sustainable production and consumption models. As a reflection of this situation, it can be stated that there is an increase in the number of sustainable production documents.

Although economic, environmental and social problems occur in many activities in which countries grow economically, governments focus on increasing the number of production operations (Sangwan, 2011). Further growth in the production system as compared to consumption systems also results in over-consumption of production resources. Sustainable production, which protects natural resources, has been important because of the economic contribution of production to GDP and environmental and social benefits on society (Bastas, 2021). The urgent need for sustainable consumption and production requires systems change, with action from all stakeholders (governments, financial institutions and businesses) and geographies (UN, 2021). It is therefore logical that sustainable production has attracted the interest of both many academics and practitioners in recent years. The sustainable manufacturing literature is recognized to be extensive and diverse (UN, 2021), and Table 1 literature reviews on sustainable manufacturing seem to reflect this.

A few bibliometric studies on the subject have been made to gain perspective on the development of sustainable production or sustainable manufacturing literature. This is important in determining the nature of previous efforts (Nimsai et al., 2020). Table 1 shows the literature studies directly related to sustainable production or sustainable manufacturing. Apart from Table 1, sustainable production or sustainable manufacturing can be found in other aspects such as digitalization (Shah et al., 2020), sustainable consumption (Roy and Singh, 2017), circular economy (Gundu et al., 2020) machine learning (Jamwal et al., 2022), lean manufacturing (Hartini et al., 2015; . Bhatt, Ghuman, and Dhir, 2020) industry 4.0 (Gholami et al., 2021; Jamwal et al., 2021; Sartal et al., 2020; Ching et al., 2022). There are also literature studies with keywords.

Table 1: Bibliometric reviews of the last 5 years on sustainable production or sustainable manufacturing

Yazar	Yip et al. (2022)	Malek and Tushar (2020)	Caterino et al. (2022)
Title	Discover the trend and evolution of sustainable manufacturing: a thematic and bibliometric analysis	A systematic literature review to map literature focus of sustainable manufacturing	Research trends in clean, green and sustainable manufacturing: a bibliometric review
Focus	Sustainable manufacturing	Sustainable manufacturing	Sustainable manufacturing
n	1000+	541	563
Source	Scopus and WoS	Scopus	Scopus
Timeframe	1991-2020	2001-2019	2000-2021
Search Keywords	“Sustainable manufacturing”	(“Sustainable Manufacturing”, OR “Sustainable Production”, OR “Sustainable Operations”, OR (“Sustainable” and “Manufacturing)	("green manufacturing" OR "green production" OR "clean manufacturing" OR "clean production" OR "sustain* manufacturing" OR "sustain* production")
Field	"yazar", "başlık", "kaynak" ve "özet"	TITLE-ABS-KEYWORDS	TITLE

Among the studies in Table 1, the earliest screening date is 1991, and the latest is 2021. In these reviews, the number of documents (according to Scopus and Web of Science) and the size of the document review datasets ranged from 541 to 1000+.

Considering the number of studies in Table 1, it can be said that research on sustainable production has matured, but these studies still do not adequately express sustainable production. In addition, Table 1 shows that studies on sustainable production were prepared only by Yip et al. (2022), Malek and Tuhsar (2020) and Caterino et al. Yip et al. (2022) have different aspects in common from the studies in Malek and Tuhsat (2020). Yip et al.'s study is linked to this study in several ways. Researchers mostly built their article on the keyword "sustainable manufacturing" and aimed to reveal the evolution and research trends of sustainable manufacturing studies. While doing this, it also searched both the title, the source and the "summary", causing the number of researches to be quite high. The difference of this study from Yip et al. (2022) is to conduct research with sustainable production and, most importantly, to ensure that the keywords are searched only in the titles and not distracted from the subject. Moreover, this document differs fundamentally from the document of both Yip et al. (2022) and Caterino et al. (2022) in that it even includes the first publication on the subject. The remarkable situations in Malek and Tushar (2020)'s study are the narrowing of the subject area as “Engineering”, “Business”, “Management and Accounting”, “Decision

Sciences", "Environmental Science", "Materials Science" and focusing on management issues with abstract analysis. In this document, however, there was no narrowing of the studying area. Sustainable manufacturing has been viewed from a wider perspective.

As stated in the research questions, this review updates previous literature review studies from various aspects. Firstly, the current review covers a longer period than the first study on the subject, to the end of 2022. Second, a large set of documents (n = 1264) was analyzed. Third, the unused R program was used in bibliometric analyzes on this subject.

MATERIALS AND METHOD

In this study, the literature on sustainable production as a bibliometric technique was analyzed. The widely used bibliometric scientific approach is an important technique that summarizes the available literature. Bibliometric analysis is a powerful tool that can give a general idea about the trend of a particular research area and reveal its limitations. The benefit of this analysis includes extracting original articles and citation summaries to conduct general publication analysis in a particular area of interest (Yu et al., 2019). The strength of bibliometric studies lies in their ability to synthesize patterns in knowledge production in large numbers of documents (Zupic and Čater, 2015). Bibliometric analysis is very important in determining the future research trend of the studied field by comprehensively evaluating documents from different perspectives. In such an analysis, mathematical and statistical methods are used to evaluate the publications on the relevant subject (Cabeza et al., 2020).

Although there are bibliometric studies prepared on sustainable production, it has remained in a very narrow area both in terms of content and number of studies, and a comprehensive bibliometric analysis has not been applied. In practice, there are many different bibliometric analysis tools developed such as SciMAT, Sci2, Citespace, CitNetExplorer, VOSviewer and R. On the other hand, thematic analyzes were made in this study. Thematic analysis is the search for main and subthemes in a particular research area. In this document, the R program was used, which works for bibliometric analysis of articles from databases provide visualization graphics such as thematic, trends, citation network. R is an ecosystem software which means all functionality is shared with users in an open-source environment (Dervis, 2019). Biblio-metrix package was used on this program. Biblio-metrix is open-source statistical software that can be used to simultaneously analyze and map bibliographic data. Bibliometrix has been written in R, consisting of more than 16,000 software packages to date, to analyze and visualize bibliographic data from the WoS and Scopus databases (Dervis, 2019). In addition, an R package called 'Biblioshiny' was installed to provide this analysis. Relational techniques were applied with this package to explore the relationships among units such

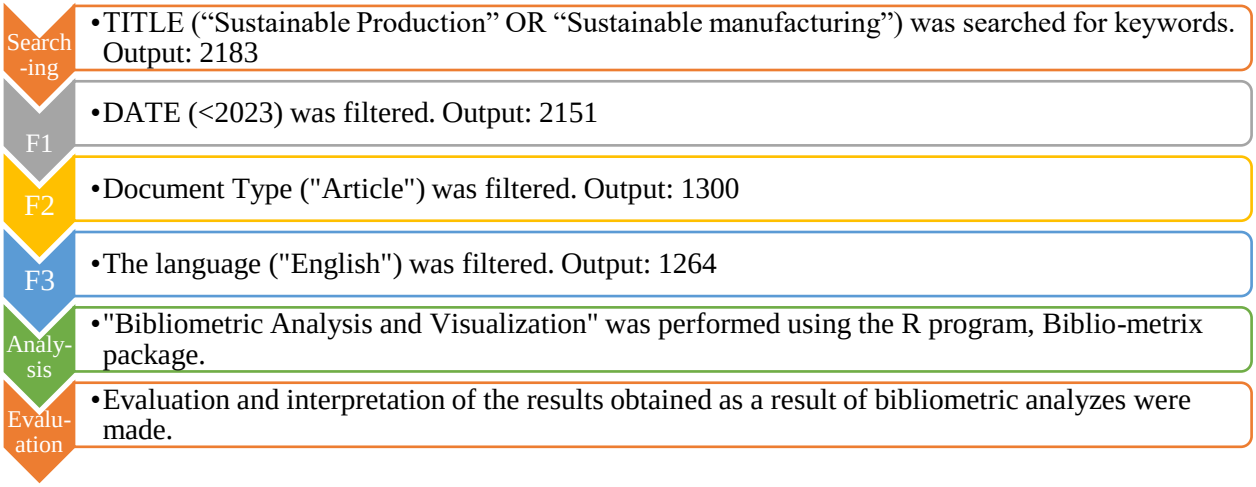
as authors, documents, sources, organizations and countries, and to evaluate the structure of the relevant research area.

Search Criteria and Identification of Sources

Web of Science (WoS) database was used to obtain the data of the study. Since Web of Science offers a multidisciplinary scope, this database has been preferred because it will also show related studies in different disciplines. The search via WoS was carried out on 01.02.2023.

Figure 1 shows the criteria used to select documents and the steps involved in the research process.

Figure 1: Methodology for article selection and analysis process



Various keywords were used in this article to search for documents in the database. Keywords form the core of a scientific article. For this reason, it is important to search for keywords with the right words. Considering that different forms of some words can be used in documents, documents with different combinations expressing a similar concept were searched. However, the issue that needs to be emphasized here is that some researchers do not adequately reflect the content of the article when they choose keywords. For this reason, all studies in the relevant literature were scanned one by one.

The keywords used in the first search on the WoS Core Collection database were TITLE-ABS-KEY (“Sustainable production” OR “Sustainable manufacturing”). However, when we look at the content of the subject, it was realized that the literature on sustainable production would not directly reflect the truth when all these documents were included. For this reason, the search criteria in the study were narrowed to TITLE. It was concluded that in cases where "sustainable production" or “sustainable manufacturing” was

mentioned in the title, the subject was directly related to sustainability. Otherwise, when searched in ABS-KEY, it was seen that the subject was directly related to "sustainability" rather than sustainable production. Accordingly, 2183 studies were reached by using the search terms TITLE (“Sustainable production” OR “Sustainable manufacturing”) on the WoS database.

It was determined that the document scanning was open-ended as of the beginning date and included the studies for the year 2023. In order to analyze the number of studies and trends by years more clearly, the literature search was narrowed to the end of 2022, since it was the beginning of 2023. As a result of the historical filtering, 2151 studies were included in the study. Another focused on document types, selecting only peer-reviewed journal articles. This was chosen to preserve the quality of the study. An issue that should be mentioned here was that review articles were not included in the research area. Because in this study, it was requested to see which areas of sustainable production are directly studied. After this filtering, the number of studies decreased to 1300. The third filtering was for the language of publication in which the relevant studies were written. In the study, journal articles published in English were filtered. As a result, 36 documents were excluded and the total number of documents decreased to 1264. Each of these studies was included, regardless of conceptual scope, industry, or geography.

Data Analysis

2022.12.02 Build 353 version of R Studio was installed on Windows 10 before performing data analysis. Secondly, the bibliometrix analysis package written in R was installed to analyze and map the bibliographic data. Data entry was made via Biblioshiny.

In the study, RQ1, RQ2 and RQ3 research questions were analyzed using descriptive statistics. For the first research question, the publication volume in the sustainable production literature was reached through the bibliometrix package. For the second research question, firstly, general information about the most influential journals in the sustainable production literature was obtained. Then, the most influential authors and documents were examined. To answer the third research question, the global distribution of the relevant literature by country was shown on the world map depending on the amount of documents. In order to answer the fourth question (RQ_4) in the study, the results related to the keyword analysis about the topic distributions, trend topics and studying trends of the sustainable production literature were obtained. For the fifth research question (RQ_5), general information about the intellectual structure of the literature on sustainable production was obtained. At this stage, the document co-citation analysis was carried out and a co-citation map was obtained and the emerging ecoles were evaluated.

RESULTS

The results of the study are shown in the following subheadings.

General Overview about Sustainable Production Literature

It is important to first evaluate the basic framework of the sustainable production literature. In Table 2, the total number of documents published on the relevant subject, the number of sources of the studies, the annual scientific productivity rate and the annual average number of citations are given.

Table 2: Main information

Criteria	Value
Timespan	1987-2022
Sources	586
Documents	1264
Avarege Citiations per Doc.	22.96
Total References	59088
Number of Authors	4411
Authors of Single- Authored	96
International co-authorships %	30.22%
Co-Authors per Doc.	4.2

It is seen that the first study on sustainable production was published in 1987. According to this result, it is seen that the relevant literature has been studied by researchers for 35 years. A total of 1264 scientific articles have been published on 586 sources on this subject. Sharing the relevant subject on many sources also signals that the subject is studied in different research fields. According to a total of 1264 original research articles published, the average number of citations for each study is 22.96.

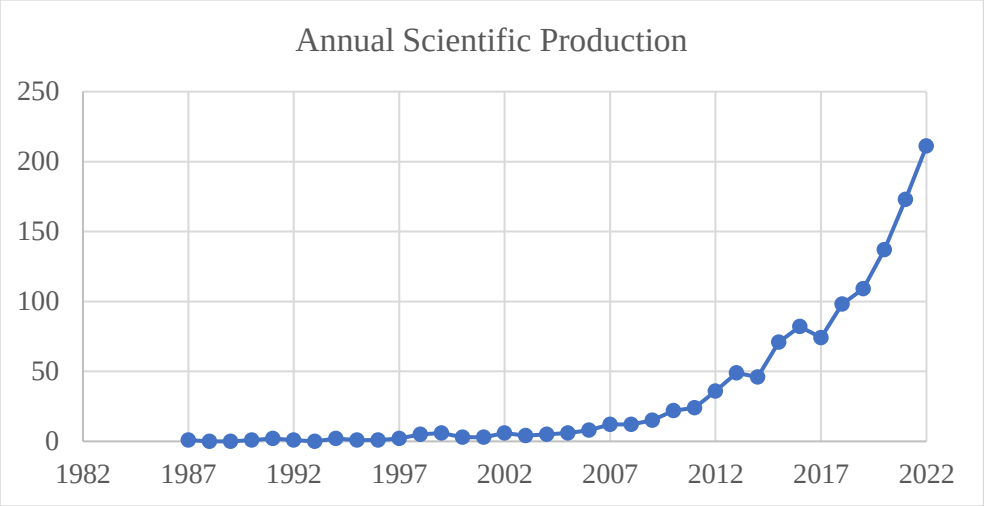
While 96 of the 4411 authors in the related literature completed their scientific studies with primary author, the others continued their studies as co-authors. Each document has an average of 4.2 co-authors. This situation shows that the documents are studied with high cooperation. The rate of 30.22% indicates the percentage of international co-authorship. In other words, it means that the documents were prepared with the cooperation of authors from different countries of the world.

Annual Scientific Production

The annual scientific productivity of the sustainable production literature is shown in Figure 2. Although the concept of "sustainable production" has entered the literature since 1987, it is seen that the

subject has been studied with a very slow growth until 2007. The annual growth rate of the literature on sustainable production is 3.93%. Although this rate is thought to be quite low, the number of documents has been limited to 57 documents in total for about 20 years since the first document emerged. Since 2007, although there have been some decreases in the number of annual scientific publications, a gradual development has been observed in general. The number of publications, which was 12 in 2007, reached 36 in 2012 and 71 in 2015. At the same time, with a continuous growth since 2017, it reached the highest number with 215 scientific articles in 2022.

Figure 2: Annual scientific production of literature on sustainable production



Descriptive Analysis of Journals, Authors, and Documents

Gaining insight into influential sources, authors and documents in the sustainable production literature was achieved through descriptive analysis. At this stage, journals, authors and articles were analyzed empirically in terms of both frequency and number of citations according to the third research question (RQ_3).

Analysis of influential journals

At least one document on sustainable production has been published on a total of 586 sources. However, the number of documents published on the subject in these journals varies greatly. The status, frequency and citation analyzes of the journals that publish with the title of sustainable production are shown in Table 3. The ranking is made according to the citation numbers of the journals that have studies on the relevant topic.

Table 3: List of most influential journals

Rank	Journal	Domain[1]	h_index[2]	g_index[3]	n	Total Cit.	CPD[2]
1	J. of Cleaner Production	Bus and Env	39	65	101	4547	441.059
2	Green Chemistry	Env and Eng	13	19	19	1106	58.210
3	Science	Eng	1	1	1	860	860
4	Int. J. of Prod. Research	Bus and Man	14	18	18	804	44.666
5	Sustainability	Bus, Env and Eng	15	25	71	764	10.760
6	Techn. Forecasting and Social Change	Man, Env and Eng	7	7	7	628	89.714
7	ACS Catalysis	Env and Eng	3	3	3	590	196.666
8	International Journal of Production Economics	Bus and Econ	9	9	18	579	32.166
9	Prod. Planning & Control	Bus and Dec Sci	4	4	4	578	144.5
10	CIRP J. of Manufacturing Science and Technology	Bus and Eng	2	2	2	552	276
11	CIRP Annals Man. Tech.	Bus and Eng	3	3	3	526	175.333
12	Int. J. of Adv. Manufac. Technology	Bus and Eng	10	18	18	454	25.222
13	Applied Energy	Env	4	5	5	440	88
14	Sust. Prod. and Cons.	Bus and Env	10	18	18	419	23.277
15	Ecological Indicators	Env	3	3	3	394	131.333
16	IEEE Transactions on Engineering Management	Eng	3	4	4	356	89
17	Journal of Catalysis	Env and Eng	2	2	2	329	164.5
18	Organic Process Research & Development	Man and Eng	4	7	7	324	46.285
19	Journal of Manufacturing Science and Engineering	Bus and Eng	6	8	8	310	38.75
20	ACS Sustainable Chemistry & Engineering	Env and Eng	12	16	26	298	11.461

[1] Domains: Bus = Business; Man = Management; Env=Environment; Eng: Engineering, Dec Sci = Decision Science. [2]CPD= citations per document.
[2] It is the case of having at least n citations in each document, according to the number of publications (n) owned by the author.
[3] The researcher has n^2 citations according to the number of publications (n).

According to Table 3, it is seen that the subject is studied interdisciplinary. Sustainable production has been a topic that has been handled from different perspectives, including production management,

business strategies, different branches of engineering, energy, technology management, social change, environmental management, logistics, and supply chains. When the most important journals are examined (see Table 3), it is seen that the fields of study of the journals are business, management, environment, engineering and decision making. The fact that sustainable production has such a wide studying area also contributed to the high number of studies.

The Journal of Cleaner Production is the open hub of knowledge production in this field, with 101 published articles with 4547 citations. The journal is the most important journal in the field with its h index value of 39. The average number of citations of the documents in the journal was found to be 441. Also, Journal of Cleaner Production is the second journal with the highest CPD on the list. In terms of this value, it can be interpreted that the number of citations to the media is quite successful.

The second journal with the highest number of citations is Green Chemistry. Green Chemistry has a total of 1106 citations in 19 documents. It is noteworthy that many journals have not published many articles on the subject in the journal list, which is listed according to the number of citations. The articles published directly on sustainable production in the journal Science, which ranks 3rd in the list, received a total of 860 citations. Due to this number of citations, Science Journal was determined as the journal with the highest CPD with only one document.

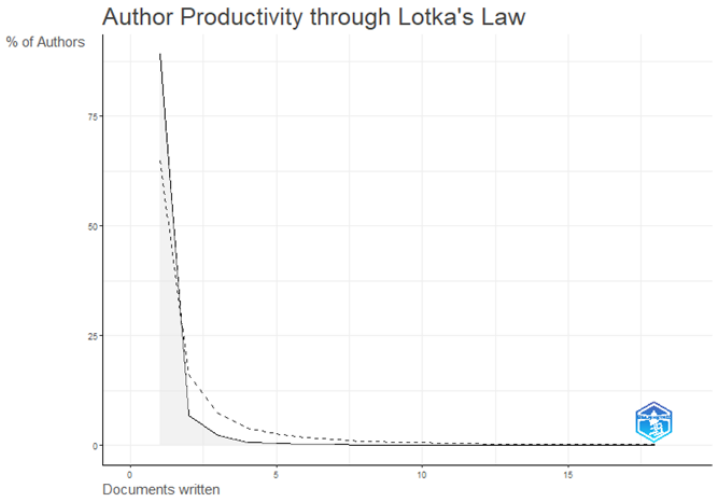
Nonetheless, it is seen that the listed journals make significant contributions to the literature, especially in terms of citation volume. Although it is seen that the number of documents on sustainable production in many journals in the list is low, the number of citations in the documents should be considered very important. The high citation count of the journals in the list reveals the quality of the literature. Considering that the number of studies has increased especially in the last 9 years, the number of citations is remarkable.

Analysis of influential authors

4411 authors have published at least one article with the title of sustainable production or sustainable manufacturing. However, the number of documents published by authors on the subject has varied widely. For this reason, these writers are not equally productive. The productivity of authors is estimated using Lotka's law, which describes the frequency of publication of an author in a given field (Pao, 1985). However, Lotka's law is more recommended when the scientific literature on the subject in a field is rich. From this point of view, the result of the analysis of the literature on the topic of sustainable production is shown in Figure 3. The results in Figure 3 show that 89.05% of the authors produced only one document. On the other

hand, 6.71% of the authors produced 2 documents and 2.26% of the authors produced 3 documents. The maximum number of articles for analysis is 18 documents produced by a single author (0.22% of authors).

Figure 3: Author productivity



In Table 4, the author citation analysis for the authors who study the most on sustainable production is presented. Author citation analysis is used in science mapping to highlight thought leaders in a research field and reveal the conceptual foundations of that field (Sanyé-Mengual et al., 2014). Table 4 presents the most productive and influential authors conducting research on SSCM. The most prolific academics in this field each have 7 or more publications.

According to Table 4, the most productive author in the field of sustainable production is Wang, who has 18 scientific articles. Wang is followed by L. Li with 13 articles, and J. Li., X. Li, Y. Liang and B.Q. Xu with 11 articles. Wang, Liang, and Xu have h-index of 11 as an indicator of productivity and success. On the other hand, 11 studies of Liang and Xu received a total of 1184 citations. Accordingly, it is seen that the most influential writers on the list are Y. Liang and B.Q. Xu.

Table 4: List of most prolific authors

Rank	Name of Author	h-index	Number of Article	Local Citiation	CPD^2	Production over the time
1	Y. Wang	11	18	392	21.77	2013-2022
2	L. Li	8	13	431	33.15	2013-2022
3	J. Li,	7	11	296	26.90	2008-2022
4	X. Li	6	11	548	49.81	2014-2022

5	Y. Liang	11	11	1184	107.63	2007-2017
6	B.Q. Xu	11	11	1184	107.63	2007-2017
7	J. Liu	3	11	24	2.18	2018-2022
8	S.H. Chai	7	8	956	119.5	2007-2014
9	Z. Chen	4	7	56	8	2017-2021
10	L.Z. Tao	7	7	356	50.85	2010-2017

On the other hand, the productivity of the authors who wrote articles on sustainable production research over the years is also shown in Table 4. It is seen that Y. Wang, who has the highest number of articles, was active from 2013 to 2022. Similarly, L. Liu continued its studies on the related subject, which it started to be published in 2013, until 2022. While the first studies of Y. Liang and B.Q. Xu, who started studying on sustainable production issues earlier than others, were published in 2007, the authors remained productive until 2017. Another noteworthy situation in Table 4 is that Z. Chen is the newest author on the list. Chen started his studies on the subjet in 2017.

Analysis of influential documents

Document analysis on Bibliometrix was carried out to identify the most effective documents. The list in Table 5 shows the top ten most frequently cited articles on sustainable production. In addition, Table 5 shows that other authors studying in this field have benefited from these documents to get a better idea. The first study in the list was prepared by Galvis et al. (2012) and has been cited 860 times in the last eleven years. This study was prepared in the field of science and technology research, to achieve sustainable production by obtaining a new particle under environmental and supply constraints.

The second most cited article is by Jayal et al. (2010) with 543 citations. In this study, it was aimed to gain a perspective on new production trends and concepts to develop sustainable products. The third most cited article was published in the field of engineering by Li et al. in 2016. Similar to the document of Galvis et al. (2012), this study was designed to propose new components to ensure sustainable production due to material supply constraints. The fourth most cited paper has a total of 428 citations and was written in the field of engineering and operations management (Garetti and Taisch, 2012). In this article, the authors focused on the trends in sustainable production and a number of research barriers in this path.

The fifth most cited article with 371 citations is the newest document (Jabbour et al., 2018) in the list. Citations for this study have been reached over a period of 4-5 years. Researchers aimed to shape the current production and consumption patterns of sustainable production with Industry 4.0, focused on the synergy between them and carried out a study that revealed the success factors. Pusavec et al. (2010)' s article,

published in 2010, is an important document that received 344 citations in total. The researchers presented a case study aiming to achieve sustainable production through alternative processing technologies that reduce resource consumption and generate less waste.

The seventh most cited document in the list, with 326 citations, belongs to Chai et al. (2007). This study was prepared in the field of science and technology, directly related to the field of chemistry. In this document, the authors proposed new ingredients to make the materials more sustainable. The eighth most cited document, with a total of 309 citations, belongs to Srirangan et al. (2012). In this study unlike other studies, the authors focused on the energy requirement to ensure sustainable production and presented a perspective on the unlimited use of fossil resources. The study focused on biomass for clean energy production and evaluated technologies to obtain it in an economic way.

The ninth most cited scientific article belongs to Joung et al. (2013) with 303 citations. In this study, the authors aimed to determine the production indicators to be used in sustainable production. The last part of the document analysis is the tenth most cited document with 289 frequencies by Jimenez-Gonzalez et al.(2011) In this article, the researchers aimed to identify green engineering research areas and research challenges in these areas and to explain improvement opportunities from a pharmaceutical industry perspective.

Finally, when the ten most cited documents on sustainable production are evaluated, it is seen that 60% of the studies are empirical and 40% are conceptual. It was observed that none of the studies were of the type 'review'. This was because these studies were not included in the research design.

Table 5: List of most influential documents

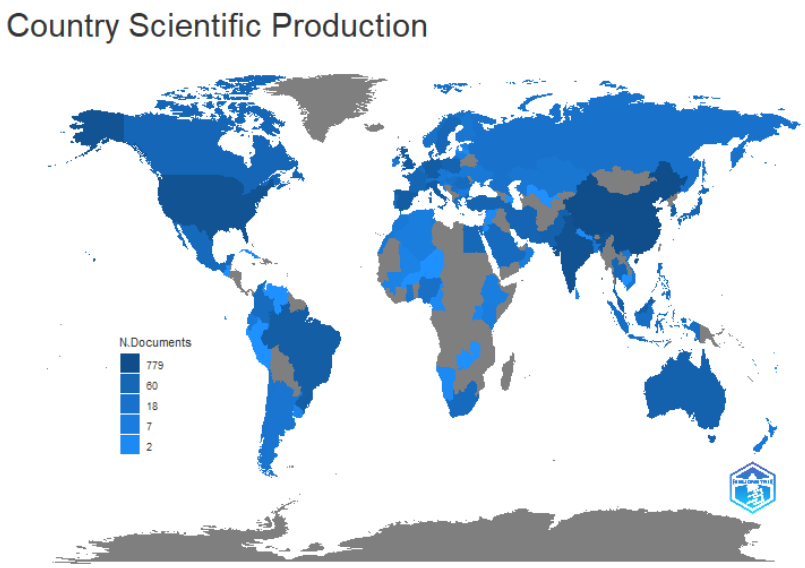
Rank	Authors and Year	Title	Journal	Type	Total Citiation
1	Galvis et al. (2012)	Supported Iron Nanoparticles as Catalysts for Sustainable Production of Lower Olefins	Science	Empirical	860
2	Jayal et al. (2010)	Sustainable manufacturing: Modeling and optimization challenges at the product, process and system levels	CIRP Journal of Manufacturing Science and Technology	Conceptual	543
3	Li et al. (2016)	Furfural: A Promising Platform Compound for Sustainable Production of C4 and C5 Chemicals	ACS Catalys	Empirical	470

4	Garetti and Taisch (2012).	Sustainable manufacturing: trends and research challenges.	Production Planning and Control	Conceptual	428
5	Jabbour et al. (2018)	When titans meet - Can industry 4.0 revolutionise the environmentally-sustainable manufacturing wave?	Technological Forecasting and Social Change	Conceptual	365
6	Pusavec et al. (2010)	Transitioning to sustainable production - Part I: application on machining	Technologies. J. of Clenaer Production	Empirical	344
7	Chai et al. (2007)	Sustainable production of acrolein: Investigation of solid acid-base catalysts for gas-phase dehydration of glycerol.	Green Chemistry	Empirical	326
8	Srirangan et al. (2012)	Towards sustainable production of clean energy carriers from biomass resources	Applied Energy	Empirical	309
9	Joung et al. (2013)	Categorization of indicators for sustainable manufacturing	Ecological Indicators	Emprirical	303
10	Jimenez-Gonzalez (2011)	Key Green Engineering Research Areas for Sustainable Manufacturing: A Perspective from Pharmaceutical and Fine Chemicals Manufacturers	Organic Process Research & Development	Conceptual	289

The Geographic Scientific Production

The colors on the map showing the scientific productivity of the countries are adjusted according to the frequency of scientific publications and show that productivity increases as the shade of blue increases. According to Figure 4, China, India and USA are seen as the countries with the highest frequency. The number of scientific publications in China is 779, the number of scientific publications in India is 488 and the number of scientific publications in America is 467. In this respect, China, India and the USA are the countries that most influence research on sustainable production. On the other hand, the subject has been studied extensively in countries such as UK, Italy, Spain, Germany and Brazil.

Figure 4: Country scientific production



Keyword Analysis

Keyword analysis is based on the analysis of the most preferred keywords by researchers in the sustainable production literature. The authors provide statistical analyzes to examine keywords (Du et al., 2019). At this stage, wordcloud can be preferred as well as treemap in order to visually present the most frequently used keywords. In this article, the keywords used in scientific articles prepared with the title of sustainable production are shown in Figure 5 as wordcloud.

In order to correctly interpret the word analysis on the Biblio-metrix package, some arrangements had to be made in the data. These arrangements are provided by loading a synonym list. The keywords “Industry 4”, “0”, “industry 4 0” and “industry 4.0” were combined as “industry 4”, and the keywords “environment” and “environmental” were combined as “environment”. At the same time, the keywords "modeling" and "model" were combined as "modeling", and the keywords "life cycle assessment", "life cycle" and "life cycle assessment" were combined as "life cycle assessment". Finally, the keywords “green manufacturing”, “green” and “cleaner production” were combined as “green manufacturing”, and the keywords “sustainable development” and “development” were combined as “sustainable development”. In addition, the keywords "sustainable production" and "sustainable manufacturing", "production", "manufacturing", "sustainable" and "sustainability" were removed from the analysis in order to see the thematic topics of the relevant literature.

Figure 5: WordCloud About Sustainable Production Literature

According to Figure 5, the most striking word in this study is seen as "industry 4". This result shows us that the word “Industry 4” is the most frequently used keyword in sustainable production. It can also be concluded that many of the studies carried out on sustainable production are related to “Industry 4”. Keywords are important to quickly understand the subject and focus of the studies. On the other hand, “sustainable development” is seen as the second highest frequency word group. It is undoubtedly an expected situation that sustainable development takes place in studies on sustainable production.

The third most used keyword by the authors is “green manufacturing”. In addition, it can be stated that the keywords environment, modeling, circular economy, and life cycle assessment are overemphasized. It should be noted that the common side of these keywords is directly related to sustainability. In addition, energy concepts have been used a lot in studies related to sustainable production. For example; keywords such as “biodiesel”, “biomass”, “biorefinery”, “energy consumption”, “renewable energy”, “biofuels”, “bioenergy”, “biofuel”, “energy efficiency” are also included in the word cloud.

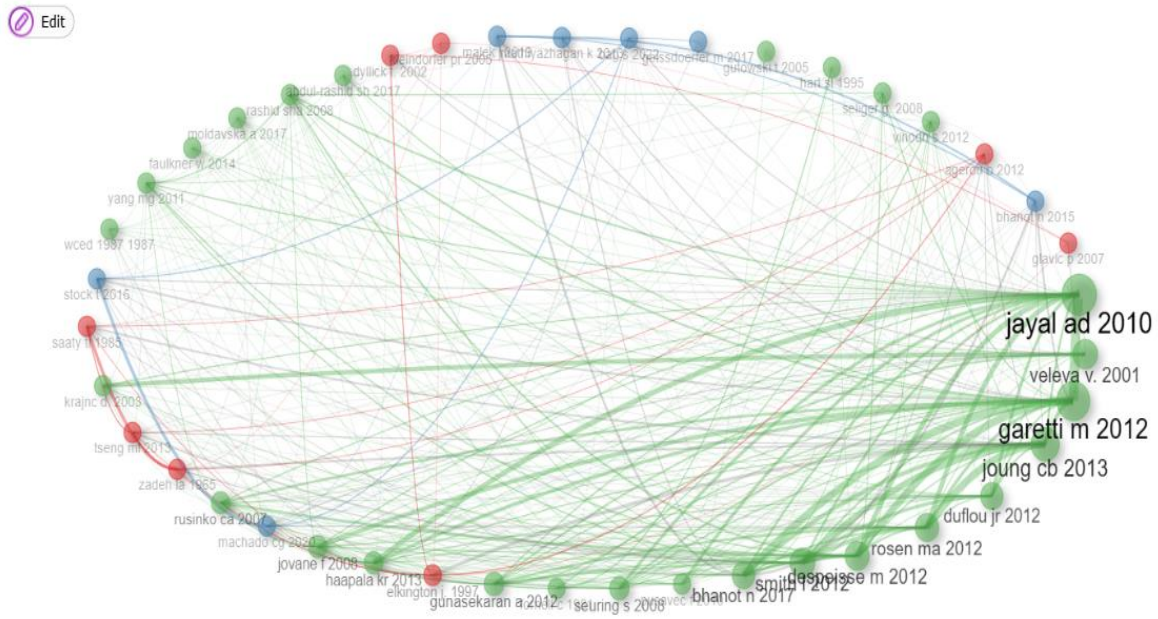
In addition, Figure 5 gives us ideas about some of the methods used in the related literature. The methods with the highest frequency are "optimization", "simulation", "decision making", "Dematel", "fuzzy set theory". In this direction, it can be stated that methods such as optimization, multi-criteria decision-making methods and simulation are used in studies on sustainable production.

Intellectual Structure About Sustainable Manufacturing

One of the features of scientific mapping is the creation of "network maps" to show relationships for any factor. This factor can be author, document, journal or keywords. A co-citation map shows the scientific structure of a literature with the frequency with which two publications are cited jointly in a third document (Mumu, Saona, Russell, and Azad, 2021). The citation count of an article is represented by the size of its node. The proximity of the nodes indicates the degree of intellectual closeness. Here, authors who are close to each other are often cited jointly, and authors who are far from each other are cited less frequently. Also, the lines connecting the nodes represent common citations of documents by other documents. Each of the clusters with the same color represents schools (Van Eck and Waltman, 2017). Document co-citation maps visualize similarities between documents based on co-citation frequencies. In this case, it is assumed that the frequently cited documents share a common intellectual tradition or perspective (Boyack and Klavans, 2010).

In this study, co-citation analysis was performed on 50 articles to create a document co-citation map. Co-citation analysis was used to analyze the intellectual structure of the literature on sustainable production. Figure 6 shows the results of the document co-citation map. Figure 6 includes the name of the first author and the publication date. The document co-citation map provides a useful complement to WoS document citation analysis by identifying key literature from which academics are drawn. As a result of the analysis, a grouped map was formed in a set of three colored documents, each representing a thought group. That is, the coloring of often commonly cited sets of documents represents the "schools of thought" that make up the intellectual fabric of a discipline or a field of research (in this case, sustainable production).

Figure 6: Document co-citation network of sustainable manufacturing literature



As a result of the co-citiation analysis applied in this study, three different schools emerged. For the three schools in this study, 50 documents are displayed between the years 1987-2022. Figure 6 shows that there is significant cross-fertilization between documents in the three thought groups.

The cluster in red in Figure 6 is the cluster of the oldest publications in the analysis (Zadeh 1965; Elkington, 1997; Dyllick and Hockerts, 2002). Since the studies of this school are older sources, they have worked with the theme of "sustainability" as a broader subject rather than sustainable production (Kleindorfer and Saad 2005; Glavic and Lukman, 2007; Ageron, B.; Gunesekaran and Spalanzani, 2012; Tseng, Chiu, and Tan, 2013). The most striking issue in this ecole is the examination of sustainability within the framework of business strategies. This school focuses on sustainable business development, designing sustainability strategies, and developing a sustainable framework for business practices. For this reason, it can be stated that the documents in this cluster are quite consistent.

Most of the documents in the second set (blue) draw attention because they are very recent documents. It can be easily stated that the most important theme of this school is new approaches in sustainable production. When the documents are examined in detail, the latest developments related to sustainable production are included in these studies. It is seen that the documents in this school are designed for practitioners in a way that can guide sustainable production and contribute to the renewal of the literature

(Mathiyazhagan, Govindan, and Haq, 2013; Stock and Seliger, 2016; Geissdoerfer et al., 2017; Machado, Winroth, and Ribeiro, 2019; Malek and Tushar, 2020). Among the documents in this school, Mathiyazhagen et al.'s (2013) study includes the implementation of new environmental activities in the production systems of the enterprises. Machado et al. (2020) and Stock and Seliger (2016) focused on the relationship between sustainable production and industry 4.0. Geissdoerfer et al. (2017) focused on the relationship between sustainability and the new circular economy concept. In short, it can be stated that the documents in this school are guiding the relevant literature in terms of revealing new concepts in sustainable production.

As a result of the analysis, the green colored cluster, which represents a different school, stands out. Consisting of 34 documents, this school is the largest of the three clusters. In particular, it is clearly seen that this school directs sustainable production. At the same time, it is seen that the documents in this school are more effective than the documents in the other school in terms of the number of citations. The theme of the studies in this school is on the conceptual framework of sustainable production, which is quite broad compared to other schools of thought. Setting a general framework for sustainable production (Haapala et al., 2013; Jovane et al., 2018), identifying trends and barriers to sustainable production (Garetti and Taisch, 2012; Bhanot et al., 2017), defining indicators (Veleva et al., 2001; Joung, Crrell, Sarkar, and Feng, 2013), identifying sustainable production models (Jayal et al., 2010; Smith and Ball, 2012), setting practices (Rusinko, 2007; Despeisse et al., 2012) are the general writing purposes of the documents in this school.

In the co-citation map in Figure 6, it is seen that the most cited work is Jayal et al. (2010)'s document. Based on the influence of Jayal's article across all three schools, it has been a "cross-border" study in the literature. When the document was analyzed, it provided an overview of the effects and concepts in the development of sustainable production systems. The study focused on developing models and optimization techniques about sustainable production processes. Other key studies in this cluster are Veleva (2001), Garetti and Taisch (2012), Joung et al. (2013). In Garetti and Taisch’study, the second major study of the most influential school of thought (the green cluster), the authors conducted a survey of developments and challenges in sustainable production. On the other hand, the studies in Joung et al. (2013), Veleva et al. (2001) focused on indicators that accurately measure sustainability.

CONCLUSIONS AND LIMITATIONS

The study focuses on analyzing sustainable production research using bibliometric analysis. In this study, it tries to answer a number of preprepared research questions. The results of bibliometric analysis in research have many practical and theoretical implications. This study shows the efficiency of sustainable production by years. In addition, the most influential journals, the most productive authors, and the most

influential documents in the relevant literature are also shown. Finally, the document also highlights the number of studies by country. These results can provide a good basis for showing which journals the researchers will submit their studies to, which researchers will benefit from their resources and which critical studies of the field, and in which countries they will be able to conduct advanced studies.

In this study, the literature on sustainable production was prepared by including all published studies from the year the study was first conducted, including 2022. However, it should be noted that the literature began to form and take shape after 2007. Until 2007, the number of studies was so limited that it did not exceed single digits per year. After 2015, an increase in academic studies was observed with the UN's publication of the SDG and their acceptance by many countries (UNEP, 2015; Moldavska and Welo, 2019). All over the world, climate change and scarcity of natural resources have required a new paradigm in which economic and social development guarantees sustainable development (Martinez et al., 2022). However, it has been noted that in some countries the subject has been studied very little. However, sustainable supply chain management has increased the focus on sustainable development with the acceleration of population growth and global warming (Xu and Wang, 2018; Yip et al., 2022; Zhou et al., 2022).

On the other hand, in this study, the thematic subjects of the sustainable production literature and trends on the basis of years were determined. These results are important in terms of identifying research trends in the field of sustainable production and revealing future research agendas. In addition, research gaps in the relevant subject were also revealed. For example, it is seen that especially environmental issues are on the agenda in studies on sustainable production. In this context, it was determined that environmental indicators were among the prominent themes. On the other hand, an indication of the researchers' focus on environmental issues is the frequent use of the "green manufacturing" theme, which focuses more on the environmental aspects of sustainable production.

In reality, there are three dimensions in the concept of sustainability: economic, environmental, social sustainability (Ahmad and Wong, 2019; Malek and Tushar, 2020). In sustainable production, economic issues are as critical as environmental issues. In other words, social and economic conditions should not be excluded from sustainable manufacturing (Hussain and Jahanzaib, 2018; Bastas, 2021). Because sustainable manufacturing deals with business from an economic, environmental and social perspective, it is important to explore many of its distinctive features for a better understanding of the research field (Garetti and Taisch, 2012). Although it was seen that a certain group of researchers examined sustainable production directly in terms of business strategies, it was seen that social and economic dimensions were neglected in the prominent themes. For example; It is thought that the issue will be multifaceted with the inclusion of economic performance indicators in studies related to sustainable production. Its economic sustainable

performance can be examined in terms of investment themed issues, as well as various costs. In this context, researchers should conduct research on various aspects of sustainability in relation to sustainable production.

At the same time, although it is stated that environmental issues are mostly on the agenda in sustainable production studies, it has been determined that environmental indicators also focus on certain themes. The focus of sustainable production on reducing the negative environmental impacts from products and processes has been effective in this case (Jimenez-Gonzalez et al., 2011; Moktadir et al., 2018; Jabbour et al., 2018; Malek and Tushar, 2020; Jasti et al., 2022). Sustainable production has been studied more in the fields of energy use, energy efficiency, especially in relation to fuel consumption (Srirangan, et al., 2012; Li and Sun, 2013; Ghadiri et al., 2017; Sun et al., 2020; Kazakova and Lee, 2022). Energy consumption in industry is a serious concern in production operations (Sun et al., 2020). Researchers may need to do more research on sustainable production in terms of greenhouse gas emissions, carbon emissions, water consumption, and water efficiency.

In addition, industry 4 studies have come to the fore in the sustainable production literature. The development towards the fourth stage of industrialization, which is expressed as Industry 4.0, has a significant impact and offers enormous opportunities for the realization of sustainable production (Lasi et al., 2014; Stock and Seliger, 2016; Sartal et al., 2020; Rakic et al., 2021; Gholami et al., 2021; Jamwal et al., 2021). The fact that Industry 4.0 is the new industrial revolution has directly affected the radical change in production. Sustainable production literature also responded to this expected situation. On the other hand, it was expected that the major technologies examined under Industry 4.0 would also come to the fore in this bibliometric study on sustainable production. The physical systems of the factory have been integrated with the internet of things, cyber-physical systems, robotic systems with Industry 4.0, and production technologies have changed radically (Lasi et al., 2014; Khaitan and Mccalley, 2014; Lee, Bagheri, and Kao; 2015). However, only "additive technology" came to the fore among these seven major technologies according to the results of the analysis (Nanda et al., 2016; Ozguner and Ozguner, 2022). The fact that other technologies of Industry 4.0 have not come to the fore has enabled us to define the research gap in this regard. It may be important for this literature that researchers include technologies such as the internet of things, advanced robotics, augmented reality, and cloud computing in their studies.

Secondly, “Sustainable development” is one of the most striking themes (Esfahbodi et al., 2016; Zhou et al., 2022). Interest in academic studies in this field increased in 2015 with the United Nations' determination of 17 SDG and the agreement of 193 countries. “Responsible Consumption and Production”, one of the 17 goals here, has been accepted as an inclusive sustainable development priority (Esmaeilian, Behdad, and Wang, 2016). One of the prominent themes in the literature review was “green

manufacturing". Green production and sustainable production are topics that many researchers deal with together (Rusinko, 2007; Wang, 2010; Despeisse et al., 2012; Esmaeilian et al., 2016; Xia and Lin, 2022). The emerging circular economy paradigm and subsequent changing consumption patterns have led the manufacturing industry to more sustainable designs and operations (Jawahir and Bradley, 2016). Many researchers have discussed the links between the theoretical vision of sustainable production and the practical ideas and management practices of the circular economy (Jawahir and Bradley, 2016; Moktadir et al., 2018; Gundu et al., 2020; Bag and Pretoriun, 2020; Kazakova and Lee, 2022). As expected, the concept of "waste" has also come to the fore in the studies where circular economy and sustainable production take place together. It is always desirable to control material losses and maximize output for an ideal production process (Teigiserova et al., 2019). One of the goals of sustainable production is to ensure sustainable waste management in a way that will ensure maximum use of resources, do not waste materials and pose the least risk to the environment. The primary goal of sustainable production is to increase the efficiency of each product produced throughout its entire life cycle (Jovane et al., 2018). This situation has been one of the important focus of the studies prepared by many researchers about sustainable production (Bilge et al., 2017; Gbededo, Liyanage, and Garza-Reyes, 2018; Chen et al., 2022).

Finally, three limitations emerged in the study. This bibliometric study for sustainable production was conducted by including only studies in the Web of Science (WoS) database to examine specific findings. The use of other important databases such as Scopus, Dimension, and PubMed may also be included in future research projects for further investigation. Secondly, the documents on sustainable production in the study were created by searching the keywords "sustainable manufacturing" or "sustainable production" only in the article titles. Because in the search for ALL FIELD (such as "TOPIC", "TITLE", "ABSTRACT") thousands of studies appeared in the relevant literature. When these documents were examined, it was determined that many documents were not directly related to sustainable production. When only the titles of the articles were searched, the documents that appeared were directly related to sustainable production. Future researchers can include them in the study by searching all areas, examining all documents for content, to expand the study findings. In other words, it can expand the working context by applying content analysis to all documents. The third limitation is that only "articles" are included in the search criteria. Due to the lack of missing data entry, "early published studies" and books and conference documents were not included in the study. In addition, due to the purpose of the subject, review articles were excluded. The study can be expanded by removing the constraints in this study, examining conference proceedings and book chapters in detail, and including documents that have not been entered incompletely.

YAZAR BEYANI/AUTHOR STATEMENT

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Researchers have jointly contributed to the article. Researchers have not declared any conflict of interest.

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