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Review Article

Green Chemistry in Education: A Bibliometric Study and Research Trends (2002–2022)

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Abstract
Research on green chemistry in education is always evolving. Existing studies found that incorporating green principles into undergraduate education has significant benefits. In addition to the growing interest in green chemistry among researchers, a lot of literature evaluations on green chemistry have been conducted during the past ten years. This study presents the results of a bibliometric study of 444 articles on green chemistry in education from the Scopus database in the last two decades until 2022. The literature on green chemistry has previously been mentioned in an article published in 2021 about green and sustainable chemistry education (GSCE) in mainland China. This study was conducted to see research trends on green chemistry and its implementation in education for the last two decades (2002-2022) comprehensively. Based on the analysis' findings using VOSviewer software, the most cited documents were written by Alfonsi, Tobiszewski, and Clark. The Journal of Chemical Education is the most prolific publishing source followed by the ACS Symposium Series and Physical Sciences Reviews. The nations having the most publications are the US, Canada, and the UK. Regarding the writers who contributed the most in this field are Dicks, Eilks, and Machado. The keywords most often used are "green chemistry", "sustainability" "laboratory instruction" and "hands-on learning / manipulatives".

Keywords: Bibliometric, education, green chemistry

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1. INTRODUCTION

Green chemistry was initially proposed twenty years ago by Paul Anastas and John Warner, which was a fresh concept that was developed in the USA to changing chemistry practices (Anastas & Warner, 1998). Green chemistry is based on 12 guiding principles that seek to minimize or reduce hazards, resource use, and creation of dangerous substances throughout the developmentthe production and utilization of chemical materials. Green chemistry is a scientific discovery that uses ecologically friendly chemical reactions to manufacture molecules. Innovative scientific approaches to industrial production and current environmental issues are sought for by green chemistry (Karpudewan et al., 2011). Therefore, in order to support sustainable development, future scientists need have a solid understanding of green chemistry (Cummings, 2013; UNEP, 2019).

In line with the global action plan in efforts to prosper society through the Sustainable Development Goals, one of the objectives in point 4.7 is is to make sure that every learner has the knowledge and abilities necessary to advance sustainable development, including among others through ESD and sustainable lifestyles, gender equality, human rights, global citizenship, promotion of a culture of peace and non-violence, and an awareness of cultural diversity and the role that culture plays in advancing sustainability (UN, 2015). ESD's primary contribution to sustainable development is to create the conditions for a more sustainable future (Pauw et al., 2015). ESD makes sustainable development possible. It concurrently promotes innovation in education and has an impact on all levels of education as well as all fields in general (UNESCO, 2014), as well as chemical education specifically (Burmeister et al., 2012). As a result, teaching

chemistry through green chemistry is a way to solve environmental issues while also teaching students about sustainable development. (Yakob et al., 2012; Karpudewan et al., 2009).

Due to the intimate relationship between chemistry and modern industry, which strives to create more environmentally friendly goods and production methods in all spheres of human life, chemical education is crucial to ESD (Hofstein and Kesner, 2006). The idea of green and sustainable chemistry is one response to the many difficulties confronted by sustainable development. Sustainable chemistry is a challenging equation that must assure the survival of all living species, including those of plants, animals, and humans. It must also take into consideration challenges with, global warming, access of energy, the exponential growth of the human population, for which chemistry must enable peaceful development, the social and environmental effects of the value chain, and the loss of biodiversity (Marion, 2017). This concept deals with a revised view of how to apply chemistry and create more environmentally friendly procedures and goods (UNEP, 2019) Since one of the suggestions for improvement is the application of chemistry, We need to think about how chemistry is taught and learned at the secondary and tertiary levels of school (UNEP, 2019).

Research on green chemistry in education is always evolving. According to an article, incorporating green chemistry principles into curricula can draw in creative and motivated students, improve the chemical sector image in the public eye, and support the chemical industry's long-term growth on a national and international level (Kitchens, 2006). Other studies say that incorporating green principles into undergraduate education has significant benefits for students, including deeper understanding, fuller conversations, the ability to offer creative solutions, and improved memory recall of previously learned key concepts (Andraos, 2012)

In addition to the growing interest in green chemistry among researchers, a lot of literature evaluations on green chemistry have been conducted during the past ten years. For example, Riandi et al. (2022) conducted a bibliometrics study and research trends of the implementation of biotechnology in education towards green chemistry teaching. Recently Demir and Sharma (2021) conducted bibliometrics to analyze studies on water remediation based on the 12 green chemistry principles. Specifically, Li & Eilks (2021) conducted a comprehensive analysis of the literature in mainland China on green and sustainable chemistry education.

1.1 Aim of the Study

Comparatively to earlier investigations, in this bibliometric analysis, 444 articles over the last two decades were looked at. It thus offers a current summary of developments in Green Chemistry education according to annual publications, citations, most-cited papers, major nations, organizations, and sources, prolific contributors, and distribution of author keywords. The following research questions (RQs) are addressed by the current review:

RQ 1: How have publications and citations changed over the year?

RQ 2: Which nations, colleges, and references get the most citations?

RQ 3: Which authors are the most well-known?

RQ 4: How are author keywords distributed, and what is the status of co-authorship for authors and countries?

2. METHODS

2.1 Research Design

By using a bibliometric mapping approach and a global perspective, the purpose of this review is to examine the studies on green chemistry and examine the trends and conditions of the variables for publication, nation, institution, journal, citation, author, and keyword. The study period included the years

2002 to 2022. Bibliometric analysis is a famous measurable strategy for investigating and dissecting a lot of logical information in a specific field. The first step in the bibliometric analysis was to search online databases for any publications that were relevant to green chemistry in education.

2.2 Data Collection

By utilizing the Scopus database (http://www.scopus.com/), a total of 476 documents were gathered. The Scopus database was chosen as the source of this review's documents because it selects documents for its index using a consistent standard. In addition, it provides reviews of research in education and the social sciences with access to a wider variety of documents than other data the Web of Science does. Lastly, it provides more advanced export capabilities for bibliographic data than Google Scholar does.

After the inclusion and exclusion criteria were applied, the search produced a total of 3201 documents. These measures are introduced in Table 1.

Table 1. The Standards for Inclusion and Exclusion

The Criteria
Inclusion Criteria (IC)
IC-1. The document's title, abstract, and keywords were the only things used in the keyword search.
IC-2. The language of documents is English.
IC-3. Documents relating to green chemistry in education
IC-4. All publishing dates
IC-5. All kinds of documents
Exclusion Criteria (EC)
EC-1. Documents in languages other than English
EC-2. Documents unrelated to Green Chemistry in Education
EC-3. Documents released under 2002

This study's data search procedure refers to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses framework, is depicted in Figure 1. The collection of metadata was obtained on October 13, 2022. All kinds of materials, including books, book chapters, reviews, conference reviews, and brief questionnaires, were examined for this study. It sought to offer a a fuller comprehension and representation over the past 20 years in this field. To locate these items, the following primary search was carried out: TITLE-ABS-KEY ("education" AND "Green chemistry"). At the time of the data set analysis, it was discovered that the chosen articles linked to green chemistry consisted of 59 countries with 12 different languages.

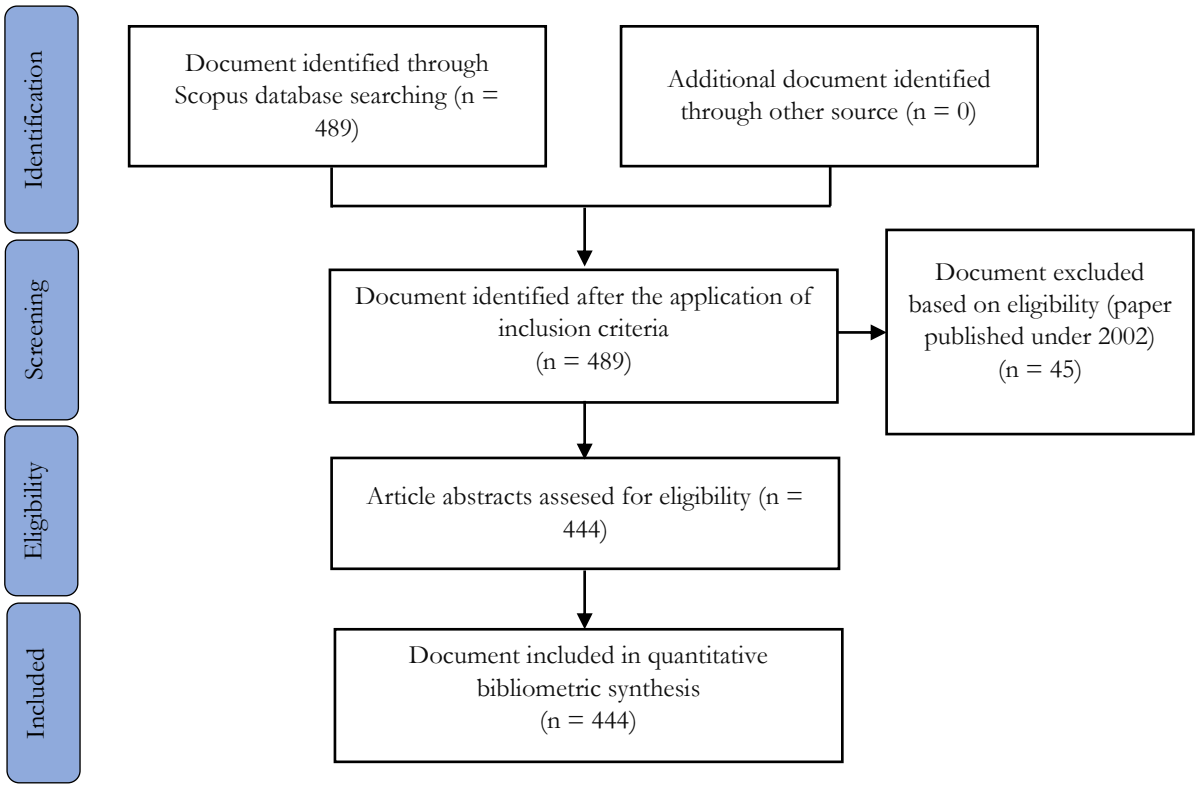

Figure 1. The Study's Protocol

There were 14.64% paper proceedings (n=65), 55.86% journal articles (n=248), 9.91% book chapters (n=44), and 19.59% other document types (n=87) among the 444 documents. Afterward, the data is exported as CSV and RIS files (comma-separated values and research information system). Microsoft Excel is used to analyze data in this study. The majority of the data is presented as percentages and frequencies. VOSviewer is also used to facilitate the visualization of bibliometric networks.

2.3 Data Analysis

In this study, VOSviewer software is used to analyze and generate various visualization maps based on bibliographic data, such as keyword co-occurrence, co-authorship, citation, and co-citation maps. The analysis results were presented as tables and network visualization maps. Each network node corresponds to a single object (eg, article, keyword, author, nation, institution). The node size indicates the number of items, the larger the node size, the greater the number of items. While the links between nodes indicate collaboration between items. Link thickness indicates the intensity of collaboration between items. Each node color represents a thematic cluster, where nodes and links within the cluster can be used to explain the intensity of the relationship between nodes in one cluster or with other clusters.

3. RESULTS

3.1 Publication and Citation Trends

The search results show that there were 444 documents published during the 2002-2022 period. Figure 2 shows the quantity of articles and citations made per year to green chemistry over the past two decades.

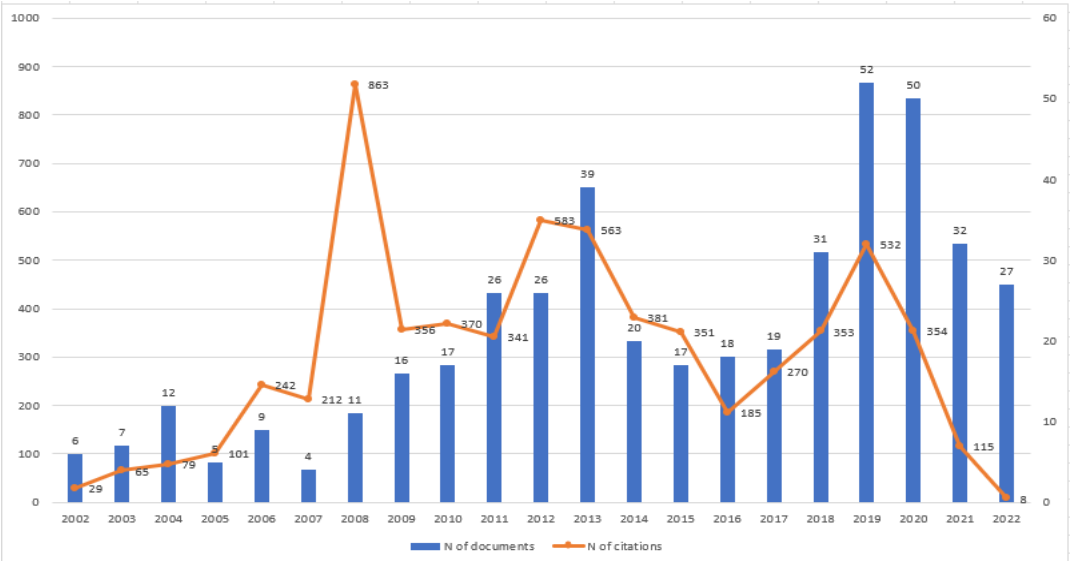

Figure 2. Distribution of Publications on Green Chemistry by Year

The first publication on Green Chemistry in education with 6 documents appeared in 2002. There were 113 documents (25.45%) in the first 10 years, from 2002 to 2011. During the second decade, there were much more studies in this topic (2012-2021), when 304 documents were published (68.4%). The number of publications reached 27 articles (6.08%) in 2022 until this study was conducted.

This pattern persists year after year according to the quantity of citations, which is in line with the growing number of publications in the field. There have been 6353 citations so far, or about 14.30 citations per paper. This expansion indicates that Green Chemistry in education is attracting more researchers' attention.

3.2 Top 10 Most Cited References

The top 10 documents with the most citations throughout the year are listed in Table 2. Alfonsi's article entitled Green chemistry tools to influence a medicinal chemistry and research chemistry based organization according to the quantity of citations (C), is the most often mentioned document with 812 citations. The second place is occupied by the article entitled Green chemistry metrics with special reference to green analytical chemistry written by Tobiszewski with 200 citations. The top three most cited articles are Clark's article entitled Green chemistry: Today (and tomorrow) with 166 citations.

Table 2. The 10 Most Cited References

Author	Document Title	Source	C	C/A
Alfonsi, K	Green chemistry tools to influence a medicinal chemistry and research chemistry based organisation	Green Chem.	812	58.00
Tobiszewski, M	Green chemistry metrics with special reference to green analytical chemistry	Molecules	200	28.57
Clark, J.H	Green chemistry: Today (and tomorrow)	Green Chem.	166	10.38

Author	Document Title	Source	C	C/A
Wilson, M.P	Toward a new U.S. chemicals policy: Rebuilding the foundation to advance new science, green chemistry, and environmental health	Environ. Health Perspect.	155	11.92
Garcia-serna, J	New trends for design towards sustainability in chemical engineering: Green engineering	Chem. Eng. J.	143	9.53
Sharma, R.K	Preparation of gold nanoparticles using tea: A green chemistry experiment	J Chem Educ	103	10.30
Chen T.L	Implementation of green chemistry principles in circular economy system towards sustainable development goals: Challenges and perspectives	Sci. Total Environ.	101	50.50
Marion, P	Sustainable chemistry: How to produce better and more from less?	Green Chem.	85	17.00
Andraos, J	Green chemistry teaching in higher education: A review of effective practices	Chem. Educ. Res. Pract.	74	7.40
Wardencki	Green chemistry - Current and future issues	Pol. J. Environ. Stud.	68	4.00

3.3 Most Productive Sources

The collection of 444 documents used in this study was published in 154 different places. Table 3 lists the top ten most productive sources in terms of the total number of articles (A). Appropriately, these 10 sources have published 254 articles, representing 57.20 percent of all publications with some citations of 4278 (67.33%). The Journal of Chemical Education reached first place for the most productive sources with 137 articles. The journal also had 2380 citations per document, which was the most and followed by Green Chemistry and Chemistry Education Research and Practice. The ACS Symposium Series and Physical Science Reviews occupied the second and third place for the most productive source.

Table 3. The 10 Most Productive Source

Source	A	C	C/A
Journal of Chemical Education	137	2380	17.37
ACS Symposium Series	34	102	2.00
Physical Sciences Reviews	13	23	1.77
Journal of Physics: Conference Series	12	11	0.92
Green Chemistry	11	1139	103.55
Green Chemistry Letters and Reviews	11	201	18.27
Sustainability (Switzerland)	10	29	2.90
Current Opinion in Green and Sustainable Chemistry	10	142	14.20
Sustainable Chemistry and Pharmacy	9	41	4.56
Chemistry Education Research and Practice	7	210	3.00

3.4 Most Productive Countries

In terms of countries, green chemistry literature is written by authors from 59 nations. A total of 48 countries (81.35 percent) contributed less than 10 documents, while 18.65% (n=11) contributed more than

10 documents. The top ten nations and regions in this literature are listed in Table 4. Based on Table 4, United States occupies the first rank among the top 10 most productive countries with 204 articles that have been published. The next two ranks are occupied by Canada (43) and the UK (40).

Table 4. The top 10 Nations in terms of Productivity

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	US	7
University of Haifa	Israel	7
Universidade Federal de São Carlos	Brazil	7
University of Toronto	Canada	7

3.5 Most Productive Authors

The top ten most productive authors of Green Chemistry in education publications from 2002 to 2022 are shown in Table 5. A.P. Dicks and Eilks are regarded as the most prolific writers with 16 and 14 article, respectively. Both writers are regarded as the pioneers of green chemistry publishing thus far. Machado and J.H. Clark are third with 9 articles each, demonstrating their active participation in the field. The table shows that the authors of the most often cited documents are from Europe.

Table 5. The 10 Most Productive Authors

Author	Affiliation	Country	A	C	C/A
Dicks, A.P.	University of Toronto	Canada	16	292	18.25
Eilks, I.	University of Bremen	Germany	14	184	13.14
Machado	Universidade do Porto	Portugal	9	174	19.33
Clark, J.H.	University of York	UK	9	987	109.67
Ribeiro	Universidade do Porto	Portugal	8	141	20.13
Hurst, G.A.	University of York	UK	7	86	12.29
Mahaffy, P.G.	King's University College	Canada	7	139	19.86
Zuin, V.G.	Federal University of São Carlos	Brazil	7	135	19.29
Linkwitz, M.	Otto-Hahn-Gymnasium Bensberg	Germany	6	9	1.5
Anastas, P.T	School of Forestry and Environmental Studies	US	6	106	17.67
Warner, J.C.	Monash University	Australia	6	22	3.67

Table 6. The 10 Most Productive Institutions

Institution	Country	A	C	C/A
University of Toronto	Canada	20	336	16.80
University of York	UK	17	396	23.29
University of Bremen	Germany	12	180	15.00
King's University College	Canada	7	139	19.85
University of Minnesota	US	6	76	12.67
University of Delhi	India	5	150	30.00
Rowan University	US	5	37	7.40
Gdańsk University of Technology	Poland	4	158	39.50
University of Wisconsin-Madison	US	4	109	27.25
Federal University of São Carlos	Brazil	4	110	27.50

3.6 Most Productive Organizations

There are 769 institutions from around the world that publish about green chemistry. Based on the top 10 most productive institutions, the University of Toronto (Canada) occupies the first position with 20 articles. The University of York (UK) came in second with 17 articles, followed by the University of Bremen (12) and King's University College (7). Based on Table 6, it can be seen that there are two universities from Canada with a total of 27 articles, and three universities from the US with a total of 15 articles. The institution with the most citations is the University of York followed by the University of Toronto, University of Bremen, and the Gdańsk University of Technology. The top 10 producing institutions are in America, Europe, or Asia.

3.7 Co-occurrence of Author Keywords

To find out the frequency of the most used words in the article, a VOSviewer was used to mapping study of the co-occurrence of author keywords. Analysis of the co-occurrence of author keywords shows the frequency of occurrence of keywords in articles and visualizes the linkage network between keywords. The criteria is met by 98 keywords, with 3 being the lowest number of keyword occurrences. The keyword visualization network map is shown in Figure 3.

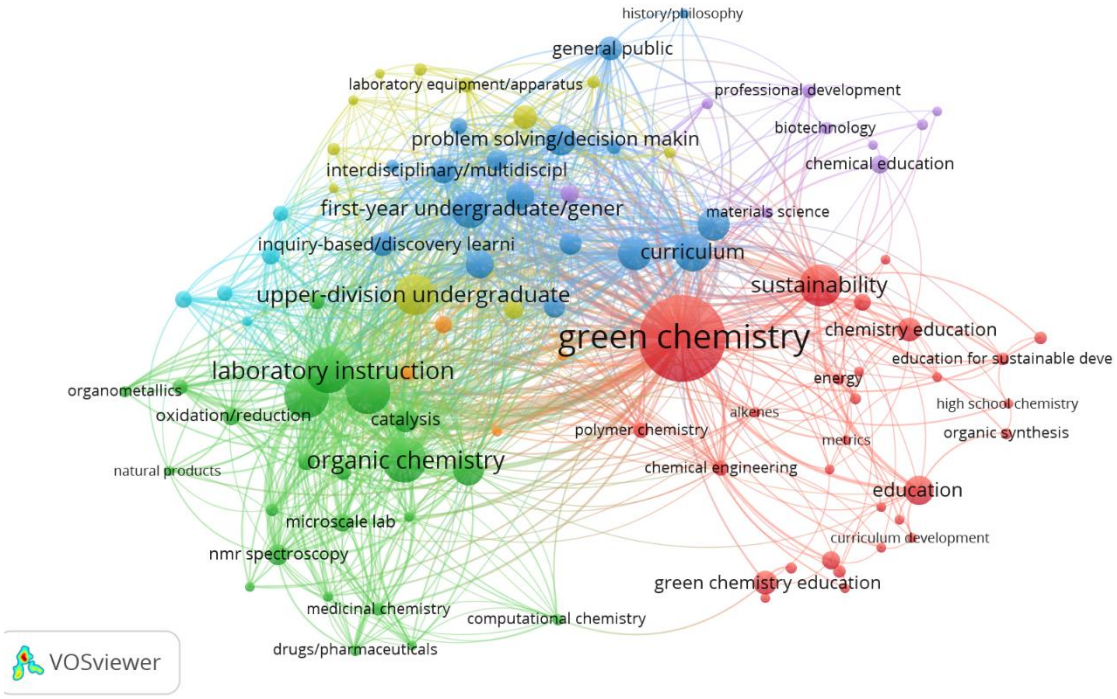

Figure 3. Co-keywords Network Visualization

In Figure 3, the visualization shows keywords that are divided into 5 clusters. The most used keywords based on clusters are green chemistry (red cluster), laboratory instruction (green cluster), curriculum (blue cluster), upper-division undergraduate (yellow cluster), nanotechnology (purple cluster), and physical chemistry (light blue cluster)), and reactions (orange clusters). Based on Table 7, the top 10 keywords that appear most often are Green Chemistry (202 occurrences, 925 TLS), Laboratory Instruction (58, 432), and Hands-on Learning/Manipulatives (55, 408). As shown in figure 3 and Table 7 the keywords most often used is green chemistry followed by laboratory instruction and Hands-on Learning/Manipulatives. This shows that most green chemistry studies discuss laboratory activities by manipulating the chemicals used to achieve the standard 12 principles of green chemistry in a chemical process.

Table 7. Top 10 Most Frequently Used Keywords

Author Keyword	OCC	TLS
Green Chemistry	202	925
Laboratory Instruction	58	432
Hands-on Learning/Manipulatives	55	408
Second-year undergraduate	54	412
Organic Chemistry	53	388
Sustainability	48	192
Upper-division undergraduate	46	344
Curriculum	40	240
First-year Undergraduate/general	37	262
Environmental Chemistry	32	231

3.8 Co-Authorship for Authors and Countries

Co-authorship network analysis was performed to create a map showing the number of collaborations between authors. Co-authorship analyzes collaboration between authors in a publication. The required minimum for an author was changed to 2 and the minimum number of citations to an author was made to a minimum of 3. Out of 1157 authors, 124 authors met the thresholds and 49 authors were linked to form 6 groups. Figure 4 shows a collaborative network map of the 49 authors. The size of each node, which represents a single author, corresponds to the number of articles the author has authored. More articles have been published as node size increases.

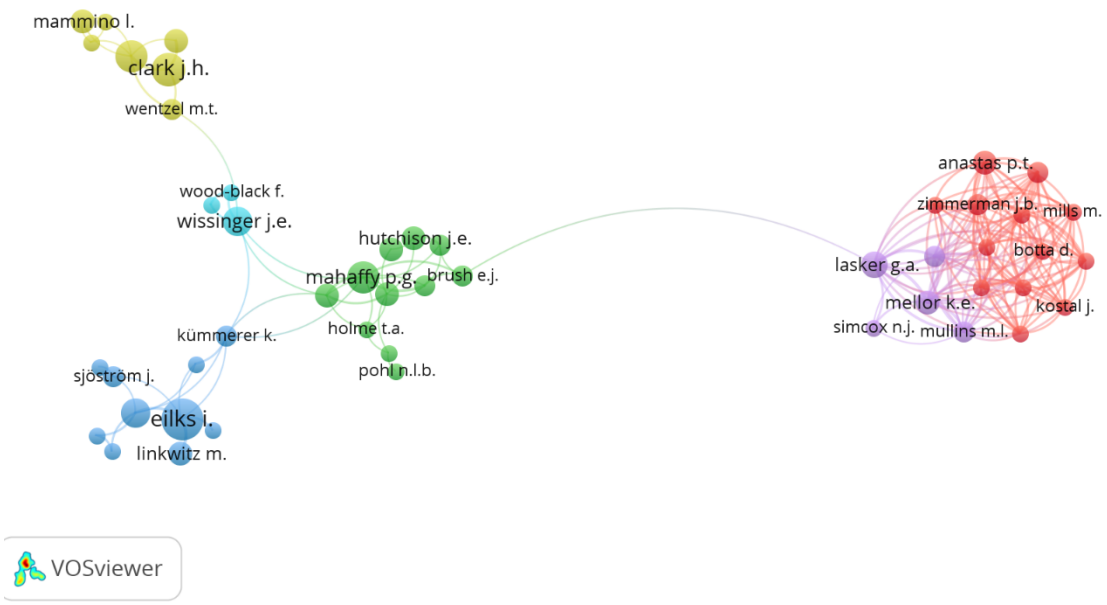

Figure 4. The Co-Authorship of the Author Network Visualization

Based on the results of the analysis using VOSviewer there are 6 clusters. Each color represents a thematic cluster, where the nodes and links in the cluster can be used to explain the relationship (link) between authors (nodes). The first cluster is indicated by a red node color with a total of 13 authors including Anastas P.T (4 documents, 34 TLS), Zimmerman J.B (3, 34), and Kostal J (2, 32). The green cluster consists of 11 authors including Mahaffy P.G (7, 13), Constabel D.J.C (4, 8), and Matlin S.A (4, 9). Followed by the next cluster, the dark blue cluster (10 authors), the yellow cluster (7), the purple cluster (5), and the light blue cluster (3). Author from Bremen University Germany, Ingo Eilks is in the blue cluster with a total of 12 documents and 12 TLS which is one of the top 10 most productive writers followed by Clark J.H (8, 9) from the University of York appears in the yellow cluster.

In addition, an analysis of co-authorship for countries was also carried out. After it was determined that the minimum number of documents for a country was 2 and the minimum number of citations was 3, the result is 36 countries met the thresholds out of a total of 57 countries. Based on the results of an analysis with VOSviewer as shown in Figure 5, for the co-authorship network map for countries there are 32 interrelated countries which are divided into 7 clusters.

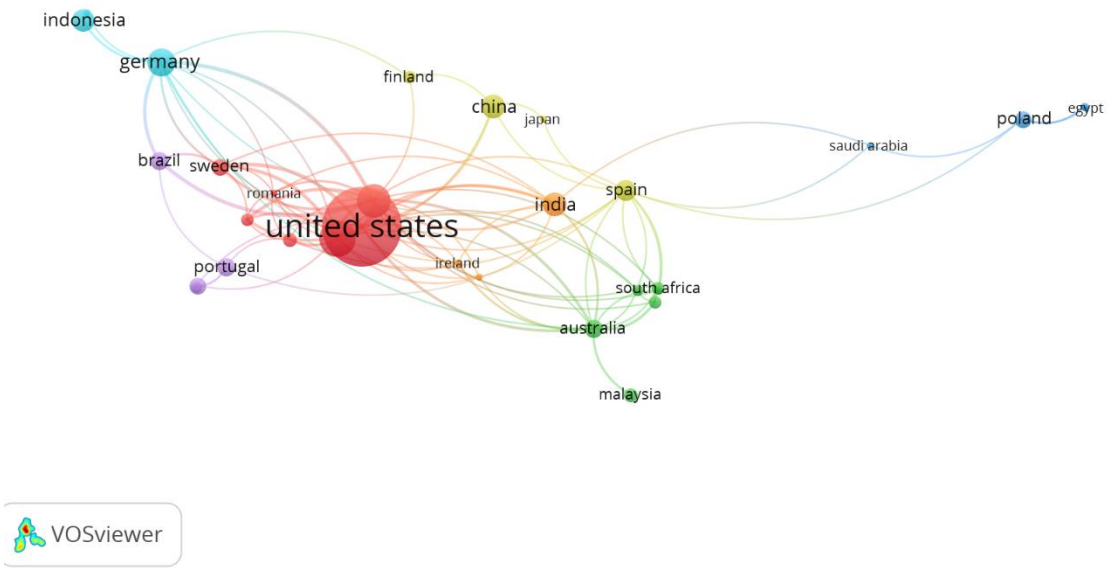

Figure 5. The Co-Authorship for Country Network Visualization

First, the red cluster (consisting of 7 countries) shows a clear collaboration between the US (196 documents, 45 TLS) with the UK (37, 46) and Canada (43, 35). The green cluster (n=6) shows collaboration between Australia (11, 22) and the Netherlands (5, 8), and South Africa (6, 6). Followed by collaborations between Poland (9, 5), Egypt (2,3), and Saudi Arabia (2,3) in the dark blue cluster (n=5). The yellow cluster (n=4) has collaboration between China (18, 6), Spain (14, 13), and Japan (2, 2). The purple cluster (n=5) includes Brazil, Italy, and Portugal. Germany, Austria, and Indonesia are in the light blue cluster (n=3) followed by New Zealand, India, and Ireland which are in the orange cluster (n=3). US, UK, and Canada are in a cluster with the largest node size indicating the number of publications made. Followed by Germany in the blue cluster and India in the orange cluster.

4. DISCUSSION AND CONCLUSION

This article examines research trends related to green chemistry in an educational context from 2002 to 2022 through bibliometric analysis. There were 444 documents from Scopus that were further studied and analyzed using the VOSviewer software. In 2002 there were 6 articles related to green chemistry that was published and experienced fluctuations over time until the highest publication in 2019 reached 52 articles or equivalent with 11.71%. In addition to the number of publications, there has also been an increase in the number of citations, in 2002 there were 29 citations and in 2008 there were 863 citations from 11 published articles. The significant increase in the number of publications and citations in a short period indicates an increase in research interest in this area. Although the number of citations has relatively decreased since 2008 and tends to be stable until 2020. This is because the latest articles require more time to obtain a larger number of citations.

In terms of the most prolific authors, Dicks, A.P, of the University of Toronto takes first place with 16 publications and 292 citations. Ingo Eilks is the second most prolific author with 14 publications and 184 citations coming from the University of Bremen in Germany. Followed by Machado an author from Universidade do Porto (Portugal) and Clark, J.H from the University of York (UK) with 9 publications. The next six of the top 10 most prolific authors published 6 to 8 articles which showed no significant difference in the number of articles published. Based on the results of the analysis, Clark J.H, who occupies the fourth position of the top 10, has the highest number of citations, reaching 987 citations from 9 of his publications.

Journal of Chemical Education by the American Chemical Society is ranked first with 137 published articles. The high number of publications is likely to occur because the *Journal of Chemical Education* is the world's premier chemical education journal which has been certified as a transformative journal in the field of chemistry. The published journals usually discuss chemical content and its applications, laboratory experiments, teaching methods, and pedagogy. Followed by *ACS Symposium Series* and *Physical Sciences Reviews* in the second and third place.

Regarding the average citation per article (C/A), it can be seen in Table 3 that *Green Chemistry* is in the first position of the top 10 sources with the most articles published. *Green Chemistry* is published by the Royal Society of Chemistry. This professional institution based in London is very well known in publications related to chemical issues. In second place are *Green Chemistry Letters and Reviews* with an average citation per article of 18.27. *GCLR* is an international, cross-disciplinary journal by Taylor & Francis that focuses on how chemistry contributes to sustainable development. In third place, *Journal of Chemical Education* along with its first position in terms of the highest number of publications, has an average of 17.37 citations per article. The top ten most productive sources are dominated by countries from the European continent.

Regarding institutions, the University of Toronto is the most productive organization with 20 published articles (4.50% of the total). The University of York (UK) ranks second with 17 publications or around 3.82% of the total. Interestingly, although it ranks second in terms of the number of documents, the University of York is number one in terms of the number of citations compared to the University of Toronto with a difference of 60 citations. Followed by the University of Bremen (Germany) and King's University College with 12 and 7 articles respectively in third and fourth positions. Five of the ten most productive institutions are in the Americas and the rest are from Europe and Asia. This is also in line with the most prolific writers who come from Canada, America.

Regarding countries with the highest number of publications, based on the results of the analysis it was found that the US (204 articles), Canada (43 articles), and the UK (40 articles) are the top three countries based on the number of publications in the last two decades. In addition, these three countries also occupy the top three positions based on the number of citations obtained, reaching 3537 citations (America), 2193 citations (English), and 709 citations (Canada). This shows that these countries are pioneers in the field of green chemistry in education. This is in line with the fact that this country has leading publishers such as the American Chemical Society (ACS) from the US.

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In the last two decades, research on green chemistry has increasingly developed. This is possible because the application of green chemistry is the first step to supporting sustainable development. Green chemistry has made a significant contribution to cleaning the environment and improving the quality of life on our planet (Khare, 2017). Greener methods make technology and research safer, more affordable, and less wasteful while keeping them on the right track.

By implementing the application of the 12 principles of green chemistry in an industrial process involving chemical compounds, it will have a good impact on humans and the environment. The creation of clean air is due to the minimum amount of chemicals released into the air which can have a good impact on lung health. Availability of clean water due to low waste that pollutes water. The use of chemicals that are degraded into compounds that are safer and not harmful to the environment can also minimize chemical disturbance to ecosystems to provide space for animals and plants to live and grow safely. In addition, it is expected to minimize the potential for global warming and depletion of the ozone layer.

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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REFERENCES

Alfonsi, K., Colberg, J., Dunn, P. J., Fevig. T., Jennings. S., Johnson. T. A, Kleine, H. P., Knight, C., Nagy, M. A., Perry, D. A., & Stefaniak, M. (2008). Green chemistry tools to influence a medicinal chemistry and research chemistry based organisation. *Green Chemistry, 10*(1), 31-36.

Anastas, P. T., & Warner JC. (1998). Principles of green chemistry. *Green Chemistry: Theory and Practice, 29*.

Andraos J, & Dicks AP. (2012). Green chemistry teaching in higher education: a review of effective practices. *Chemistry Education Research and Practice, 13*(2), 69-79.

Burmeister M, Rauch F, & Eilks I. (2012). Education for Sustainable Development (ESD) and chemistry education. *Chemistry Education Research and Practice, 13*(2), 59-68.

Clark, J. H. (2006). Green chemistry: today (and tomorrow). *Green Chemistry, 8*(1), 17-21.

Chen TL, Kim H, Pan SY, Tseng PC, Lin YP, & Chiang PC. (2020). Implementation of green chemistry principles in circular economy system towards sustainable development goals: Challenges and perspectives. *Science of the Total Environment, 716*,136998.

Cummings SD. (2013). ConfChem conference on educating the next generation: green and sustainable chemistry solar energy: a chemistry course on sustainability for general science education and quantitative reasoning. *Journal of Chemical Education, 90*(4), 523-4.

Moher, D., Liberati, A., Tetzlaff, J., & Altman, D. G. (2009). Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *BMJ, 339*, 332-336.

Demir H, & Sharma SK. (2021). Green chemistry and water remediation: bibliometric study and research applications. *Green Chemistry and Water Remediation: Research and Applications,* 1-33.

García-Serna J, Pérez-Barrigón L, & Cocero MJ. (2007). New trends for design towards sustainability in chemical engineering: Green engineering. *Chemical Engineering Journal, 133*(1-3), 7-30.

Hofstein A, & Kesner M. (2006). Industrial chemistry and school chemistry: Making chemistry studies more relevant. *International Journal of Science Education, 28*(9), 1017-39.

Karpudewan M, Ismail ZH, & Mohamed N. (2009). The integration of green chemistry experiments with sustainable development concepts in pre-service teachers' curriculum: Experiences from Malaysia. *International Journal of Sustainability in Higher Education.*

Karpudewan M, Hj Ismail Z, & Mohamed N. (2011). Greening a chemistry teaching methods course at the school of educational studies, Universiti Sains Malaysia. *Journal of Education for Sustainable Development, 5*(2), 197-214.

Khare R, Kulshrestha A, Pandey J, & Singh N. (2017). Importance of green chemistry in oxidation and reduction. *International Journal of Engineering and Technical Research, 7*(7), 264972.

Kitchens C, Charney R, Naistat D, Farrugia J, Clarens A, O'Neil A, Lisowski C, & Braun B. (2006). Completing our education. *Green Chemistry in the Curriculum. Journal of Chemical Education, 83*(8), 1126.

Li B, & Eilks I. (2021). A systematic review of the green and sustainable chemistry education research literature in mainland China. *Sustainable Chemistry and Pharmacy, 21*, 100446.

Marion P, Bernela B, Piccirilli A, Estrine B, Patouillard N, Guilbot J, & Jérôme F. (2017). Sustainable chemistry: how to produce better and more from less?. *Green Chemistry, 19*(21), 4973-4989.

Riandi R, Permanasari A, & Novia N. (2022). Implementation of biotechnology in education towards green chemistry teaching: A bibliometrics study and research trends. *Moroccan Journal of Chemistry, 10*(3), 10-13.

Sharma RK, Gulati S, & Mehta S. (2012). Preparation of gold nanoparticles using tea: A green chemistry experiment. *Journal of Chemical Education, 89*(10), 1316-8.

Tobiszewski M, Marć M, Gałuszka A, & Namieśnik J. (2015). Green chemistry metrics with special reference to green analytical chemistry. *Molecules, 20*(6), 10928-46.

Tucker JL. (2010). Green chemistry: cresting a summit toward sustainability. *Organic Process Research & Development, 14*(2), 328-31.

UNEP. (2019). *Global chemicals outlook II (GCO-II) – from legacies to innovative solutions: implementing the 2030 Agenda for sustainable development.* https://www.unenvironment.org/explore-topics/chemicals-waste/what-wedo/policy-and-governance/global-chemicals-outlook

Wardencki W, Curyło J, & Namieśnik J. (2005). Green chemistry--Current and future issues. *Polish Journal of Environmental Studies, 14*(4).

Wilson MP, & Schwarzman MR. (2009). Toward a new US chemicals policy: rebuilding the foundation to advance new science, green chemistry, and environmental health. *Environmental Health Perspectives, 117*(8), 1202-9.

Yakob H, Yusof F, & Hamdan H. (2012). Land use regulations towards a sustainable urban housing: Klang Valley conurbation. *Procedia-Social and Behavioral sciences, 68*, 578-89.