Sustainable Development and Industry 4.0: A Bibliometric Analysis Identifying Key Scientific Problems of the Sustainable Industry 4.0

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Abstract: The main aim of the manuscript is the identification of key research problems in the field of sustainable development, in the era of implementing the Industry 4.0 concept. The manuscript presents results of the bibliometric analysis in the subject: "Sustainable Industry 4.0". The bibliometric analysis was realized in three segments: Sustainability, Industry 4.0 and Sustainable Industry 4.0. In the analysis, the following databases were used: Web of Science (WoS), Scopus, Google Scholar. The main purpose of the analysis was to outline the dynamics of publications in the categories: citation, author, country, type document, science field, research area. The review of sources carried out in this way allowed us to identify key research areas and confirm the research thesis adopted in the manuscript. The research thesis: Sustainable Industry 4.0 allows the integration of the Industry 4.0 concept with sustainable development goals. The article is dedicated especially to scientists looking for still unsolved research problems in the implementation of sustainable Industry 4.0. Furthermore, the manuscript could be an inspiration for scientists, stakeholders, practitioners and governments to complete today's knowledge about the problems of sustainability in Industry 4.0.

1. Introduction

In recent years, modern enterprises have been increasingly implementing new technologies belonging to the Industry 4.0 concept. Industry 4.0 is understood as a fourth industrial revolution, and is a consequence of the advances in ICT (information and communication technologies) being implemented in industry. Industrial changes are focused on industrial production and information technology. The combination of industry and information technology is the basis of the new Industry 4.0 (abbreviation: I 4.0). The term "Industry 4.0" was first used by Henning Kagermann at the 2011 Hanover Fair. Kagermann is a professor of physics, was CEO of SAP AG, and was involved in changing the development strategy of German industry [1,2]. Therefore, in order to define the key competences for the preceding period, the focus should be on research before this symbolic date. The Industry 4.0 concept can be understood as the technical integration of virtual-physical systems called cyber-physical systems (CPS) in production and logistics systems, and the application of the Industrial Internet of Things (IIoT) and the Internet of Services (IoS) in industry [3]. The Industry 4.0 concept means the formation of new value chains, changes in business models and the reorganization of processes of service provision and work [4–8]. Klaus Schwab, president of the World Economic Forum, published a

book entitled "The Fourth Industrial Revolution", (2016), in which he points out the new changes in industry, economy, and society [9].

1.1. Industry 4.0—Background

The Industry 4.0 concept is based on key pillars which result from continuous advances in new technologies, such as the Internet of Things, cloud computing, Big Data, modelling and simulation, autonomous systems AS), augmented reality (AR), additive manufacture (AM) and cybersecurity [10–14]. The new approach, which connects effective production technologies, digitalization and information and communication technologies (ICT), was introduced as part of the Industry 4.0 concept, and is called "smart". The word "smart" is used often in reference to the smart factory, smart innovations, smart supply chain and smart city, smart products and services, etc. [14] The Industry 4.0 concept uses the technical achievements of the third industrial revolution, mainly in the field of the automation and digitization of production processes. Currently, the main focus is on the integration of intelligent machines, equipment and control systems with network communication. This means increasing production efficiency and enabling flexible product changes in the assortment, through a combination of operational technology (OT) and information and communication technologies (ICT). The symbol of the Industry 4.0 is the network (Internet), not as we know it, but rather as a semantic network [15], i.e., the Internet, which enables machines to understand semantic documents and data rather than human speech and writing (analysis of the meanings of words and examination of the relationships between language expressions and the objects to which they relate). Such a network can operate in real-time. The Internet connects not only people, but also devices (IoT). The main driving force of new changes is artificial intelligence (AI), which allows you to efficiently connect technological devices in the Internet space, using IoT, IoS and Big and Mining Data technologies to create cyber-physical systems. In 2006, Lee defined CPS as the integration of computational with physical processes [16]. In 2015, Lee et al. presented the CPS architecture-based manufacturing, and the implementation of CPS into the factory [17]. The new architecture of business models is called 5C architecture by its authors. The 5C means smart connection, data-to-information conversion, cyber, cognition and configuration. These components create the structure of the new business model [18].

The Industry 4.0 concept is not only about smart technologies in businesses, but also about new ways of life for people, where mobile equipment plays an important role in communication. Intelligent technology is building a new image of cities—smart cities which use information technologies and mobile forms of communication to increase the efficiency of urban infrastructure [19]. A city's infrastructure consists of a smart grid, with intelligent building systems, intelligent systems embedded in household appliances, intelligent transport systems (ITS, P+R), smart electricity grid, intelligent water supply systems, intelligent waste management and safety systems, etc. [20].

Solutions promoted by the fourth industrial revolution are used in sustainable development. Mobile and cyber technologies increase the environmental, economic and social impact of different stakeholder groups. New technologies enable (stakeholders) to work actively for sustainable development.

1.2. Sustainable Industry 4.0—State of Research

Sustainable development (sustainability) is rooted in the 1987 Brundtland's report (document of the World Commission on Environment and Development). The idea of this development is to find balance in three areas: social, economic and environmental. Although the concept of sustainable development as a policy for the economies of many countries has been formulated in the past century, it is still valid. Economies use environmental resources and, with technological progress, build capital and knowledge that increase the well-being of societies.

Modern business is becoming increasingly digital and intelligent. Companies are implementing new technologies of the Fourth Industrial Revolution in a sustainable environment. Various areas of innovation related to Industry 4.0 create a new structure of modern business models [21].

Intelligent production with the paradigm of sustainable development is a new concept of industrial development known as "sustainable industry 4.0". The challenge of this new concept is the cooperation of companies and stakeholders in the value chain for sustainable development.

Industry 4.0 solutions enable the control of the entire product life cycle and create the potential to create innovative, sustainable solutions. Sustainable Industry 4.0 can mean the rational allocation of natural resources, minimizing waste, its proper processing, possible utilization and the use of industrial ecology [22]. In the transformation of sustainable development into Sustainable Industry 4.0, the following aspects are important: economic (type and value of investment, intelligent products, market presence, etc.), social (good business practices, social responsibility with safety of employees, stakeholders and communities, sustainable consumption), environmental (environmental aspects), which relate to the whole product life cycle (design, transport, use of raw materials for production, recycling, etc.) [23]. Thus, the elements of Industry 4.0 are aimed at achieving sustainable development in economic, social and environmental dimensions. Environmental protection is the most important activity in sustainable development [24].

Sustainable Industry 4.0 has been discussed in scientific literature since the introduction of smart technologies in businesses. This concept has been gaining increasing interest among scientists and practitioners in recent years. Factories are becoming smarter, more efficient, safer and more environmentally friendly, by combining and integrating manufacturing technologies and equipment, ICT, data and services in network infrastructures [25]. From a global perspective, sustainability and Industry 4.0 are very important directions for global development. We are facing the challenge of producing more and more products from depleted resources, causing less pollution and damage to meet growing consumption. The development towards Industry 4.0 offers great opportunities to implement sustainable production using the ubiquitous ICT infrastructure. On the other hand, digital technologies can increase the trend in energy demand, and therefore the world must increasingly use renewable energy sources [26]. The opportunities for sustainable industry 4.0 are visible in both macro and microeconomic perspectives [27]. From a micro perspective, a smart factory is a key facility in a sustainable environment. Both horizontal and vertical integration in smart factories create a new business model. Smart factories will increasingly use renewable energy sources in self-sufficient supplies [28].

Thus, the factory will become both a supplier and a consumer of energy. The electrical network, as well as the plant's intelligent energy management system, will have to meet the dynamic demand for energy supply and feedback. What's more, a smart plant is also another important resource stream that requires adequate and undisturbed water resources [27].

Sustainable Industry 4.0 should include many elements, such as: energy management, reduction of greenhouse gas emissions, reduction of negative environmental impact, reduction of raw materials consumption, water management, social and economic sustainability, and even life cycle assessments (LCA).

Investments in Industry 4.0 are the subject of many studies (BCG USA, Astor Poland, PwC UK, McKinsey USA) and a growing number of scientific papers. Based on the analysis of the literature, a clear research gap in the field of Sustainable Industry 4.0 was identified. The implementation of the Industry 4.0 concept changes the way the national and global economy, modern enterprises and the whole society functions. This means the need to conduct research in the field of implementation of technologies identified with Industry 4.0, to study the effects of changes in production processes, the impact on the environment, and the adaptation of society to new conditions shaped by the personalisation of production and the networking of economies. An important problem is to include the sustainable development idea in the implementation of the Industry 4.0 concept, and to solve economic, social and environmental problems on an ongoing basis. Currently, the authors of many scientific articles draw attention to the lack of recognition of both positive and negative effects on sustainable development and therefore undertake research on Sustainable Industry 4.0. The article is dedicated especially to scientists looking for still unsolved research problems in the sustainable

Industry 4.0 implementation. The main aim of the manuscript is the identification of key research problems in the field of sustainable development, in the era of implementing the Industry 4.0 concept.

2. Materials and Methods

A research thesis was formulated in the manuscript: Sustainable Industry 4.0 enables the integration of the concept of Industry 4.0 with sustainable development objectives. A bibliometric analysis was used to prove the thesis. The bibliometric analysis is a method of evaluation of the research results, and a comprehensive view of current scientific achievements. It is based on the use and quantification of quantitative data on scientific papers, and the use of quantitative indicators of various databases. It is a measure of texts and information [29]. Bibliometric information related to a given scientific articles includes the author, affiliation, quotations from other publications, use by the reader and related key words. It may describe research related to a specific field or similarly describe the quantity and purpose of research in a given organization [30]. As an assessment method, it may help to determine the impact of technology or the effectiveness of the author or research organization. Finally, it serves as a monitoring tool, as it allows one to track the level of activity in a given field of research over a specific period of time.

Bibliometric studies are often used by researchers, public institutions, universities and businesses. The subjects in bibliometric analyses are determined by researchers. Researchers who identify research subjects also decide on the criteria for analysing databases. Quantitative bibliometric studies can be used to analyse market trends [31] and the development dynamics of individual thematic studies: sustainable logistics and sustainable production [32]; Industry 4.0 [33], supply chain sustainability [34], research at flexibility [35], green supply chains [36], smart factory concept [25]; reverse logistics considerations [37]; urban logistics [38]; renewable energy [39], etc. The results of the analysis are most often presented numerically (researchers use mathematical and statistical methods), or descriptively, using semantic maps, matrices, clusters, trends, etc. [32,33,39,40]. The bibliometric analysis was carried out according to the stages of systematic literature review (SLR) [41–46]. According to the methodology adopted in the study, the following stages were carried out: planning, implementation, reporting (Figure 1). The structure of the applied methodology is presented in Table 1.
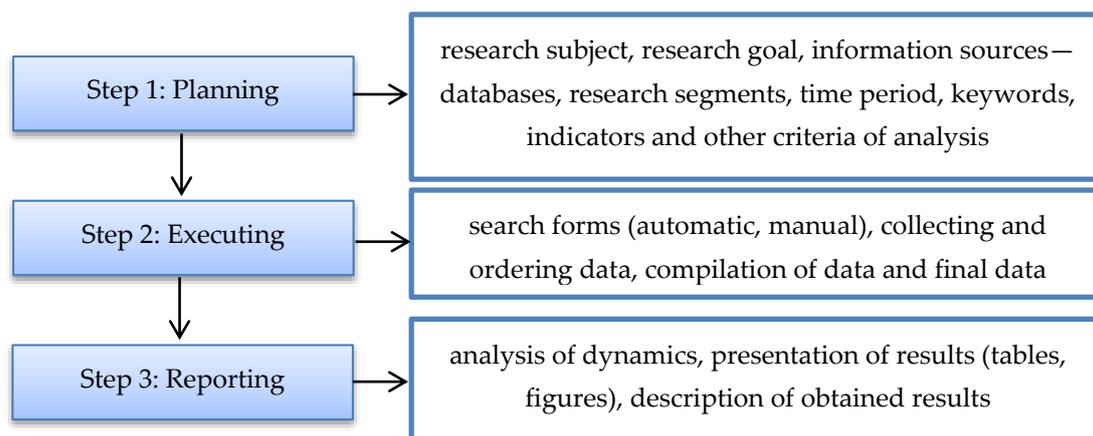

Figure 1. Bibliometric process based on SLR. Source: Own study.

Table 1. Steps of bibliometric analysis in the subject: "Sustainable Industry 4.0".

Steps	Stages	Detailing the Stages	Comments
Planning:	research subject	Evolution of Industry 4.0 into sustainability	result: new scientific subject: Sustainable Industry 4.0
	research goals (question forms)	What are the dynamics of scientific publications? What are the research areas of scientists? What are the sources and types of scientific publications?	goals apply to particular segments (S1, S2, S3)
	databases (B)	B2: Web of Science (WoS) database B3: citations of publications in Google Scholar	the choice of bases was made due to their size and availability
	segment (S):	S1: Sustainability S2: Industry 4.0 S3: Sustainable Industry 4.0	assumption: the first two segments will form the third segment
	time period (T):	T1: for "Sustainability" (S1) from 1987 to 2019 T2: for "Industry 4.0" (S2) from 2011 to 2019 T3: for "Sustainable Industry 4.0" (S3) from 2014 to 2019	the used time periods for particular segments are different because particular segments have different life cycles: the longest for "Sustainability", longer for "Industry 4.0" and the shortest for "Sustainable Industry 4.0".
	search fields (F):	title, abstract, keywords (B1), topic: title, abstract, keywords (B2), title, keywords (B3); document type: all, access type: all, limit: time	these fields are more representative
	keyword (KW) • for segment S1:	S1 KW1: sustainability S1 KW2: sustainable business S1 KW3: sustainable production	used keywords in the layered analysis were fixed on based experts knowledge
	• for segment S2:	S2 KW1: industry 4.0 S2 KW2: smart factory S2 KW3: smart production	
	• for segment S3:	S3 KW1: sustainable industry 4.0 S3 KW2: sustainable smart production	presumption about the information gap in the research subject
	indicator (I)/filter (F):	I1: number of publications (B1, B2, B3), filter by year (F1) I2: type and form documents (B1, B2), filter by year (F1) I3: number of citations (B3), citation per year (B3), citation per author (B3) I4: author publications (B1, B2, B3), filter by name author/F2 I5: countries (B1, B2) I6: subjects and research areas (B1, B2)	according to form of a database (B)
Executing	form of searching:	automatic (by using program Publish or Perish), manual	manual form was used for preparing a discussion as the part of the publication
	search results:	S1 KW1 I1, S1 KW1 I2, S1 KW1 I3 … etc. for each segments (S1, S2, S3)	results of searching data bases were organized into three parts of the paper according to analyzed segments: S1, S2, S3
Reporting	form of reporting:	description, presentation: tables, figures, diagrams	additional information about analyzed subject by analyzing particular scientific papers

The research focused on three thematic/research areas:

- (S1)—Sustainability; it was the largest area due to the age/maturity of the concept (1987—the Bruntland report—was the beginning of the concept of "Sustainability"). The time span of the analysed period is 1987–2019.
- (S2)—Industry 4.0, whose time span in the analyzed period was 2011–2019. The beginning of this research area is 2011, when the German government introduced an industrial development strategy based on high and intelligent technology. The author of the name "Industry 4.0" is Henning Kagermann (2011) [1].
- (S3)—Sustainable Industry 4.0; the time span of the analysed period is 2014–2019. It was assumed that "Sustainable Industry 4.0" is an evolved form of Industry 4.0 towards sustainable development.

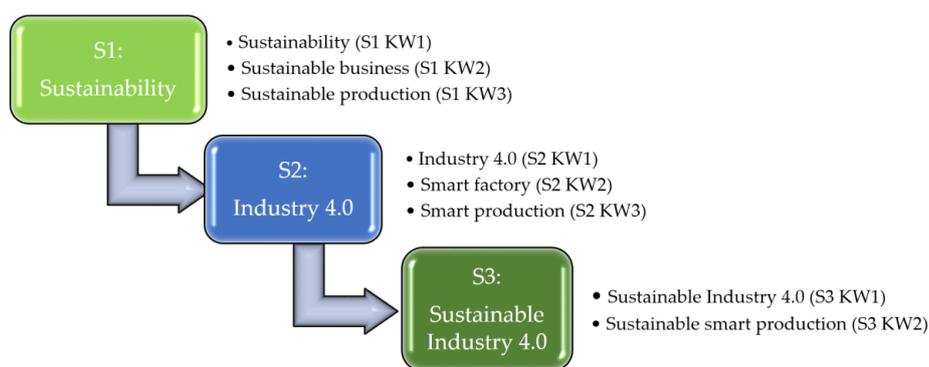The structure of the stratified analyses, which was carried out in three segments, is shown in Figure 2.

Figure 2. Segments of bibliometric analysis. Source: Own study.

In the adopted research methodology, the keyword list is a closed list. The search method adopted in the study allowed us to achieve the aim of the article, which was to signal a new, common research area called "Sustainable Industry 4.0".

According to the adopted methodology, the focus was on a homogeneous set of research, which is "Sustainable Industry 4.0", and not on parallel sets: Industry 4.0 AND Sustainable Development. The separation of separate collections of scientific articles according to keywords: Sustainability (S1) and Industry 4.0 (S2) were used by the authors to show the evolution of the publication dynamics. Supplementing the list of keywords with additional synonyms related to "Industry 4.0" and "Sustainable Development" in a bibliometric analysis would result in a significant increase in the number of selected scientific papers, and the need for an additional qualitative analysis of their content.

3. Results of Bibliometric Analysis

3.1. Results of the Bibliometric Analysis in the Segment (S1): Sustainability

Based on bibliometric analysis, it was found that the most search results concerned the keyword "sustainability" (which in the manuscript is marked with code S1 KW1):

- In the Scopus database (B1), this keyword has 207,494 results, including open access: 39,503,
- In the WoS database (B2): 155,278 results, of which open access: 44,549 scientific papers,
- In Google Scholar, in 1000 papers, there were 371,633 quotes (2020 June 29), including 11,261.61 quotes per year and 371.63 quotes per paper,
- The average number of authors per publication (paper) was 2.21 (median 2),
- The Hirsch index for "Sustainability" was: 289 (a = 4.45, m = 8.76).

For the second keyword: "sustainable business" (S1 KW2):

- In the Scopus database (B1), this keyword has 2276 results, including 343 in open access,
- In the WoS database (B2), there were 1491 results, including 414 in open access,
- Citations in Google Scholar (2020 June 29) were 122,157 for 1000 papers, including 4524.33 citations per year and 122.16 citations per paper,
- The average number of authors per publication (paper) was 2.35 (median 2),
- The Hirsch index for "Sustainable business" was: 168 (a = 4.33, m = 6.22).

Results for the keyword: "sustainable production" (S1KW3):

- In Scopus database (B1), this keyword was mentioned in 5875 papers, including 1161 in open access,
- In the WoS database (B2), 4812 papers were found, including 1287 in open access,
- In Google Scholar, there were 123,226 citations for 1000 papers (2020 June 29), including 3735.33 citations per year and 123.27 citations per paper,
- The average number of authors per publication (paper) was 2.93 (median 3),
- The Hirsch index for "Sustainable production" was 179 (a = 3.85, m = 5.42).

The number of scientific papers (total) in particular databases is shown in Figure 3.
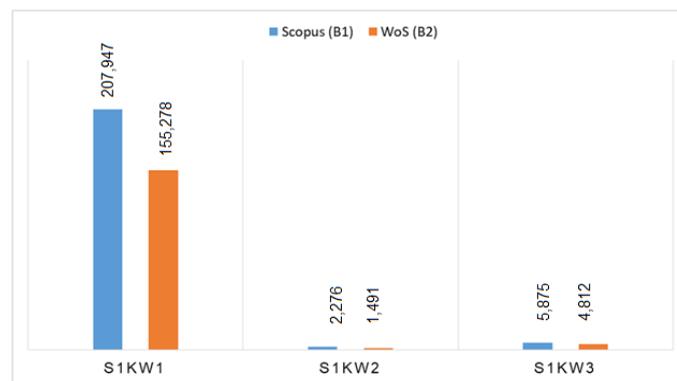

Figure 3. Number of scientific papers for particular keywords (KW) in the segment S1 "Sustainability". Source: Own study based on the databases: Web of Science and Scopus.

The dynamics of publications for keyword "Sustainability" in the period from 1987 to 2019 are shown in Figure 4.
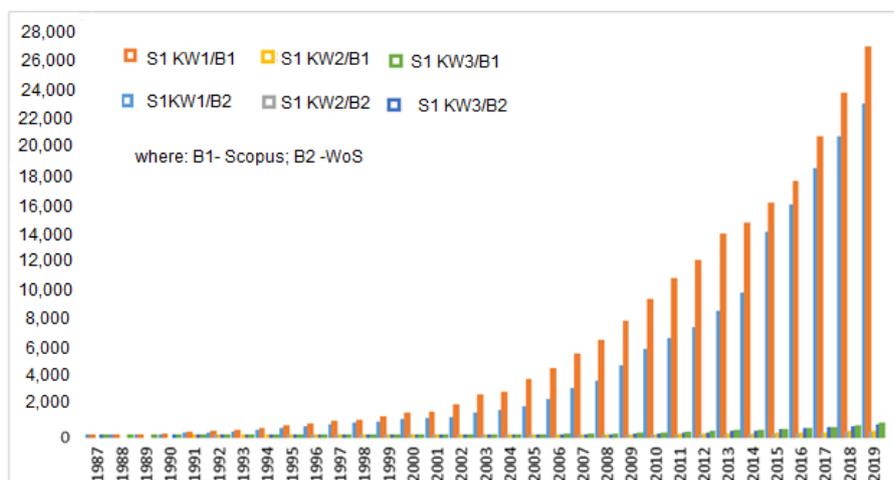

Figure 4. Dynamics of publishing for particular keywords (KW) in the segment S1 "Sustainability". Source: Own study based on the databases: Web of Science and Scopus.

Moreover, the number of scientific papers in recent years was compiled in Table 2.

Table 2. Number of published scientific papers in the period from 2010 to 2019.

Data-Base	Keyword	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Scopus (B1)	S1 KW1	9184	10,594	11,854	13,585	14,338	15,673	17,150	20,174	23,106	26,215
	S1 KW2	93	124	129	151	140	171	187	224	295	322
	S1 KW3	193	253	304	356	395	468	523	590	703	843
WoS (B2)	S1 KW1	5808	6560	7293	8387	9655	13,754	15,575	18,044	20,185	22,361
	S1 KW2	47	57	70	86	81	137	154	197	239	248
	S1 KW3	152	205	224	290	318	435	472	538	616	717

Source: Own study based on the Web of Science and Scopus.

The next analyzed category was "document type". Among different types, the most share belonged to scientific articles. For the keyword "sustainability", the share was 64% (Scopus) and 72% (WoS). In second place were proceedings paper/conference paper (above 20%); the next positions were: reviews, book chapters and materials editorial. In the "source title" category, the most results were achieved for journal "Sustainability": in the Scopus database: 6135 results; in the WoS database: 5630. The next items in the "source title" category were occupied by the journal: *Journal of Cleaner Production* (3720 results in the database Scopus and 4319 results in the database WoS); and *Ecological Economics* (1040 results in the Scopus database and 1086 results in the WoS database).

For the keyword "sustainable business" in both databases using the filter "type document", these also brought up the most scientific articles. The share of scientific articles in the WoS database was 64%, and in the Scopus database was 60%. In second place were conference papers: 21% in the Scopus database and 29% in the WoS database. The next places belonged to book chapters, reviews and editorial materials. In the Scopus database, the most popular journals were: *Journal of Cleaner Production* (127), *Sustainability Switzerland* (109), *Business Strategy and the Environment* (29), and in the WoS database: *Journal of Cleaner Production* (120), *Sustainability* (106), *Business Strategy and the Environment* (23).

In the Scopus database for the keyword "sustainable production", 64% of all documents belonged to the category "article"; the second category was "conference paper" with 14%, and third was "review" with 5.5%. Other types of documents were: book chapters (7.5%), and books (1.4%). In the WoS database, the following shares were obtained: 72% for the category: "article", 17% for the category "proceeding paper" and 11% for the category "review". Categories: book chapters (4%) and books (2%) had less than 5% share in the total number of scientific papers. In the WoS database for keyword "sustainable production", most of the results were obtained by journals: *Journal of Cleaner Production* (225), *Acta Horticulturae* (151) and *Sustainability* (82), and in the Scopus database: *Journal of Cleaner Production* (222), *Acta Horticulturae* (170) and *Sustainability* (78).

Figure 5 shows the document types in two databases (Scopus—B1 and WoS—B2) for particular keywords. Table 3 shows an overview of the most important scientific journals (Top 3), with the largest number of papers included "sustainable", "sustainable business" or "sustainable production". The order of presentation in the table is related to scientific impact.
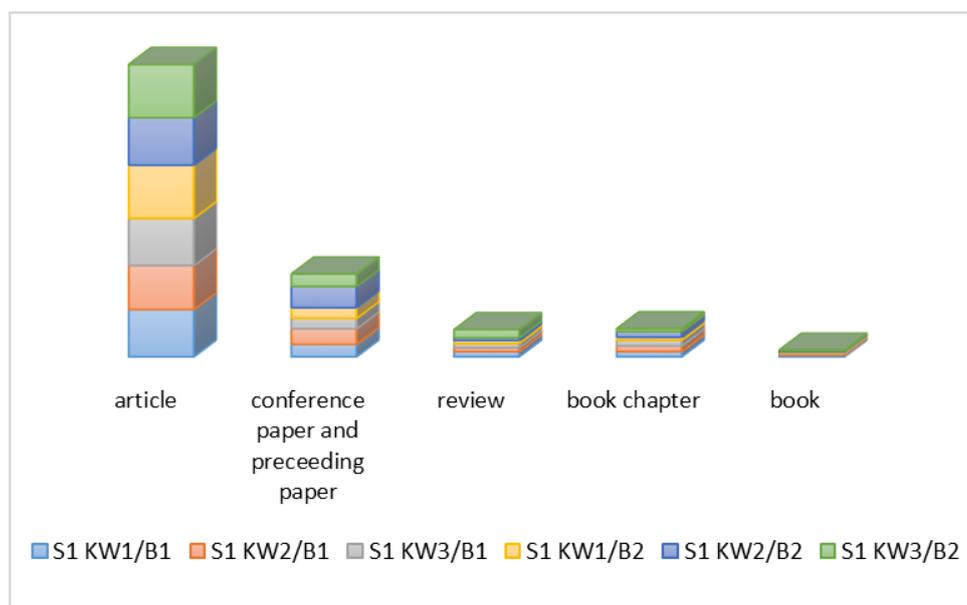
Figure 5. Types of published scientific papers for particular keywords (KW) in the segment S1 "Sustainability". Source: Own study based on the databases: Web of Science and Scopus.

Table 3. The most important scientific journals with the largest number of scientific papers which include keywords: "sustainable", "sustainable business" or "sustainable production" (TOP 3).

Database	Keyword	Source Title	Record Count	% of Total Search Results (%)	Total Search Results (100%)
Scopus (B1)	S1 KW1	*Sustainability*	6135	2.957	
		Journal of Cleaner Production	3720	1.793	207,497
		Ecological Economics	1040	0.501	
	S1 KW2	*Journal of Cleaner Production*	127	5.580	
		Sustainability	109	4.789	2276
		Business Strategy and the Environment	29	1.274	
	S1 KW3	*Journal of Cleaner Production*	222	3.779	
		Acta Horticulturae	170	2.894	5875
		Sustainability	78	1.328	
WoS (B2)	S1 KW1	*Sustainability*	5630	3.626	
		Journal of Cleaner Production	4319	2.781	155,278
		Ecological Economics	1086	0.699	
	S1 KW2	*Journal of Cleaner Production*	120	8.045	
		Sustainability	106	7.109	1491
		Business Strategy and the Environment	23	1.543	
	S1 KW3	*Journal of Cleaner Production*	225	4.676	
		Acta Horticulturae	151	3.138	4812
		Sustainability	82	1.704	

Source: Own study based on the databases: Web of Science and Scopus.

In both databases for the three categories of keywords, the most popular journals were: *Sustainability* and *Journal of Cleaner Production*. These journals have achieved, together, in all categories, the following results: *Sustainability*—6322 results in the Scopus database and 5818 results in the WoS database; *Journal of Cleaner Production*—4069 in the Scopus database and 4664 results in the WoS database.

The next analyzed category was "author name":

- In Google Scholar, the most citations for the keyword "Sustainability" were for: Dierickx, I., and Cool, K. (1989) [47], cited by 12,219 (394.16 per year). The second place belonged to: Tilman, D., Cassman, K.G., Matson, P.A., Naylor, R. (2002) [48]—cited by 6629 (368.28 per year), and the third place belonged to: Carroll, A.B., and Buchholtz, A.K. (2014) [49]—cited by 5436 (906 per year). The next places in the number of citations category belonged to the authors, who obtained results

above 3000: Mowforth, M. and Munt, I. (2015) [50], cited by 3919 (783.80 per year), Dyllick, T., and Hockerts, K. (2002) [51], cited by 3814 (211.89 per year), Turner, B.L., Kasperson, R.E., Matson, P.A. (2003) [52], cited by 3791 (223.00 per year), Kates, RW, Clark, WC, Corell, R., Hall, J.M. (2001) [53], cited by 3225 (169.74 per year), Pauly, D., Christensen, V., Guénette, S., Pitcher, T.J. (2002) [54], cited by 3365 (186.94 per year), Fullan, M. (2005) [55], cited by 3333 (222.20 per year), Newman, P., and Kenworthy J. (1999) [56], cited by 3284 (163.24 per year), Tilman, D., Wedin, D., Knops, J. (1996) [57], cited by 3047 (126.96 per year).

- For "Sustainable business" in Google Scholar (for 1000 analyzed papers), a lot of citations were for two scientific aticles: Bocken, N.M.P, Short, S.W, Rana, P., Evans, S. (2014) [45] Elsevier, cited by 1861 (310.17 per year); Boons, F., Lüdeke-Freund, F. (2013) [58], Elsevier, cited by 1529 (218.43 per year).

- In the same database, for the keyword "sustainable production", the most citations were obtained by the authors: Brezet, H. (1997) [59] cited by 1078 (46.87 per year) and Vermeir, I., Verbeke, W. (2006), [60], cited by 2036 (145.43 per year).

Results for the filter "author name" are shown in Table 4 (TOP 5).

Table 4. Number of published scientific papers according to author names (TOP 5).

		Author Name				
Database	Keyword	1	2	3	4	5
Scopus (B1)	S1 KW1	Dincer, I. (117)	Azapagic, A. (116)	Sarkis, J. (112)	Lal, R. (90)	Nijkamp, P. (82)
	S1 KW2	Svensson, G. (24)	Evans, S. (20)	Bocken, N.M.P.(14); Padin, C. (14)	Høgevold, N.M. (13); Wagner, B. (13)	Ferro, C. (8); Rana, P. (8)
	S1 KW3	Xu, B.Q. (12)	Alkaya, E. (11); Demirer, G.N. (11); Liang, Y. (11)	Centi, G. (9); Franke, J. (9); Nielsen, J. (9)	Azapagic, A. (8); Friedl, A. (8); Irabien, A. (8)	
WoS (B2)	S1 KW1	Anonymous (445)	Zhang, Y. (200)	Wang, Y. (174)	Liu, Y. (173)	Li, Y. (163)
	S1 KW2	Evans, S. (18)	Svensson, G. (16)	Bocken, N.M.P. (13)	Aagaard, A. (9)	Anonymus (9)
	S1 KW3	Centi, G. (15); Li, X.L. (15)	Perathoner, S. (14); Xu, B.Q. (14)	Hallenbeck, P.C. (13)		

Source: Own study based on the databases: Web of Science and Scopus.

By country category, the publications searched for contained all the key words from the segment (S1); these most often came from the USA, China or EU countries. Table 5 presents details of this search, including scientific papers from India and Australia. Over 95% of all papers in the WoS and Scopus databases were written in English.

Table 5. Number of published scientific papers in S1 segment by country/region category (TOP 5).

		Order in Search List: Country/Region				
Database	Keyword	1	2	3	4	5
Scopus (B1)	S1KW1	United States (47,341)	UK (22,595)	Australia (14,152)	China (12,177)	Germany (11,374)
	S1KW2	United States (435)	UK (311)	Germany (159)	Australia (132), India (132)	Netherlands (111)
	S1KW3	United States (943)	Germany (529)	China (527)	India (494)	UK (378)
WoS (B2)	S1KW1	United States (35,108)	England (14,295)	China (11,653)	Australia (10,710)	Italy (8919)
	S1KW2	United States (775)	China (531)	Germany (431)	India (354)	Italy (306)
	S1KW3	United States (775)	China (531)	Germany (431)	India (354)	Italy (306)

Source: Own study based on the databases: Web of Science and Scopus.

3.2. Results of the Bibliometric Analysis in the Segment (S2): Industry 4.0

In the limited time period from 2011 to 2019 (filter: TITLE-ABS-KEY), 8241 search results for "Industry 4.0" (S2 KW1) were obtained in all content of scientific papers available through the Scopus database, including: open access: 2096. In the second database (WoS), 4933 papers were established for the "Industry 4.0" (the filter: "Topic"), including open access: 1579. There were 50,550 citations for 460 papers in Google Scholar (29 June 2020). According to the database, there were 7221.43 citations

per year and 109.89 citations per paper. The average number of authors per paper was 2.99 (median 3). The Hirsch index for „Industry 4.0" was: 107 (a = 4.42, m = 15.29).

For the next keyword used: "Smart Factory" in the Scopus database, there were 1542 papers, including open access: 355 papers. In the WoS databases, there were 684 results, including open access: 216. In Google Scholar (29 June 2020), for the keyword "smart factory" (S2 KW2), there were 20,379 citations for 998 papers. According to this database, there were 2264.33 citations per year and 20.42 citations on paper. The average number of authors per paper was 2.93 (median 3). The Hirsch index for "smart factory" was: 64 (a = 4.98, m = 7.11).

For the last keyword in segment no 2: "smart production" (S2 KW3) were established 253 results in the Scopus database, including open access: 60 papers. For the same keywords in the database WoS, there were 166 papers, including open access: 49 papers. In Google Scholar (29 June 2020), for the keyword "smart factory" (S2 KW2), there were 1496 citations for 200 papers. According to this database, there were 166.22 citations per year and 7.48 citations per paper. The average number of authors per paper was 2.08 (median 2). The Hirsch index for "smart factory" was 18 (a = 4.62, m = 2.00). The number of scientific papers (total) in particular databases is shown in Figure 6. The dynamic of publications for the keyword "Industry 4.0" in the period from 2011 to 2019 in Figure 7 is shown.
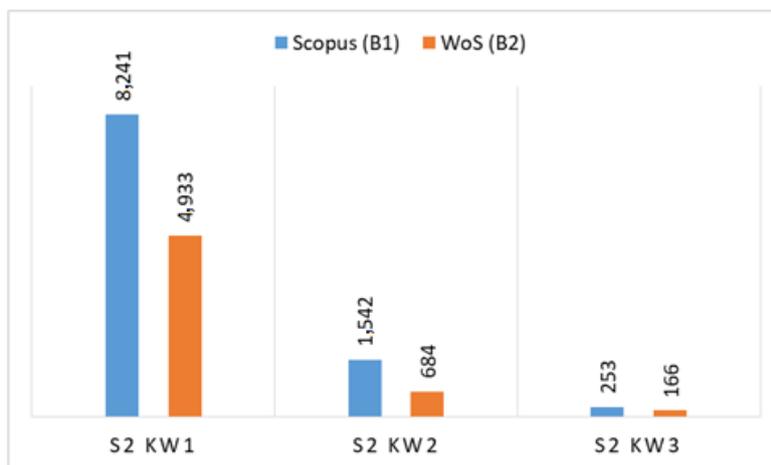

Figure 6. Number of scientific papers for particular keywords (KW) in the segment S2 "Industry 4.0". Source: Own study based on the databases: Web of Science and Scopus.
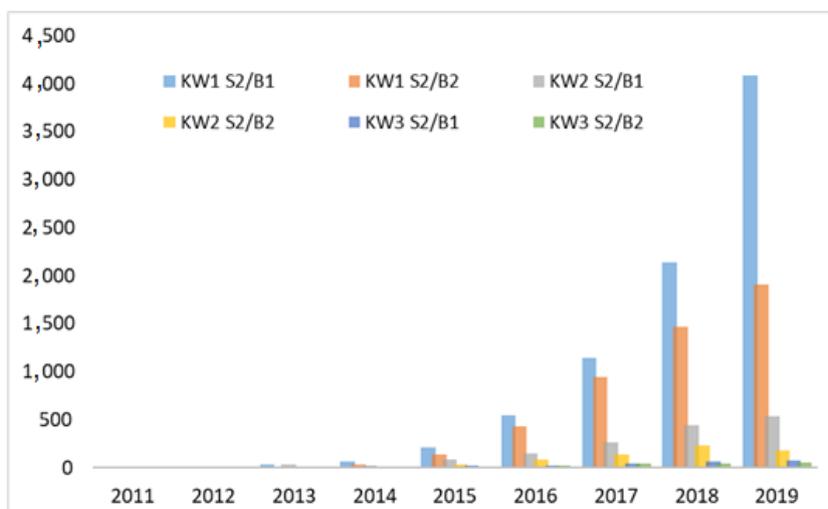

Figure 7. Dynamics of publishing for particular keywords (KW) in the segment S2 "Industry 4.0". Source: Own study based on the databases: Web of Science and Scopus.

An increase of scientific papers on Industry 4.0 happened after 2016. From 2011, when the Industry 4.0 development strategy was presented in Germany, to 2016, the number of scientific papers was small in each of the analyzed segments. In the first years after the emergence of the Industry 4.0 concept in Europe, the number of papers was low (in 2011, three scientific papers were recorded in Scopus). When L. Mahlmann Kipper et al. (2019) [33] analyzed the databases until 2015, the interest of scientists and researchers subject "Industry 4.0" was low. It was only in 2016 that an upward trend could be observed in the number of papers on Industry 4.0. In recent years (the period from 2017 to 2019), the number of publications was more than a thousand annually (there were, in 2017—1146 documents, in 2018—2136 documents, and in 2019—4079 papers, in the Scopus database). The number of scientific papers in Scopus database over time (2011–2018)—source: SciMAT—were: 2011—3, 2012—8, 2013—22, 2014—67, 2015—170, 2016—372, 2017—664, 2018—567. In the WoS database in particular, the years were: 2019—1909, 2018—1465, 2017—942, 2016—429, 2015—140, 2014—35, 2013—12, 2012—1 [33]. The results of our own study and L. Mahlmann Kipper et al.'s study [33] in Figure 8 are shown. Table 6 presents the number of publications in the period from 2011 to 2019.
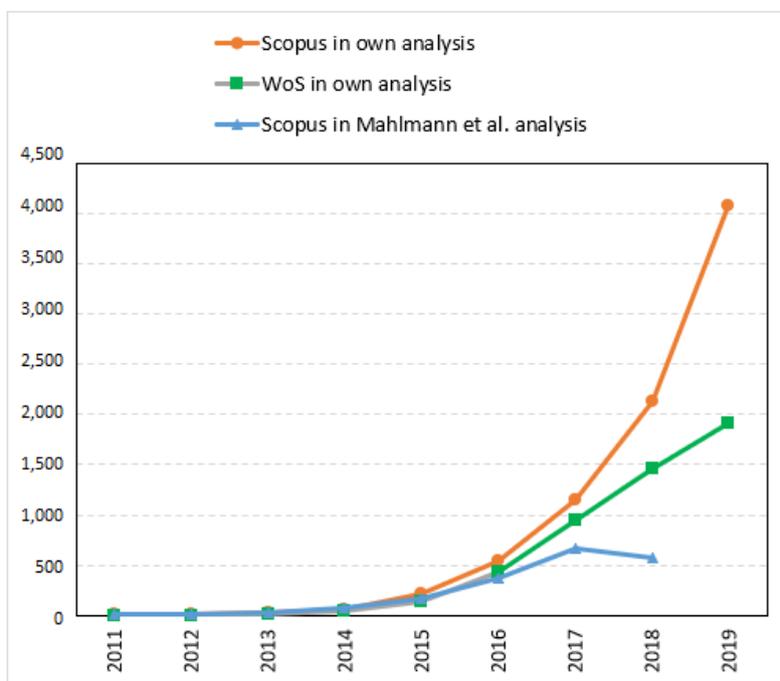

Figure 8. Number of publications for subject "Industry 4.0" over time (2011–2019).

Table 6. Number of published scientific papers in the period from 2011 to 2019.

Database	Keyword	2011	2012	2013	2014	2015	2016	2017	2018	2019
Scopus (B1)	S2 KW1	3	8	31	63	208	546	1146	2136	4079
	S2 KW2	3	13	28	25	82	151	263	438	539
	S2 KW3	5	3	2	12	20	21	48	69	73
WoS (B2)	S2 KW1	0	1	12	35	140	429	942	1465	1909
	S2 KW2	0	5	4	12	31	86	140	230	179
	S2 KW3	1	2	1	5	4	17	40	45	51

Source: Own study based on the Web of Science and Scopus.

The analysis of publications by category "document type" showed the popularity of conference papers. In the Scopus database, for keyword "Industry 4.0" (S2 KW1), there were: 4831 conference papers, 2528 articles, 270 book chapters, 207 conference reviews, 168 reviews, and others. The share of conference papers in all publications (total 8241) was 59%, and the share of articles was 31%.

Other types of documents were less popular. In the same database for the keyword "smart factory" (S2 KW2) there were: 864 conference papers (56%), 546 articles (35%), 41 conference reviews (3%), 36 book chapters (2%), 28 reviews (2%), and other types of scientific documents. The last keyword "smart production" (S2 KW3) was in: conference papers (118 results, share 47%), articles (112 results; 44%), conference reviews (8 results; 3%), book chapter (5 results; 2%), review (3 results; 1%) and other types (less than 5% other publications). In the WoS database for "Industry 4.0" (S2 KW1), such document type results were found: 2815 proceedings papers (57%), 1773 articles (36%) and others (10%): editorial materials, reviews, book chapters. In the same database, for the keyword "smart factory" (S2 KW2), there were: 404 proceedings papers (59%), 245 articles (36%), 30 reviews (4%) and about 5% belonged to book chapters, editorial materials, letters/news. For "smart production" (S2 KW3), the following results were obtained: 89 (54%) proceedings papers, 77 (46%) articles, and less than 5% others. All results for the filter "document type" are shown in Figure 9. Procedia manufacturing often appeared in the segment, among other sources (Table 7).
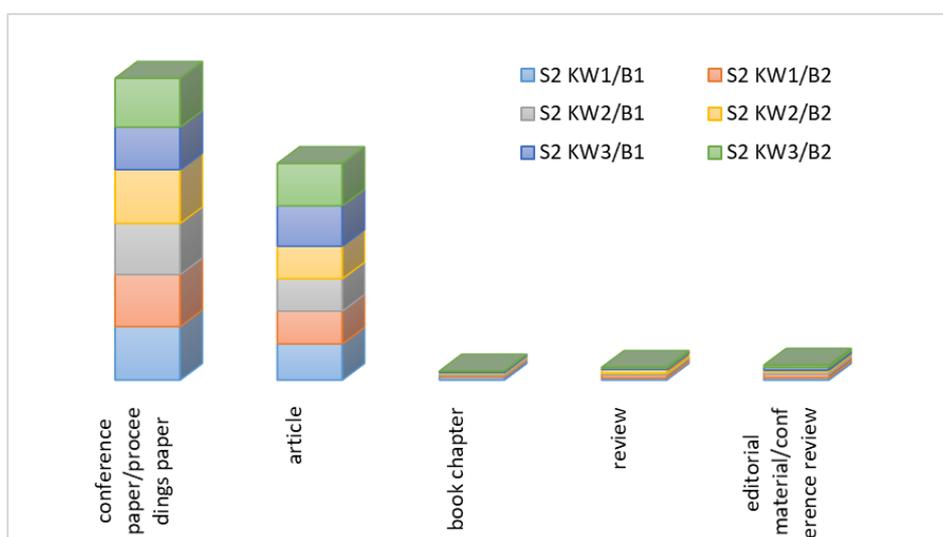

Figure 9. Types of scientific papers for particular keywords (KW) in the segment S2 "Industry 4.0".
Source: Own study based on the databases: Web of Science and Scopus.

Kipper, L.M. and Furstenau L.B., with their team (2019) [33], conducted a detailed bibliometric analysis of scientific papers, on the subject "Industry 4.0", in the Scopus database. They found that the ZWF was a popular journal, and the authors who had the most scientific papers were: Li, D. (25), Wan, J. (17), Zhang, Y. (16), Wang, S. (15), Tao, F. (15), Liu, C. (14), Zhang, C. (11), Metternich, J. (11), Wang, J. (10) and Rauch, E. (10).

Results of own analysis for the subject: "Industry 4.0" in the Scopus database are presented in Table 8. According to Google Scholar, among the quoted items on the subject of "Industry 4.0", the first place was taken by the publication: Hermann, M., Pentek, T. Otto, B. Design principles for Industry 4.0 scenarios, published in 2016 during the 49th International Hawaiian Conference [8]. These papers received 1614 quotations (12 December 2019) (a total of 19,600 search results for "Industry 4.0" in Google Scholar).

Table 7. Top 3 most important sources with the largest number of articles for the keywords: "Industry 4.0", "smart factory" or "smart production".

Database	Keyword	Source Title	Record Count	% of Total Search Results (%)	Total Search Results (100%)
Scopus (B1)	S2 KW1	Procedia Manufacturing	284	3.446	
		Procedia Computer Science	229	2.779	8241
		Iop Conference Series Materials Science and Engineering	200	2.427	
	S2 KW2	Procedia Manufacturing	57	3.696	
		Lecture Notes in Computer Science including Subseries			1542
		Lecture Notes in Artificial Intelligence and Lecture Notes In Bioinformatics	49	3.178	
		Procedia CIRP	42	2.724	
	S2 KW3	Procedia Manufacturing	23	9.091	
		Lecture Notes in Computer Science Including Subseries			253
		Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics	9	3.557	
		ACM International Conference Proceeding Series	7	2.767	
WoS (B2)	S2 KW1	IFAC Papersonline	188	3.811	
		Procedia Manufacturing	158	3.203	4933
		ATP Edition	126	2.554	
	S2 KW2	Procedia CIRP	29	4.234	
		(1) IFAC Papersonline			685
		(2) IFIP Advances in Information and Communication Technology	19	2.774	
		IEEE Access	18	2.628	
	S2 KW3	Procedia Manufacturing	13	7.831	
		(1) Computers Industrial Engineering (2) IFAC Papersonline	5	3.012	166
		(1) 27TH International Conference on Flexible Automation and Intelligent Manufacturing FAIM2017 (2) 7TH Conference on Learning Factories CLF 2017	4	2.410	

Source: Own study based on the databases: Web of Science and Scopus.

Table 8. Number of published scientific papers according to author names (TOP 5).

		Author Name				
Database	Keyword	1	2	3	4	5
Scopus (B1)	S2 KW1	Zakoldaev, D.A. (41) Zharinov, I.O. (41)	Rauch, E. (38) Shukalov, A.V. (38)	Matt, D.T. (33)	Telukdarie, A. (26)	Rivera, M. (25), Wuest T. (25)
	S2 KW2	Zharinov, I.O. (23)	Shukalov, A.V. (22)	Li, D. (17) Wan, J. (17)	Gurjanov, A.V. (12)	Wang, S. (10)
	S2 KW3	Chien, C.F. (10)	Madsen, O. (5)	Cheng, Y. (4), Møller, C. (4) Sarkar, B. (4) Tao, F. (4) Zhang, Y. (4)	Bakir, D. (3) Chen, Y.J. (3) Dhungana, D. (3)	
WoS (B2)	S2 KW1	Anonymous (52)	Li, D. (23)	Wan J.F. (20)	Leitao P (19) Romero D (19)	Garcia MV (18) Jeschke S (18) Li, Y. (18) Rauch E (18)
	S2 KW2	Li, D. (14) Wan, J.F. (14)	Kim, H. (9) Kim, S. (9) Wang SY (9)	Jeong, J. (8) Lee, H. (8) Shukalov, A.V. (8) Zakoldaev, DA (8) Zharinov I.O. (8)	Lee, J. (7) Lee, J.Y. (7) Liu, C.L. (7) Zhang, C.H. (7) Zhong, R.Y. (7)	Anonymous (6) Bauernhansl, T. (6)
	S2 KW3	Chien, C.F. (11)	Cheng, Y. (4) Madsen, O. (4) Sarkar, B. (4) Tao, F. (4) Zhang, Y.P. (4)	Alavian, P. (3) Chen, Y.J. (3) Eun, Y. (3) Guo, H.Z (3) Hong, T.Y. (3) Meerkov, S.M. (3) Sarkar, M. (3)	Lorenzoni, A. (2) Luder, A. (2) Mazak, A. (2) Moller, C. (2) Mortensen, S.T. (2) Neser, F.W.C. (2)	Bartels, G. (1) Beghi, A. (1), Calay, R.K. (1)

Source: Own study based on the databases: Web of Science and Scopus.

In the analyzed segment (S2) for the keyword Industry 4.0, the most popular country was Germany, in second place among countries was Italy, and on the third, was the United States. For the keyword "smart factory", in second place was South Korea, and in third place was China. For the keyword "smart production", such results were found: Germany, China, Austria (TOP 3). In the WoS database publications ("Industry 4.0"), realized by German authors in 2011–2019, were 992 papers. Second place in the WoS: Italy—498, third place: China—408, fourth place: Spain—290, fifth place: US—268. The next keywords in the first place were German authors too. Most of the scientific papers were written in English language, 94% (Scopus); in second place was German language (5%). Table 9 presents more information about scientific papers by using the filter: country.

Table 9. Number of published scientific papers according to: country/region (TOP 5).

		Order in Search List: Country/Region				
Database	Keyword	1	2	3	4	5
Scopus (B1)	S2 KW1	Germany (1591)	Italy (824)	United States (487)	China (462)	United Kingdom (394)
	S2 KW2	Germany (317)	South Korea (219)	China (154)	Italy (119)	United States (108)
	S2 KW3	Germany (66)	China (30)	Austria (25)	United States (17)	Taiwan (15)
WoS (B2)	S2 KW1	Germany (992)	Italy (498)	China (408)	Spain (290)	United States (268)
	S2 KW2	Germany (139)	China (114)	South Korea (103)	Italy (58)	United States (49)
	S2 KW3	Germany (51)	China (22)	Taiwan (16)	Austria (13)	South Korea (11)

Source: Own study based on the databases: Web of Science and Scopus.

3.3. Results of the Bibliometric Analysis in the Segment (S3): Sustainable Industry 4.0

The analysis of this segment in the Scopus and WoS databases was limited to two keywords: "sustainable Industry 4.0" and "sustainable smart production". The databases were also searched using other keywords, but no significant results were obtained. The shortest analysis period was adopted because the topic "Sustainable Industry 4.0" is the newest of the analyzed topics, and had a short history. The period limit was set for 2014–2019. For the keyword "sustainable Industry 4.0" (S3 KW1), such results were obtained: 4 articles in the Scopus database, 2 in 2018, and 2 in 2019, including 3 in the form of open access. Using the filter country, such results were obtained: United States (2), Australia (1), India (1), Spain (1). For the same keywords (S3 KW1) in the second database,

2 papers were found, including one in open access. The papers were published in 2018. One of the papers was classified as an article and second was a review. Results of analysis by the filter country were: India (1), Spain (1), US (1). Table 10 presents results for the categories: authors and sources. For the keywords "sustainable Industry 4.0" in Google Scholar, 213.25 citations per year were found, including 5.80 citations per paper and 2.80 authors per paper (median 3.0). The Hirsch index was: 11 (a = 7.05), m = 2.7 (limit: 147 papers). Two papers had over one hundred citations in the period from 2014 to 2019: Morrar, R., Arman, H., Mousa S. (2017) [61] (169 citations, 56.33 per year) and Kamble, S.S., Gunasekaran, A., Gawankar, S.A. (2018) [62] (166 citations, 83.00 per year). In 2020, for the subject "Sustainable smart production system", one paper was obtained: Sarkar, M., and Sarkar, B. (2020) [63]. For previous years, no papers in the databases Scopus and WoS were found. In Google Scholar, there were: 200 papers with 942 citations, including 157.00 citations per year and 4.71 citations per paper, and 1.31 authors per paper. The Hirsch index was: 11 (a = 7.79, m = 1.83).

Table 10. Authors and papers in the subject: "Sustainable Industry 4.0".

Database	Title	Author	Year	Place	Citation/Time Cited
Scopus	The smart cyber-physical systems of sustainable Industry 4.0: Innovation-driven manufacturing technologies, creative cognitive computing, and advanced robotics	Cosgrave, K.W.	2019	Journal of Self-Governance and Management Economics 7(3), pp. 7–13	0 citation/the Scopus database
Scopus and Google Scholar	Sustainable Industry 4.0: Product decision-making information systems, data-driven innovation, and smart industrial value creation	Lafferty, C.	2019	Journal of Self-Governance and Management Economics 7(2), pp. 19–24	1 citation/the Scopus database 4 citations/Google Scholar
Scopus, WoS and Google Scholar	Sustainable Industry 4.0 framework: A systematic literature review identifying the current trends and future perspectives	Kamble, S.S., Gunasekaran, A., Gawankar, S.A.	2018	Process Safety and Environmental Protection 117, pp. 408–425	105 citations/the Scopus database 66 citations/the WoS 166/Google Scholar
Scopus, WoS, and Google Scholar	IoT Heterogeneous Mesh Network Deployment for Human-in-the-Loop Challenges Towards a Social and Sustainable Industry 4.0	Garrido-Hidalgo, C., Hortelano, D., Roda-Sanchez, L., (...), Ruiz, M.C., Lopez, V.	2018	IEEE Access 6, pp. 28417–28437	20 citations/the Scopus database 10 citations/the WoS 29/Google Scholar

Source: Own study based on the databases: Web of Science and Scopus.

4. Discussion

Based on the bibliometric analysis, it was found that most science articles concerned the topic of "sustainable development". This is due to the long period of research on this issue (from the end of the last century to the present day). A smaller set of publications consists of the subject of "Industry 4.0", and the smallest one is "Sustainable Industry 4.0" (see diagram Venna). Even if the same analysis period 1987–2019 was used for all three segments, significant changes in the results would not be achieved, as both the concepts of "Industry 4.0" and "Sustainable Industry 4.0" are new concepts. The concept of "Sustainable Industry 4.0" is gradually being built, using the pillars of Industry 4.0 to achieve sustainable development. The results of the bibliometric analysis confirm the thesis that: Sustainable Industry 4.0 allows the integration of the Industry 4.0 concept with the goals of sustainable development. Contemporary business organizations recognize changes in the Industry 4.0 concept as important for sustainable development. This means that "Sustainable Industry 4.0" is a developed form of "Industry 4.0", taking into account the aspects of sustainable development (see Figure 10).
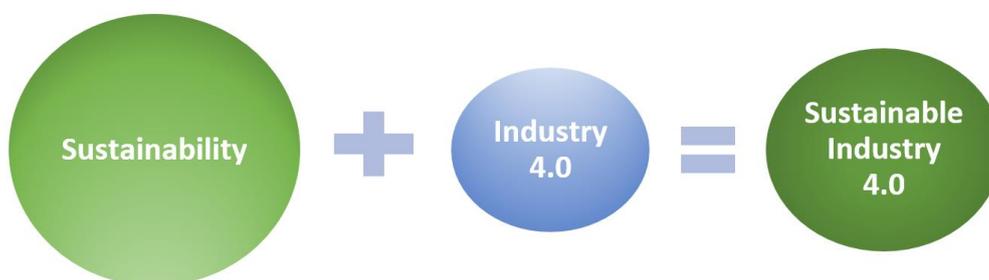

Figure 10. The synthesis of bibliometric analysis: Sustainable Industry 4.0. Source: Own study based on bibliometric analysis.

Moreover, when analyzing the content of scientific articles in bibliometric analysis, it can be concluded that three keywords: sustainable business, sustainable production and sustainable enterprise with intelligent innovations, create a new research area: "Sustainable Industry 4.0" (see Figure 11).
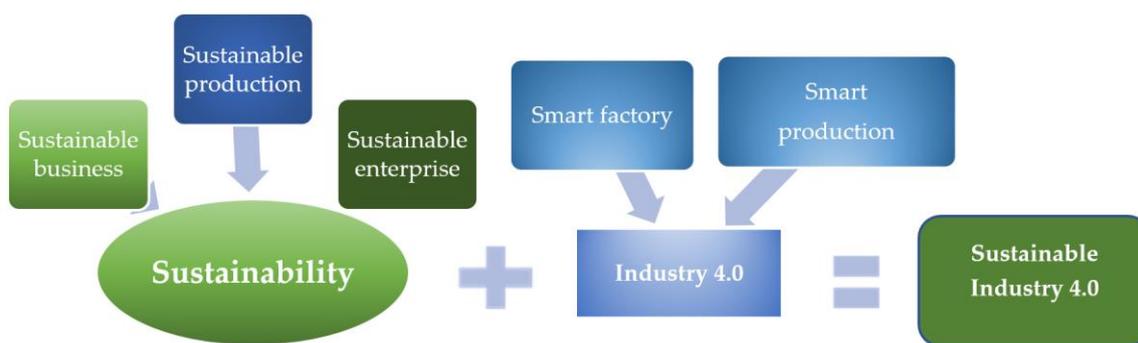

Figure 11. Subjects of the synthesis of bibliometric analysis: Sustainable Industry 4.0. Source: Own study based on bibliometric analysis.

Using Venn diagrams (Figure 12), the set of scientific articles from the research area "Sustainable Industry 4.0" was presented as a subset of a larger set of "Sustainability". The set of articles from the research area "Industry 4.0" was inside the larger set of "Sustainable development", and its further evolution in the set led to the creation of another subset "Sustainable Industry 4.0". The discussion about the directions of evolution of the Industry 4.0 concept in a sustainable environment concerns the search for an answer to the question: How sustainable is smart and how smart is sustainable? [64]. Figure 12 shows the evolution of the interest of scientists in particular areas of research. In our opinion, the share of sustainable Industry 4.0 will fill the Sustainability area, while the interest in

Industry 4.0 will decrease in the future. Based on the bibliometric analysis, the collections presented in Figure 12a) are those that best reflect the current situation with regard to the topics of scientific papers and research areas. The authors who deal with the topic of "Sustainability" try to explore a new area, Sustainable Industry 4.0, using the solutions offered by Industry 4.0 to achieve a sustainable but modern environment. Another set relationship, marked as Figure 12b) in Figure 12, is the detailing of set Figure 12a), where only "smart" technology is extracted from Industry 4.0 in order to apply it for sustainability. Figure 12c) illustrates a situation where there are scientific papers that fall into both sets, i.e., the research set called "Sustainability" and called "Industry 4.0", but present a new thinking pattern that can be classified as Sustainable Industry 4.0. The last collection (part d) of Figure 12 is the future, when the authors' research on Sustainable Industry 4.0 will be so extensive that the currently popular area of research "Industry 4.0" will be included in the collection of research on Sustainable Industry 4.0. Sustainability is likely to remain the largest collection, due to the wide range of research on what it contains. An interesting issue of the considerations is the level of interest in the issues of "Sustainable Industry 4.0" in the future. This requires an answer to the following question: whether "Sustainable Industry 4.0" will be a more extensive area of research and analysis than "Industry 4.0". Future research may lead to the expansion of the Sustainable Industry 4.0 concept, due to the fact that sustainable development is a popular and fashionable direction of change in the world economy. The "Sustainable Industry 4.0" as a research area is the result of the penetration of a strong set: "Sustainable" with the smaller (currently) set "Industry 4.0". Sustainable Industry 4.0 has a common part with the two sets:" Sustainability "and" Industry 4.0". The common part is "smart" [65]. The discussions about the role of Industry 4.0 in sustainable development and the evolution of Industry 4.0 to sustainable Industry 4.0 were provided in scientific papers [66–68]. Similarly, the problem of the distinctiveness of the features of "Sustainable Industry 4.0" and "Industry 4.0" was considered in the work of Erol (2016) [69]. In addition, other authors (2019) [70] propose a new approach to Industry 4.0 organizations and business models that are able to lead to a more sustainable society.
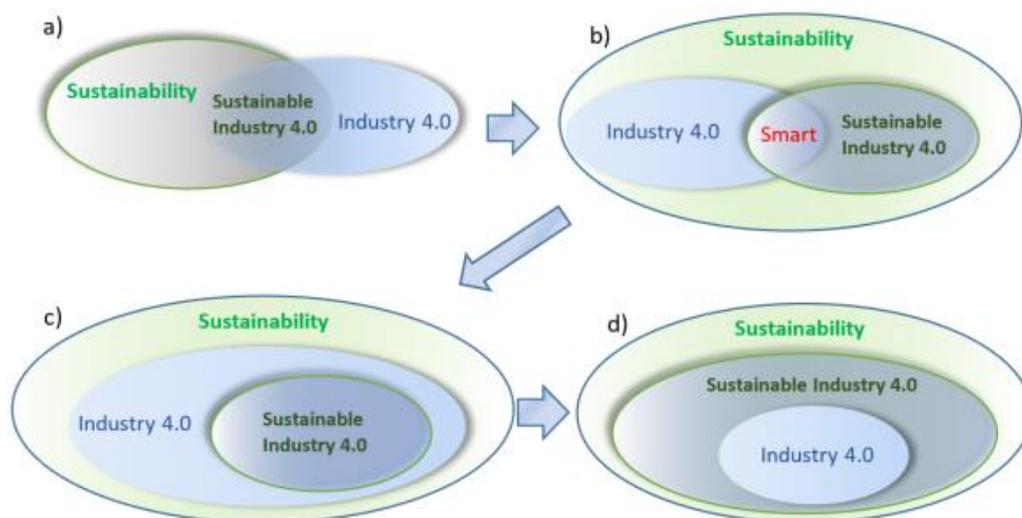

Figure 12. Evolution process in scientific papers towards Sustainable Industry 4.0 based on Venn diagrams. Evolution process in scientific papers towards Sustainable Industry 4.0 based on Venn diagrams. (**a**) Current situation with regard to the topics of scientific papers and research areas. (**b**) A set of "smart" technology is extracted from Industry 4.0 in order to apply it for sustainability. (**c**) A situation where exist both sets, i.e., the research set called "Sustainability" and called "Industry 4.0", but present a new thinking pattern that can be classified as "Sustainable Industry 4.0". 12d) Expected situation presenting that the authors' research on Sustainable Industry 4.0 will be so extensive that the currently popular area of research "Industry 4.0" will be included in the collection of research on "Sustainable Industry 4.0". Source: Own study based on bibliometric analysis.

As a result of the conducted research, common research areas were distinguished for the scientific papers under consideration. A detailed analysis of the content of the selected papers shows that the Industry 4.0 implementation in the sustainable environment most often concerns urban spaces and creates a research area: "Sustainable smart cities" or "Sustainable smart urbanization". Detailed research in these areas is presented in the works of: Farag, SG (2019) [71], Lom, M., Pribyl, O., Svitek, M. (2016) [72], Solano et al. (2016) [73], Vaquero-García et al. (2016) [74], Laconte, P. (2018) [75], Bululukova and Wahl (2015) [76], Bibri, SE (2018) [77,78], Bueti and Ip (2019) [79], Somayya and Ramaswamy (2016) [80], Schipper and Silvius (2018) [81], Govada et al. (2019) [82], Al Khalifa, FA (2019) [83], Trillo, C. (2016) [84], Yonezawa T. (2016) [85]. The authors of scientific papers have formulated the following problems: Do cities want to become smart or sustainable? [86,87]; What are the components of smart cities? [84], etc. They have defined the components of smart cities as smart tourism, smart transport [88,89], smart buildings, smart public services, smart eco-system, etc.

The second large area of research of scientists is the use of Industry 4.0 solutions for energy management. This area was the subject of the following works: Hidayatno, Destyanto, and Hulu (2019) [90], Wang, L. (2014) [91], Kakegawa, M. (2019) [92]. Among the scientific papers about sustainable and smart energy, there is also a paper about using sustainable energy for smart cities [93]. An interesting problem was considered in the paper [63], where the authors have presented the approach to reduce waste and energy consumption, within an interesting approach called "multi-stage smart sustainable biofuel production system".

The third area of research is "Sustainable Smart Manufacturing". The topic was presented in the following papers: Rodrigo Goyannes Gusmão Caiado, Osvaldo Luiz Gonçalves Quelhas (2019) [94], Kamble et al. (2018) [62], Lafferty, C. (2019) [95], Cosgrave, K.W. 2019 [96], Garrido-Hidalgo, and Hortelano (2018) [97], Tseng, Tan, Chiu, Chien 2018) [98], Machado, Winroth and Elias Hans Dener Ribeiro da Silva, (2020) [99], Stock, and Seliger 2016 [27], Wang et al. 2016 [26]. Authors show the use of Internet of Things technologies, Big Data and CPPS (cyber-physical systems) in industrial environments, to create smart factories. The intensive development of new technologies is heading towards the functioning of artificial intelligence in a sustainable environment. Modern sustainable production uses IT solutions, new materials (smart, green, renewable materials) [100] and new products.

A detailed analysis of scientific papers allowed one to define current research areas in the field of sustainable development of economies, markets and individual industries. Using the "Sustainable Industry 4.0" filter, the following areas of research were found: smart sustainable tourist [101]), sustainable smart agriculture [102], smart ecosystem [103], sustainable smart service design [104], smart sustainable data [105,106] and intelligent supply chain [107–109]. Based on the number of scientific papers, different sizes of research areas were determined for "sustainable Industry 4.0". Scientists undertake research in the following areas: industrial sector (e.g., food, agriculture, energy), urban development, economy and society (towards society 5.0 and more connected society and economy). The social aspect "Sustainable Smart Society" was presented by Ferro, M.O. (2019) [110], Mitomo, H. Fuke, H. and Bohlin, E. (2015) [111], Bauer, W. et al. (2015), [112], Salimova, T., Guskova, N., Krakovskaya, I. (2019) [113]. The economic aspects of Sustainable Industry 4.0 in a "Sustainable Smart Economy" were presented by Müller and Voigt, (2018) [114]; Sachs and Sanders, (2017) [115]. The final result of the analysis is a map of current research areas of Sustainable Industry 4.0 with a basic cluster (Figure 13).
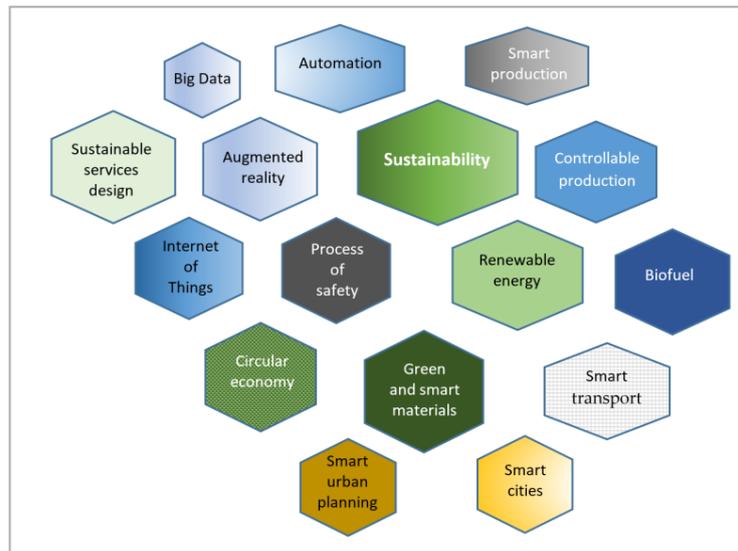
Figure 13. Cluster of current areas of interest for scientists in the field of sustainable Industry 4.0. Source: Own study based on bibliometric analysis.

Particular clusters can be grouped by micro- and macroeconomic areas and/or by levels. Such a division was made by authors Müller et al. [116], who define hypothesized relationships of Industry 4.0-related opportunities and challenges with the implementation of Industry 4.0 in sustainability. The authors examined three levels of opportunities: strategy, operations, environment and people, and identified three types of challenges: competitiveness and future viability, organizational and production fit, employee qualification and acceptance. The individual areas presented in Figure 13 can also be considered in the layout proposed by Machado et al. [99], that is, from the pillars of Industry 4.0 through the scope of sustainable manufacturing and business models, and sustainable models of development. In our analysis, the presented areas are only the final result of bibliometric analysis and may be further studied in the context of their grouping and relations between them.

5. Conclusions

Sustainability in Industry 4.0 is a new concept in the literature, and was created from the combination of sustainable development goals, in the process of implementing Industry 4.0 solutions in economies, society and enterprises. The Sustainable Industry 4.0 concept integrates sustainability and Industry 4.0, and is an area of research currently increasingly conducted by scientists and practitioners. Due to the research gap in the area of the lack of identification of research problems related to the Sustainable Industry 4.0 implementation, a bibliographic analysis was performed.

The article confirms the thesis that: Sustainable Industry 4.0 enables the integration of the Industry 4.0 concept with the goals of sustainable development. The identified new research area is poorly recognized in the literature, as are its separate components, such as Industry 4.0 or sustainability. According to conducted analyses, the sustainability has been present in scientific papers since the 1990s, that is, from the moment when the discussion about sustainability intensified. Starting from 2011, the Industry 4.0 concept appeared in scientific papers as new technological and IT solutions of the fourth industrial revolution. These two areas create a new area of research called "Sustainable Industry 4.0".

The new research area has already existed in scientific articles in analyzed databases. The scientific papers highlight a number of scientific problems in the area of Sustainable Industry 4.0, as follows: how to prepare society to implement Industry 4.0 in a sustainable environment? What skills and knowledge of employees will be required in the Economy 4.0? How will Industry 4.0 affect sustainable consumption and sustainable urban planning and smart city with smart transport? What kind of

materials and resources will be used for Sustainable Industry 4.0? What kind of Industry 4.0 technologies are fit for use in sustainable development? Which industries and sectors of the economy are most susceptible to the implementation of Sustainable Industry 4.0? What smart technologies can be used in the circular economy?

In analyzed papers, the following areas are most often considered: sustainable smart city, sustainable smart urban planning, smart energy, green and smart materials, sustainable smart manufacturing, energy efficiency, cybersecurity. Presented research problems should encourage researchers and practitioners working on Industry 4.0 implementation to conduct research, especially in area economic, social and environmental benefits from the Sustainable Industry 4.0 implementation in different contexts.

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