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Review Article

Bibliometric Analysis of Sustainability in Science Education

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Abstract
Currently, the word sustainability is increasingly being used as a narrative that leads people to carry out the vision of an environmentally friendly lifestyle. This study presents a bibliometric analysis of 498 documents from 2001 to 2022 from the Scopus database using inclusion and exclusion criteria and visualization using the Vos Viewer. Although the first research was conducted in 2001, most of the research was published in 2021-2022. The literature on sustainability is growing significantly and this pattern is expected to increase in 2022 and beyond. Data analysis including publication developments and citation trends, most cited documents, most prolific sources, most prolific institutions, most prolific authors, most prolific countries, Keyword-based and co-authoring development maps for publications for authors and countries. The findings show that 2021 has the highest number of publications on Sustainability in Science Education with 70 documents and 184 citations, while 2019 has the highest number of citations, namely 668 citations with a total of 51 documents. The most cited documents are written by Snively, G., et al., with 252 citations and an average (C/Y) of 12 per year. The most productive source comes from Sustainability (Switzerland) which has published 43 documents, 397 citations, and 29 TLS. The most productive institution comes from the Universitat Bremen, Germany with 29 documents. The most prolific author is Eilks, I., who comes from Germany with a total of 26 documents and 598 citations. Eilks, I., also has a strong collaboration network between authors. The most productive country is topped by the United States with 154 documents, and 1681 citations. The United States, Germany, and the United Kingdom are the countries that have collaborated the most with other countries. This research maps out scientific publications on Sustainability in Science Education that will be useful for future collaborations and provide a framework for future research.

Keywords: Bibliometric analysis, publications, sustainability, science education, quotations

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1. INTRODUCTION

Sustainable Development Goals or SDGs is a sustainable development agenda, in which every decision made must consider the impact on society, the environment, and the economy, and the impact on life in the future (Strange & Bayley, 2011). Indonesia is one of the countries participating in it, so it can be ensured that Indonesia will fully support the sustainable development goals which have three pillars, namely economic, social and environmental as well as 17 sustainable development goals (Alisjahbana & Murniningtyas, 2018).

The achievement of the 17 sustainable development goals can be optimized, one of which is through Education Sustainable Development. Education Sustainable Development or ESD namely a concept that education desperately needs today. ESD is a broad concept and covers various aspects of education. ESD also covers aspects of education including planning, policy development, program implementation, finance, curriculum, learning, assessment, and administration. ESD is a strong interaction between education, public awareness, and paradigms to create a quality and sustainable future (Rieckmann, 2017).

ESD is an appropriate place for students to recognize and solve a problem. Complex problems that arise both locally and globally are used as strategies for students to practice analyzing problems and being able to make the right solutions. This is an effort to train students to deal with all kinds of possible problems that will occur both in the near term and in the future (Laurie et al., 2016). In addition, ESD aims to provide students with the ability to deal with unexpected problems or events (Dale & Newman, 2005).

Achieving sustainable development goals that are applied through education, really needs references and guidelines as a benchmark for achievement in realizing these sustainable development goals. To find out how publications regarding ESD are, a bibliometric analysis is needed. Where bibliometric indicators are knowledge that has a role to evaluate the results of scientific research; examining the interaction between science and technology; producing mapping of fields of knowledge; tracking/tracing the development of new knowledge in a particular field; and an indicator in the future in providing a more competitive advantage and in making strategic plans. Bibliometric indicators are calculated over a certain period (usually 3 - 5 years) and generally use two approaches, namely the number of publications, an indicator that measures productivity; and the number of citations, an indicator that measures the impact of the articles produced (Devos, 2011). The first bibliometrics and scientometrics were introduced by Pritchard and Nalimov and Mulchencko in 1969. Pritchard said bibliometrics is a method that uses mathematics and statistics on books and other communication media. Nalimov and Mulchenko define scientometrics as a qualitative method relating to the analysis of knowledge as an information process (Glanzel, 2003). Singh JK (2014) said that scientometrics can be used to evaluate research results by analyzing the productivity of authors and citations in science and technology. Scientometrics can be used to measure and describe countries, universities, research institutes, and journals of a research topic. The next development of bibliometrics is informatics—related to electronic media so that it uses statistical analysis of text or hypertext systems,

According to Glanzel (2003) there are three components of bibliometrics, namely: a) bibliometrics for bibliometrics, which is the main domain of bibliometric research and is traditionally used as a research methodology; b) bibliometrics for scientific disciplines (scientific information), considering that researchers work scientifically orientated, their interest is very strong in their field of specialization and allows for a joint borderland with quantitative research in information retrieval; c) bibliometric for science policy and management (science policy), is the domain of research evaluation on various research topics.

Bibliometric analysis is a study of bibliographic analysis of scientific activities, which is based on the assumption that a researcher carries out his research and must communicate the results to colleagues. This will provide progress and development of knowledge if researchers carry out joint activities to study specific research topics. In research, of course, information is needed from the results of previous scientific work that has also been carried out by colleagues. In the classical input-output model to explain the scientific research process, publications are recommended to present knowledge output. Almost all publications in the form of articles and scientific monographs are known as definitive statements of research results.

The scientific concept contained in a document can be seen through the words (co-words) used. Co-word analysis is based on the analysis of the co-occurrence of words or keywords from two or more documents used to index documents (Diodato, 1994). Co-word analysis is intended to analyze the content, patterns, and trends of a collection of documents by measuring the strength of terms (De Looze, Rompie, 1997; Coulter, Monarch, Konda, 1998).

Co-word analysis is used to calculate the number of keywords from a research document that appear simultaneously in the article under study. These keywords are determined by the author. The more keywords appear in a predetermined group of documents, the stronger the relationship between these documents (Chen, 2003). The co-word analysis map of keywords is a map based on co-occurrence, important or unique terms contained in the article and can be seen by the title or abstract. This term is derived from the analysis of the subject representing a concept.

1.1 Aim of the Study

The use of non-standardized keywords can lead to non-uniform terms, and to standardize it is necessary to use a thesaurus. A thesaurus is a list of terms covering a specific field so that the terms used are more specific. A thesaurus is different from a list of subject headings which are usually general and cover all areas of knowledge. Indexing uses descriptors in every attempt to represent a single concept. Standardizing keywords with the thesaurus aims to make the words used consistent so that only one term is used for concepts that are represented in different writings and have the same meaning.

RQ 1: What is the distribution pattern of publications from 2001 – 2022 and citations every year?

RQ 2: Which document is the most cited, the most prolific source, the most prolific institution, the most prolific country, and the most prolific author?

RQ 3: How is the publication development map based on keywords?

RQ 4: What is the co-authoring status for the author and country?

2. METHODS

2.1 Research Design

This research is a cross-sectional descriptive study that uses data from international publications in the field of Sustainability in Science Education sourced from the Scopus database (www.scopus.com) accessed on 13 October 2022. This study uses Scopus-based data to retrieve relevant documents. The Scopus database was previously used in several bibliometric studies because of its advantages over other scientific databases such as PubMed and Web of Science. Scopus is the largest online database with abstracts and citations from more than 23,700 peer-reviewed journals.

2.2 Data Collection

Data collection by searching publications on Scopus with the keywords "science education" OR "chemistry education" OR "physics education" OR "biology education" AND "sustainability" with the categories of the article title, abstract, and keywords in the period 2001 – 2022. Data in the form of the number of publications per year, journals containing articles in the field of Sustainability in Science Education, authors, the origin of authors, and subjects were analyzed using Microsoft Excel 2010. As for trends in the development of international publications instrumentation, fields were analyzed using VosViewer software.

The search yielded a total of 498 documents after applying the inclusion and exclusion criteria. These criteria are presented in Table 1.

Table 1. Inclusion and Exclusion Criteria

Criteria
Inclusion Criteria
1. Keyword search is limited to title, abstract, and document keywords
2. Documents are written in English
3. The document focuses on Sustainability in Science Education
4. All types of documents
5. Documents issued over 2000
Exclusion Criteria
1. Documents are written in a non-English language
2. Documents issued under 2001

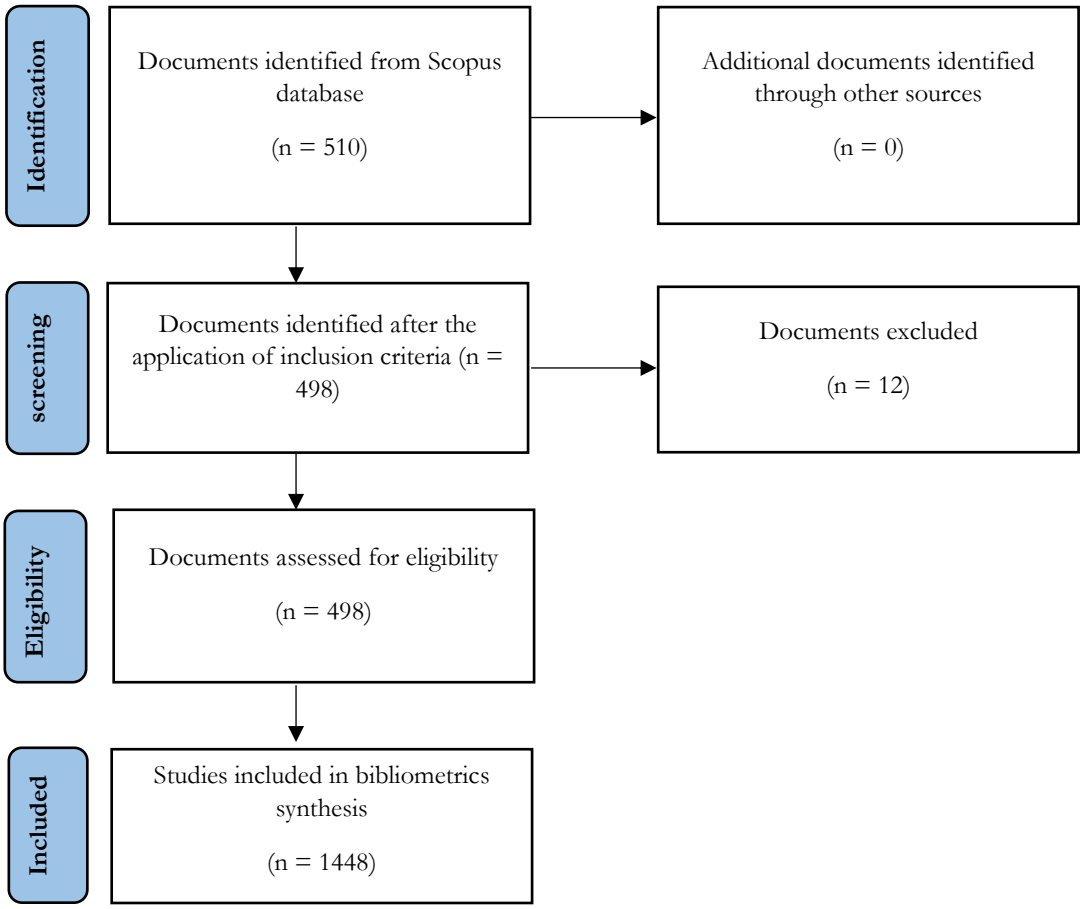

Figure 1. Research Protocol Flow Framework

The data search process in this study refers to the Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA) framework presented in Figure 1.

3. RESULTS AND DISCUSSION

Scopus is the world's largest collection of literature summaries, with citations that provide abstracts from peer-reviewed scientific literature and research. Scopus can help researchers effectively track, analyze, and visualize research. More than 22,000 high-quality abstracts published by 5,000 publishers worldwide are provided in the Scopus database from various fields, such as science, technology, medicine, social sciences, arts, and literature. Scopus has 55 million records dating back to 1823, of which 84% are sourced from references dating back to 1996 (Sánchez AD, 2017). The more specific a journal is, the higher the chance of being indexed by Scopus. Example: The minimum number of Indonesian journals indexed in Scopus is caused by the very strict requirements requested by Scopus and the selection carried out. The following are some of the minimum criteria so that journals can be assessed by Scopus: (a) journals go through a peer-review process; (b) minimal abstract in English; (c) published regularly; (d) references are written in roman script; and (e) the publication has publication ethics. In detail, the Scopus assessment categories and criteria can be seen in Table 1. The minimum number of Indonesian journals indexed in Scopus is caused by the very strict requirements requested by Scopus and the selection carried out. The following are some of the minimum criteria so that journals can be assessed by Scopus: (a) journals go through a peer-review process; (b) minimal abstract in English; (c) published regularly; (d) references are written in roman script; and (e) the publication has publication ethics. In detail, the Scopus assessment

categories and criteria can be seen in Table 2; and (e) the publication has publication ethics. In detail, the Scopus assessment categories and criteria can be seen in Table 2.

Table 2. Categories and Criteria for Scopus Indexed Publications

No	Category	Criteria
1	Journal Policy (35%)	• Convincing editorial policies • Geographical diversity in editor distribution • Geographical diversity in the distribution of authors
2	Content (20%)	• Academic contributions • Abstract clarity • Quality and conformance to stated objectives and scope • Article readability
3	Journal Standing (25%)	• Excerpt from a journal article in Scopus • Editor Writing at Scopus
4	Regularity (10%)	• There is no scheduled publication delay
5	Online Availability (10%)	• Online content available • The Journal home page in English is available • Journal home page quality

Source: Sánchez (2017)

VosViewer is a free computer program for visualizing and exploring bibliometric knowledge maps. VOS stands for in VosViewer is Visualization of Similarities. The algorithm used in this program is almost the same as Multi-Dimensional Scaling (MDS). VosViewer-generated clusters are automatically shown in color on the map. The clustering algorithm operates with a parameter (ɣ) which can be changed to get more or fewer clusters. Cluster density and color can be displayed with VosViewer (Leydesdorff & Rafols, 2012). The advantage of VosViewer compared to other analysis applications is that it uses a text mining function to identify relevant noun phrase combinations by mapping and an integrated clustering approach to examine network cocitation data and co-occurrence. Although there are many programs for analyzing text units and matrix similarity, VosViewer's strengths are in its visualization. The program's interactive options and functions make it easy to access and explore its bibliometric data networks, such as the number of citations or the co-occurrence relationships between key terms and concepts (Van Eck & Waltman, 2011; Waltman et al, 2010).

Based on search results with the keywords "science education" OR "chemistry education" OR "physics education" OR "biology education" AND "sustainability" with the category of the article title, abstract, keywords in the period 2001 – 2022 on Scopus, 498 publications were obtained which will be explained in detail as follows:

3.1 Development of Publications and Citation Trends

After applying the inclusion and exclusion criteria, 498 documents from 2001 to 2022 were included in the data analysis. Table 3 displays the distribution of document issuance per year. The first sustainability publication was published in 1995 with only 2 documents, but this became an exclusion criterion because the publication trend stopped until 1996. Then it showed a rapid increase and development from 2001 to 2022 (inclusion criteria). Publications in the last 10 years, from 2013 to 2022 have experienced significant developments. The year with the most publications on Sustainability was 2021 with 70 documents and 184 citations.

Table 3. Trends of Publication and Citation

Year of Publication	Amount	Citation
2022	56	42
2021	70	184
2020	52	419
2019	51	668
2018	42	466
2017	24	290
2016	28	237
2015	38	373
2014	28	574
2013	26	315
2012	22	526
2011	15	150
2010	15	162
2009	7	13
2008	5	145
2007	3	93
2006	5	129
2005	1	0
2004	3	54
2003	2	61
2002	3	107
2001	2	260
Total	**498**	

The bibliometric analysis reveals information about trends in Sustainability in Science Education. This finding can be used as literature to develop the application of Sustainability in Science Education. This document continues to be published annually. From 2001 – 2009 the number of documents issued each year was less than 10 documents. Then during the last ten years, the publication of Sustainability in Science Education has increased by showing good progress. This annual publication is proof that Sustainability research will continue to grow in the future. 2021 was the year with the most publications (70), while the year with the most citations was 2019, with 668 citations. Comparison between the number of documents with the number of citations does not show a positive relationship, meaning that there is no correlation between the growth in the number of documents and the growth in the number of citations, according to Table 3. The year the document was published is one of the elements that affect the high number of citations. Older documents may collect more citations than recently released publications.

3.2 Frequently Cited Documents

The top 10 most frequently cited documents are included in this section. The most frequently cited documents (C) and the number of citations each year (C/Y) are shown in Table 4. The authors of the most

frequently cited works are Snively, G., et al., with 252 citations and an average of 12 each year. The metric used to describe the impact of published articles is the number of citations each year (Kaffash, et al., 2021).

Table 4. Top 10 Frequently Cited Documents

Author	Document Title	Source	Citation	C/Y
Snively G., et al.	Discovering indigenous science: Implications for science education	Science Education	252	12
Wals AEJ, et al.	Convergence between science and environmental education	Science	193	24,13
de Jong T., et al.	Innovations in STEM education: the Go-Lab federation of online labs	Smart Learning Environments	169	21,13
Burmeister M., et al.	Education for Sustainable Development (ESD) and chemistry education	Chemistry Education Research and Practice	165	16.5
Colucci-Gray L., et al.	From scientific literacy to sustainability literacy: An ecological framework for education	Science Education	119	7,44
Chen T. -L., et al.	Implementation of green chemistry principles in the circular economy system towards sustainable development goals: Challenges and perspectives	Science of the Total Environment	101	50.5
Chinn PWU	Decolonizing methodologies and indigenous knowledge: The role of culture, place and personal experience in professional development	Journal of Research in Science Teaching	93	6,2
Van Weelie D., Wals AEJ	Making biodiversity meaningful through environmental education	International Journal of Science Education	89	4.45
Orgill M., et al.	Introduction to Systems Thinking for the Chemistry Education Community	Journal of Chemical Education	79	26,33
Zamora-Polo F., et al.	Teaching for a better world. Sustainability and Sustainable Development Goals in the construction of a change-maker university	Sustainability (Switzerland)	77	25,67

3.3 Most Productive Source

Of the 510 documents produced, it is known that the most publications in the field of Sustainability in Science Education are published in Sustainability Switzerland (43 publications, 397 citations, and 29 TLS), which is the site with the most releases regarding sustainability in Science Education. The largest number of citations (483 citations) is in the Journal of Chemical Education which ranks second with 31 publications. The top ten core journals that publish developments in the field of Sustainability in Science Education can be seen in Table 5.

Table 5. List of the Top 10 Most Productive Sources

Source	Amount	Citation	TLS
Sustainability (Switzerland)	43	397	29
Journal of Chemical Education	31	483	39
Cultural Studies of Science Education	26	221	13
ACS Symposium Series	13	10	11
Education Science	11	64	12
Environmental Education Research	9	119	4
ASEE Annual Conference and Exposition Conference Proceedings	9	8	0

International Journal of Science Education	9	222	16
International Journal of Sustainability in Higher Education	8	84	3
Research in Science Education	7	87	4

3.4 Most Productive Institution

Based on the results of data analysis, it shows that the University of Bremen in Germany is the institution that has published the most research in the field of Sustainability in Science Education with a total of 29 documents. The top ten institutions that publish research in the field of Sustainability can be seen in Table 6.

Table 6. List of the 10 Most Productive Institutions

Institution	Country	Amount
University of Bremen	Germany	29
Helsingin Ylioposto	Finland	11
Malmö Högskola	Sweden	11
King's University	London	10
Australian Catholic University	Australia	8
Deakin University	Australia	8
University of Colorado Boulder	United States	7
University of Haifa	Israel	7
Universidade Federal de São Carlos	Brazil	7
University of Toronto	Canada	7

3.5 Most Productive Author

The productivity of the top 10 authors in the field of Sustainability in Science Education in 2001 – 2022 indexed by Scopus can be seen that the highest productivity is Eilks, I. with 28 publications, 598 citations, and the highest total link strength, namely 27, as shown in Table 7 below. The second most cited is Burmeister, M. with a total of 6 documents (6th place). The relationship of authors writing for the same publication is explained by co-authorship analysis. However, total link strength (TLS) displays the total strength of co-authorship between two authors (Ali et al., 2021).

Table 7. List of the 10 Most Productive Authors

Author	Amount	Citation	TLS
Eilks, I.	26	598	27
Sjöström, J.	10	185	11
Mahaffy, PG	9	207	0
Carter, L.	7	131	0
Zoller, U.	7	116	0
Burmeister, M.	6	297	6
Siol, A.	6	42	6
Zuins, VG	6	147	5
Zidane. R.	5	47	7
Mammino, L.	5	32	0

3.6 Most Productive Country

A total of 73 different countries published 498 documents that have been analyzed. The top 10 contributors to publishing sustainability-related publications in science education are listed in Table 8. The United States is in first place with a total of 154 published publications, 1681 citations, and 229 TLS. The majority of papers examined came from the United States with a much different ratio than the second country Australia with 40 publications, 662 citations, and 193 TLS. The list of the 10 most productive countries can be seen in Table 8.

Table 8. List of the 10 Most Productive Countries

Country	Amount	Citation	TLS
United States	154	1681	229
Australia	40	662	94
Germany	39	799	193
United Kingdom	34	696	155
Spain	32	453	33
Canada	31	384	125
Sweden	29	448	141
Netherlands	19	597	47
Finland	18	244	83
Brazil	17	215	85
Israel	17	409	35

3.7 Map of Publication Development Based on Keywords

The number of research publications in the field of Sustainability in Science Education based on Scopus-indexed keywords in 2001 – 2022 shows that the sustainability keyword is the highest keyword with a total of 139 documents and a total link strength of 491, as shown in Table 9. The most frequently shared keywords used by authors when producing sustainability articles are identified using author keyword co-occurrence. When two terms appear in an article simultaneously, this is known as co-occurrence (Kushairi, 2021). This explains why the two terms are related to each other. Of the 2119 keywords present, 92 falls under the 5 occurrences minimum requirement. In Figure 2 below you can see the visualization map.

Table 9. Keywords of Sustainability in Science Education

Keywords	Amount	TLS
Sustainability	139	491
Science Education	99	249
Sustainable Development	82	300
Education	69	335
Teaching	49	256
Green Chemistry	40	198
Curriculum	37	195
Students	37	181
Environmental Education	30	94
Chemistry Education	28	90

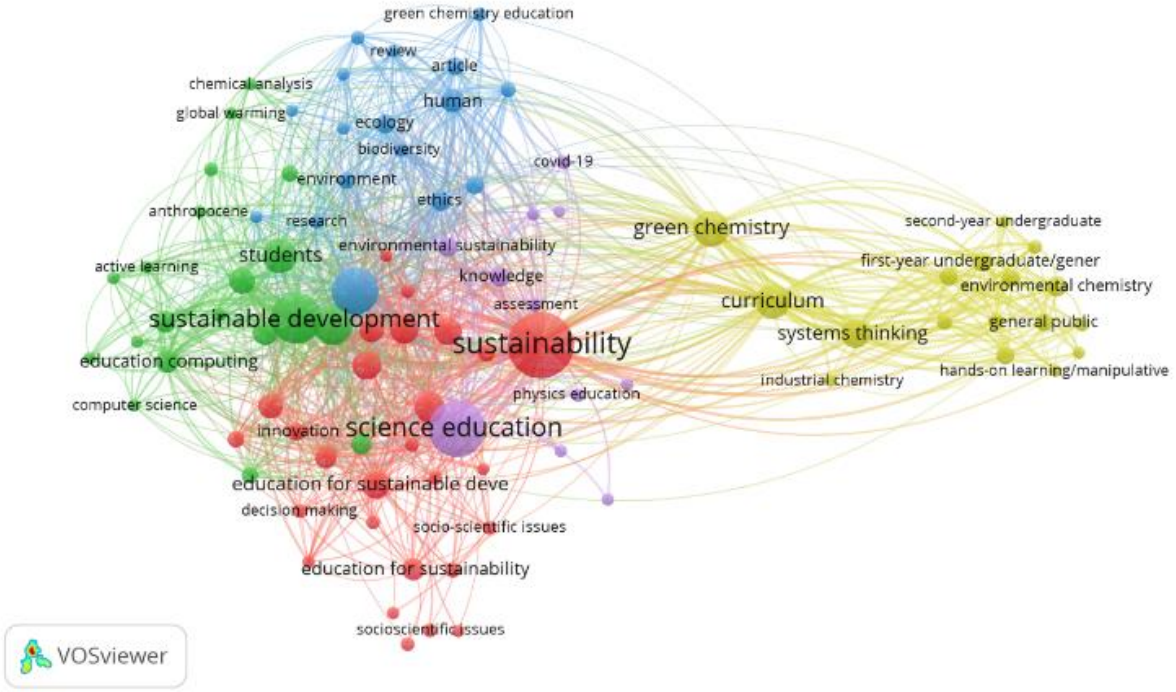

Figure 2. Author Keyword Co-occurrence Visualization Map

It is assumed that keywords with strict links exist when they appear with the same color (Kushairi, 2021). Based on Figure 2, the frequency of terms from the first five clusters is as follows: sustainability is the focus of the first cluster (red), sustainability development is the focus of the second cluster (green), education is the focus of the third cluster (blue), green chemistry is the focus of the fourth cluster (yellow), and science education is the focus of the fifth cluster (purple). This shows how often the authors link sustainability with sustainability development, education, green chemistry, and science education. This terminology may signify current research trends regarding study variables, methods, and research topics. Author keywords can represent the content of the publication and facilitate the search for the required document.

3.8 Co-Authoring for Authors and Countries

The study of the bond or collaboration between writers is carried out through co-authorship analysis. The minimum number of documents for an author in this study is two, and the minimum number of citations for an author is two. 117 of 1205 authors met the criteria. However, only 27 are well related and form the 7 clusters shown in Figure 3.

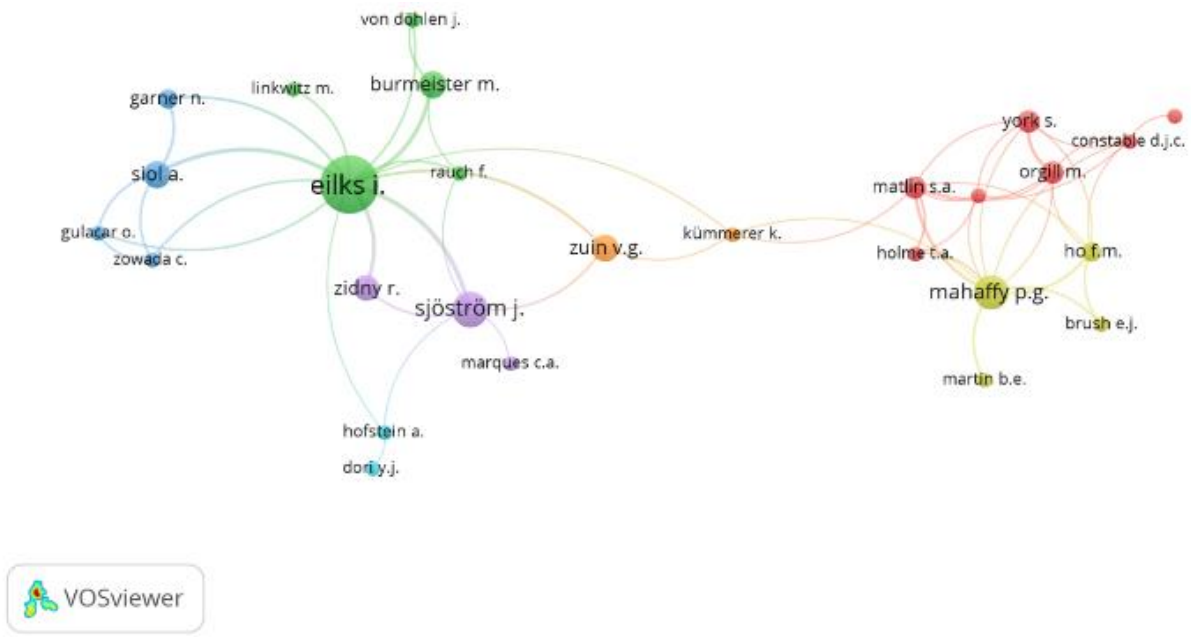

Figure 3. Co-authoring Visualization Map for Authors

It is important to remember that each node corresponds to one author. The node size indicates how many documents the author has published. The larger the size, the more documents are published (Tsai, 2020). Clusters are defined as clusters: the first cluster is red (7 authors), the second is green (5 authors), the third is yellow (4 authors), the fourth is blue (4 authors), the fifth is purple (3 authors), the sixth is light blue (2 authors) and the seventh is orange (2 authors). From the 27 authors, it can be seen that the writer Eilks, I., has the most significant node, this shows that the writer Eilks, I., has a strong inter-author collaboration network as shown in Figure 3.

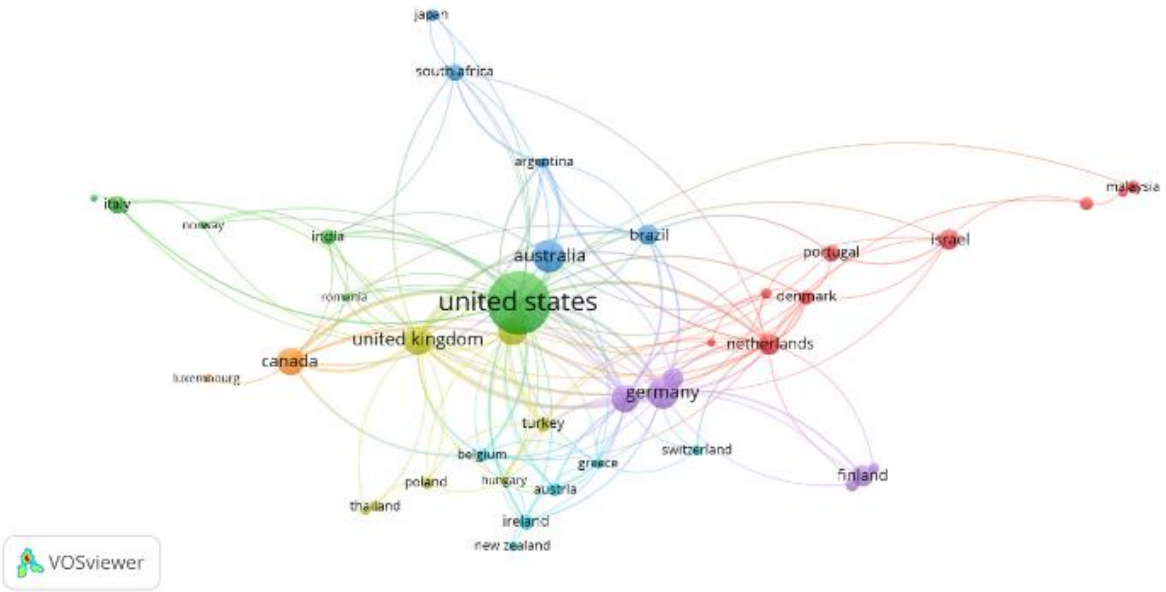

Figure 4. Visualization of Co-authorship Map for Countries

Co-authorship analysis for countries was also used to examine the relationship between authors and countries. A country must have at least two papers and two citations. These are the minimum requirements. Of the 75 countries, only 45 countries met the criteria and formed 45 of the 75 countries that met the criteria. However, only 43 countries are interconnected and form 7 clusters as shown in Figure 4.

In the first cluster it is red (9 countries) with the most prominent node namely Israel, the second cluster is green (7 countries) with the most prominent node namely the United States, the third cluster is yellow (7 countries) with the most prominent node namely the United Kingdom, the fourth cluster is light blue (6 countries) with the most prominent node namely Belgium, the fifth cluster is blue (6 countries) with the most prominent node namely Australia, the sixth cluster is purple (6 countries) with the most prominent nodes namely Germany and the seventh cluster is orange (2 countries) with the most prominent node, namely Canada. Figure 4 shows that the most prominent nodes are located in the United States, Germany, and the United Kingdom.

4. CONCLUSION

Based on the results of observations and discussion, bibliometric analysis in the field of Sustainability in Science Education from 2001 to 2022. The search results yielded data from 510 documents taken from the Scopus database and exported as CSV. After the inclusion and exclusion criteria were applied, 498 documents had to be analyzed. According to the bibliometric mapping findings, Germany has had a major influence on the publication of Sustainability in Science Education. It can be seen that the most productive institution is the Universitat Bremen in Germany and the most productive writer is Eilks, I., who is from Germany. Then Germany is also the third most productive country with 799 citations and 193 TLS.

A limitation of this study is that the data used for analysis in this study only came from the Scopus database, which may have influenced the findings. This is one research shortcoming that should be considered. The findings obtained will vary because the data obtained changes from time to time. The author suggests the need for additional keywords so that more results research is more comprehensive.

Conflict of Interest

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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