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A Bibliometric Review of Sustainable Engineering of Last 30 Years: Emerging Circular and Green Polymer Science

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Abstract

The application of sustainable engineering is a ground-breaking strategy for the long-term enhancement of the human condition. A holistic understanding is required for inviting more research on this topic therefore, this study intent to provide a decentralized framework with the aid of a bibliometric evaluation to examine the research trend on sustainable engineering. The study also contributes to the body of literature by providing insights into a robust, reliable thematic representation of this topic. All published research articles (778) over the last 30 years were examined using the multidisciplinary SCOPUS database. The framework was categorized into thematic categories by the integrative analysis, and these categories were distributed according to the year of publication, the sources of the publications, the major contributors and their locations, the keywords, the most frequently cited research papers, and many other aspects. A co-authorship network, an inter-country co-authorship network map, and a network of keyword co-occurrences were also created using the VOSviewer software. Notably, this bibliometric review expands its purview to encompass Circular and Green Polymer Science, enhancing the breadth and depth of the analysis.

Keywords: Sustainable development, sustainable development goals, Scopus, Vos viewer, bibliometric, green composite, circular and green polymer

INTRODUCTION

Sustainable engineering is defined by UNESCO as "the process of using resources in a way that does not compromise the environment or deplete the materials for future generations". Sustainable engineering is based on principles to reinforce sustainable development. Sustainable development is a development that satisfies existing demands without jeopardizing the capacity of future generations to satisfy their own needs [1]. Engineering assists as a link between the design (the notion of how to offer a solution that can be environmentally friendly to the challenges of technology) and implementation in manufacturing. It all comes down to developing and administering day-to-day operations such that the energy and resources which are sustainable, that is, consumed at a pace that doesn't threaten the environment and its potential needs to be taken care of by generations to come in order to satisfy their own necessities.

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Every facet of daily life is impacted by sustainable engineering. Sustainable engineering is essential to ensure that the life which we know can continue easily for many future generations, from the water that flows through taps to the various process of collecting and breaking down the waste that we leave in our bins. Sustainable engineering does not deplete resources that belong to future generations or harm the environment. As it will be challenging to go back and redesign and revise things from a later stage. In this view, judgments regarding industrial and research initiatives, as well

as those pertaining to supporting technological research, should all take into account the principles of sustainable engineering. A range of industries, including manufacturing, environmental remediation, energy systems, transportation, waste management, and even new and existing construction can use sustainable engineering principles [2]. In other words, accountable sustainable development may be advantageous for all sectors of the economy where there is the presence of energy or its resources. It is superior to traditional engineering as sustainable engineering is the system in which the product, processing is done, or services utilized as a whole are taken into account, and it deals with both technical and non-technical difficulties in harmony [3]. It is intended to address issues for the long term, not just the short term. It contemplates both the local and the global contexts. By working with experts from various fields, it addresses political, ethical, and societal challenges. The following are typical areas of attention in the field of sustainable engineering: housing and shelter; waste disposal and management; energy development and consumption; pollution reduction; food production and preservation; water supply; transportation; restoring the environment's natural resource reserves, using green composite and utilizing Circular and Green Polymer Science [4]. Moreover, the incorporation of "green composite" materials and advancements in Circular and Green Polymer Science further enriches sustainable engineering practices, offering innovative solutions with reduced environmental footprint and enhanced durability. By embracing sustainable engineering across sectors, we pave the way for a more resilient and environmentally responsible future

Principles of sustainable engineering are based on the three pillars of environmental, social, and economic values. Sustainable engineering is the practice of incorporating social, environmental, and economic factors into the design of products, processes, and energy systems [5]. The usage of natural resources, the prevention of pollution, biodiversity, and ecological functions are all examples of environmental aspects. Furthermore, the social components cover living standards, access to employment and education, and equitable prospects for everyone in society [6]. The economic concerns operate as catalysts for development, profit, cost-cutting, advances in research and innovation, etc. Social-economic features are created as a result of interactions between the social and economic realms. These include things like worker benefits, fair trade, and corporate ethics. Enhancing energy efficiency, creating renewable fuels and green technology, encouraging green composite and application of circular and green polymer science and developing special incentives and subsidies for environmentally friendly firms are all made possible by the confluence of economic and environmental interests [7]. Environmental justice is established, conservation and environmental protection laws are developed, and stewardship globally for the sustainable practice of natural resources is promoted as a result of the junction of the social and environmental spheres. This framework of sustainable engineering is derived from the research work of [8] and from the principles of green engineering entrenched by [9].

Similarly, [10] cited approaches that are fairly comparable to the modern understanding of sustainable development under the following five key criteria: namely sustainable resources; sustainable processes; increased efficiency; reduced environmental impact when applying LCA; and fulfillment of other sustainability aspects including economic affordability, equity, community involvement, meeting augmented resource demand, safety, and social acceptability, appropriate land use, human needs, lifestyles, aesthetics, lifestyles, and human population. [11] highlighted the updated sustainable engineering principles in the connection with the sustainable development goals (UN). The updated principles encompass “

1. Tridimensional principles
2. Environmental principles
3. Social principles and
4. Economic principles”

It is evident from a thorough survey of the literature that there is an inadequate analysis of the research trend on “sustainable engineering”. Additionally, a bibliometric analysis of “sustainable engineering” has never been attempted earlier. This underscores the need for the present study.

This Research Work Is Aimed at Answering The Following Research Questions

RQ1. To explore the annual publication research trend on Sustainable engineering, journals have contributed to the maximum number of papers, the most prolific authors in this domain, research papers have the maximum number of citations, the most productive countries, and institutions, the most prominent research areas, the most frequently appearing keywords

RQ2. What is the other structure of information like the coupling of author, country, and keywords co-occurrence analysis in this research field?

The remainder of this essay is structured as follows: The study technique based on the bibliometric approach is further described in Section 2. The findings of the study are highlighted in Section 3. Similarly, section 4 discusses the conclusion.

METHODOLOGY

In this study, bibliometrics was employed as a statistical method for quantitatively analyzing the literature to address RQ1. It is a measuring tool for numerically tracking research activity levels over time [12]. Pritchard introduced the term "bibliometrics" in 1969 and defined it as "the application of mathematical and statistical methodologies to books and other communication medium". According to [13], the goals of bibliometric analysis in research are: expanding the field of study, assessing a research group's influence, or gaining insight into a particular study's relevance. This statistical analysis determines the research activity and its trajectory in a certain discipline [14]. The results of this quantitative assessment provide both professionals and researchers in particular research areas with a great deal of data [15]. To address the RQ2, the VOSviewer application was applied. It is used to envisage the information in a more thorough and graphical approach for the analysis [16]. It allows for the integration of the most varying bibliometric data, organizing them on maps that help to portray the contents being studied [17].

A bibliometric study was carried out to evaluate the research trend on sustainable engineering. All information was gathered in August 2022. The "Scopus database" was thoroughly searched for the last 30 years of research publications on sustainable engineering, spanning the years 1991 to 2021. The selection of this database was based on its extensive coverage of more than 23,000 reputable publications across all scientific disciplines. The term "Sustainable engineering" was utilized in the current study's document search. The keyword was included in quotation quotes since many of the articles that were found when it was used alone did not address the specified topic. Only research articles with the terms "Sustainable engineering" in their title, abstract, or keywords were retrieved by the search filter. 778 papers in total, comprising 310 conference papers, 288 articles, 57 reviews, 41 book chapters, 34 conference reviews, 22 books, 16 editorial materials, 4 short surveys, and erratum and 3 notes, were included. The author personally reviewed each publication in turn to verify the veracity of the search results. Data were compiled with the intention of analyzing research trends based on the journals with the highest number of publications, yearly growth in publishing, prolific authors, productive nations and institutions, the most well-known subject areas, and frequently occurring keywords. In order to comprehensively explore and analyze the logical networks of the in-question research area, the coupling of authors, nation, and keyword co-occurrence analysis was carried out using the VOSviewer 1.6.18. [18].

RESULT AND DISCUSSION

Year Wise Publication on Sustainable Engineering

Figure. 1 depicts the year wise publications related to sustainable engineering from 1991 to the year 2021. The interest in the aforesaid topic is on the lower side from the year 1991 to 2002 but due to the increasing awareness for sustainability, we can see a sudden spike in the number of publications from the year 2003 to 2021. The number of papers published increased from 1 to 91 in 2021. It shows a huge inclination of researchers and scientists in the field of sustainable engineering.

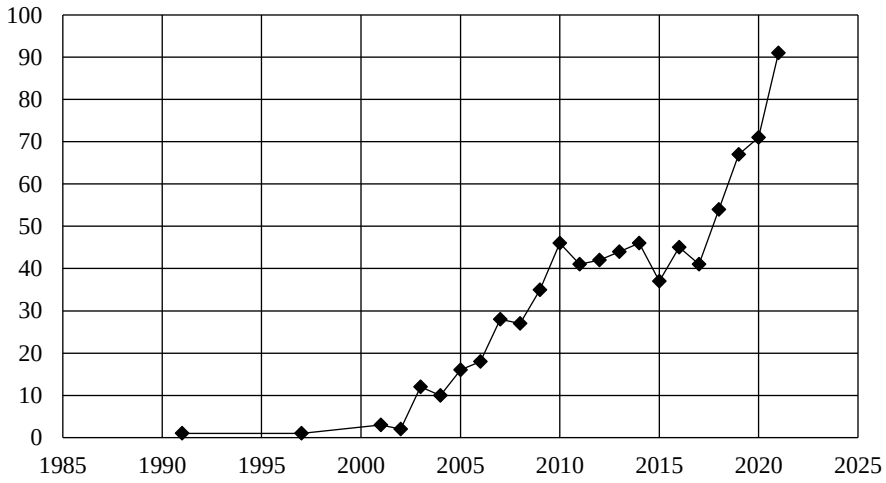

Figure 1. Year wise publication on sustainable engineering.
Source: Created by the authors

Affiliation Wise Publication

Table 1 depicts the affiliation wise distribution of publications from the year 1991 to 2021 with the overall distribution number of 778 publications in number. The researchers focused over international collaboration in the field of sustainable engineering constituting the percentage as Arizona State University (2.7%), University of Pittsburgh (2%), Carnegie Mellon University (2%), James Madison University (1.8%), University of Colorado Boulder (1.7%), The Ohio State University (1.7%), The University of Texas at Austin (1.7%), Georgia Institute of Technology (1.7%), Pennsylvania State University (1.4%), Purdue University (1.4%).

Table 1. Top 10 Affiliation Wise Publication.

Affiliation	No. of publications	Percentage
Arizona State University	21	2.7
University of Pittsburgh	15	2%
Carnegie Mellon University	15	2%
James Madison University	14	1.8%
University of Colorado Boulder	13	1.7%
The Ohio State University	13	1.7%
The University of Texas at Austin	13	1.7%
Georgia Institute of Technology	13	1.7%
Pennsylvania State University	11	1.4%
Purdue University	11	1.4%

Source: Created by the authors

Distribution of Sustainable Engineering Publications by Prominent Authors

Table 2 reveals the name of various authors doing research and having maximum publication in the field of sustainable engineering. The aforementioned topic inspired the various authors from vivid background to contribute in this field as B.R. Bakshi, (1.7%), the author is associated with The Ohio State University, Columbus, USA. C.I Davidson, presently the researcher is working with Department of Civil & Environmental Engineering and Public Policy, Carnegie Mellon University, Pittsburgh, Pennsylvania, USA (1.1%). While B Allenby, associated with Department of Civil and Environmental

Engineering, Arizona State University. The percentage distribution by other authors are as follows: A.R Bielefeldt (1%), C. Davidson (.9%), A.E Landis (.9%), D.T Allen (.8%), B.R Allenby (.8%), M.M Bilec (.8%) and C.F Murphy (.8%).

Table 2. Most Prominent Authors in The Field of Sustainable Engineering.

Author's name	No. of publications	Percentage
Bakshi, B.R.	13	1.7%
Davidson, C.I.	9	1.1%
Allenby, B.	8	1%
Bielefeldt, A.R.	8	1%
Davidson, C.	7	.9%
Landis, A.E.	7	.9%
Allen, D.T.	6	.8%
Allenby, B.R.	6	.8%
Bilec, M.M.	6	.8%
Murphy, C.F.	6	.8%

Source: Created by the authors

Sustainable Engineering Publications Distribution by Author's Countries

Figure 2 depicts the number of publications related to sustainable engineering from eminent countries. Among 75 countries, the top contributor is U.S with (321), United Kingdom (70), Australia (47), China (44), Canada (32), Germany (31), India (29), Malaysia (22), Spain (19), France (17) publications.

Distribution of Sustainable Engineering Publications by Discipline

Figure 3 highlights the number of publications in numerous disciplines from 1991 to 2021. One can observe a spike in the number of publications in recent times due to the increasing awareness related to sustainability. The results revealed the highest number of publications in the engineering discipline with (499), Environmental Science (201), Social Sciences (131), Energy (129), Computer Science (86), Chemical Engineering (74), Earth and Planetary Sciences (66), Business, Management and Accounting (61), Materials Science (60), Chemistry (43) publications.

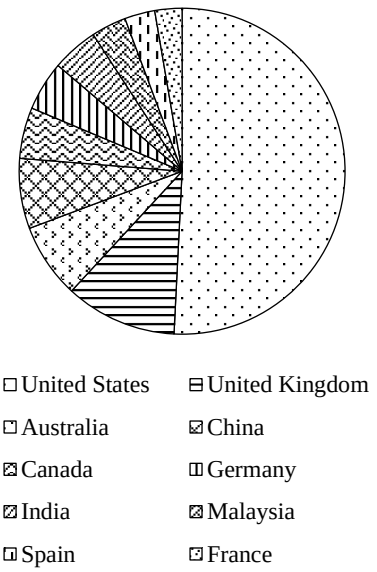

Figure 2. Top 10 Eminent Author's Countries Having Publications in Sustainable Engineering
Source: Created by the authors

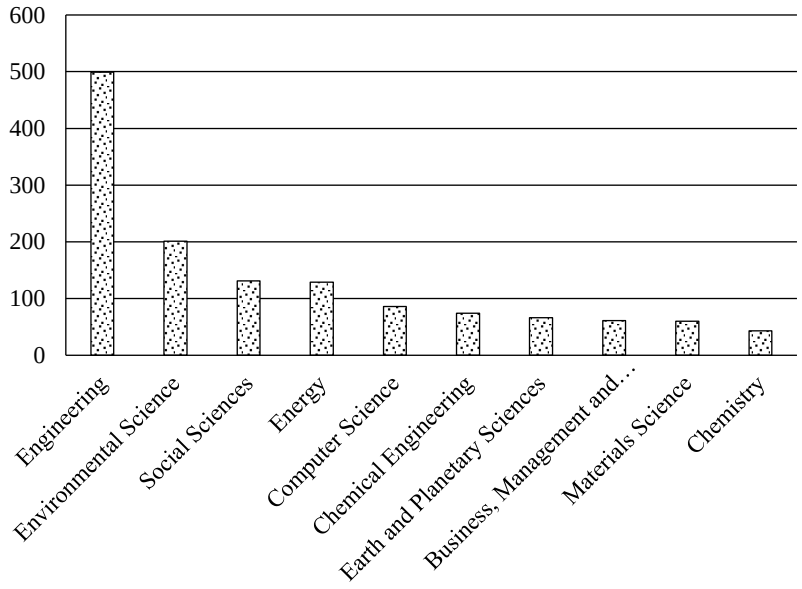

Figure 3. Top 10 most promising disciplines having publications in sustainable engineering.
Source: Created by the authors

Classification of Sustainable Engineering Papers by Journals

It is very essential to know the most prominent journal that had published in the field of sustainable engineering the most. It supports the researchers at the time of reviewing the literature to decide on which journal they need to focus on. Fig. 4 reflects the number of publications in the top 12 journals in the field of sustainable engineering. The journal which has published the highest number of articles in the Journal of Cleaner Production with 24 publications, than Sustainability Switzerland (19), Wiley Interdisciplinary Reviews Water (18), ACS Sustainable Chemistry and Engineering (16), International Journal of Sustainable Engineering (16), International Journal Of Engineering Education (13), Iop Conference Series Materials Science and Engineering (13), Iop Conference Series Earth And Environmental Science, Journal Of Professional Issues In Engineering Education And Practice, Lecture Notes In Civil Engineering with 9 publications.

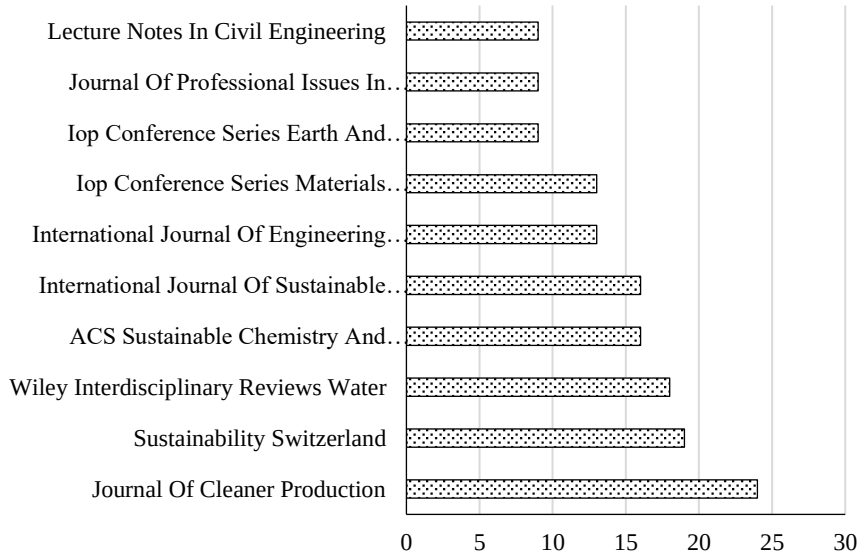

Figure 4. Top 10 Journals having publications in the field of sustainable engineering.
Source: Created by the authors

Sustainable Engineering Cited by The Report

Table 3 depicts the most cited research papers in the field of sustainable engineering. The top ten most cited papers were taken into consideration. The most cited paper is "Clean production and properties of geopolymer concrete; A review" (Amran Y.H.M. et.al. 2020) with 221 citations. The second most cited article is "Sustainable Design Through Process Integration" (El-Halwagi M.M 2012) with 196 citations. The third one is "Identifying barriers to and outcomes of interdisciplinarity in the engineering classroom" (Richter D.M. et.al. 2009) with 158 citations. Forth one is "Materials and the Environment: Eco-informed Material Choice: Second Edition" (Ashby M. 2012) with 156 citations. The fifth most cited article is "How much do engineering students know about sustainable development? The findings of an international survey and possible implications for the engineering curriculum" (Azapagic A. 2005) with 144 citations. The next one is "Single-machine sustainable production planning to minimize total energy consumption and total completion time using a multiple objective genetic algorithm" (Yildirim M.B. et.al 2012) with 140 citations. Then "Application of MCDM methods in sustainability engineering: A literature review 2008-2018", "Delignified and densified cellulose bulk materials with excellent tensile properties for sustainable engineering", "Mechanical properties of luffa sponge", "Facile access to large-scale, self-assembled, nacre-inspired, high-performance materials with tunable nanoscale periodicities" are having 127, 120, 108, 106 citations respectively.

Table 3. Top 10 Most Cited Articles in The Field of Sustainable Engineering.

Authors	Title	Year	Source title	Cited by
Amran Y.H.M., Alyousef R., Alabduljabbar H., El-Zeadani M.	Clean production and properties of geopolymer concrete; A review	2020	Journal of Cleaner Production	221
El-Halwagi M.M	Sustainable Design Through Process Integration	2012	Sustainable Design Through Process Integration	196
Richter D.M., Paretti M.C.	Identifying barriers to and outcomes of interdisciplinarity in the engineering classroom	2009	European Journal of Engineering Education	158
Ashby M.	Materials and the Environment: Eco-informed Material Choice: Second Edition	2012	Materials and the Environment: Eco-informed Material Choice: Second Edition	156
Azapagic A., Perdan S., Shallcross D.	How much do engineering students know about sustainable development? The findings of an international survey and possible implications for the engineering curriculum	2005	International Journal of Phytoremediation	144
Yildirim M.B., Mouzon G.	Single-machine sustainable production planning to minimize total energy consumption and total completion time using a multiple objective genetic algorithm	2012	IEEE Transactions on Engineering Management	140
Stojčić M., Zavadskas E.K., Pamučar D., Stević Ž., Mardani A.	Application of MCDM methods in sustainability engineering: A literature review 2008-2018	2019	Symmetry	127
Frey M., Widner D., Segmehl J.S., Casdorff K., Keplinger T., Burgert I.	Delignified and densified cellulose bulk materials with excellent tensile properties for sustainable engineering	2018	ACS Applied Materials and Interfaces	120
Shen J., Min Xie Y., Huang X., Zhou S., Ruan D.	Mechanical properties of luffa sponge	2012	Journal of the Mechanical Behavior of Biomedical Materials	108
Das P., Schipmann S., Malho J.-M., Zhu B., Klemradt U., Walther A.	Facile access to large-scale, self-assembled, nacre-inspired, high-performance materials with tunable nanoscale periodicities	2013	ACS Applied Materials and Interfaces	106

Source: Created by the authors

Most Frequently Appearing Keywords

Table 4 highlights that the researchers have used vivid keywords related to the study in order to make it more concrete. The table represents the number of frequencies a keyword is used in the study. The various keywords in the study facilitate a researcher to focus on a theme or topic. The keyword "Sustainable engineering" appeared 437 times in the study. Likewise, "sustainable development" is used 362 times, the term "Engineering Education appeared 175 times in the data set, the keyword "Students" has a frequency of occurrence 129 times and many other keywords were explored during the study.

Table 4. Keywords Whose Total Occurrence Is More Than 10 Times in The Data Set.

S no.	Keywords	Frequency
1	Sustainable Engineering	437
2	Sustainable Development	362
3	Engineering Education	175
4	Students	129
5	Sustainability	103
6	Curricula	100
7	Education	75
8	Teaching	68
9	Engineering	60
10	Ecology	15
11	Environmental Sustainability	15
12	Environmental Technology	15
13	Life Cycle Assessment	15
14	Research	15
15	Risk Assessment	15
16	Ecosystems	14
17	Engineering Practices	14

Source: Created by the authors

Keyword Occurrence Analysis

The study of keyword occurrence networks has been utilized to conduct a thorough investigation. The distance between distinct terms was utilized to identify the link between keywords in a text mining-based map that was shown using the VOSviewer analysis technique [19]. A link is defined as a gap between two or more words. Fig. 5 displays the keyword co-occurrence item density visualization map. We picked just 165 keywords out of the supplied dataset that showed up more than six times.

Co-Authorship Network Analysis

Researchers work in collaboration with other experts to provide high-quality research and fresh information. This kind of cooperation fosters creativity while expanding the scope of a research project. Scientific and research associations are explained by co-authorship network analysis, and its patterns identify the authors who have collaborated with the other authors in the data set [20]. This co-authorship network analysis thus identifies researchers' connections to other network participants. The VOSviewer programme was used to analyze the co-authorship network. where authors who have co-authored with at least four other authors in the data set were considered. Consequently, 30 such authors were discovered. The co-authorship network visualization diagram as depicted by the VOSviewer programme is shown in Figure.6. The entire strength of a researcher's co-authorship links with other researchers is reflected in their overall link strength displayed in the form of cluster. There is a total of 15 clusters, 27 linkages, and an overall link strength of 85. Most authors (five) are found in Clusters 1 and 2, while Cluster 3 is having three authors.

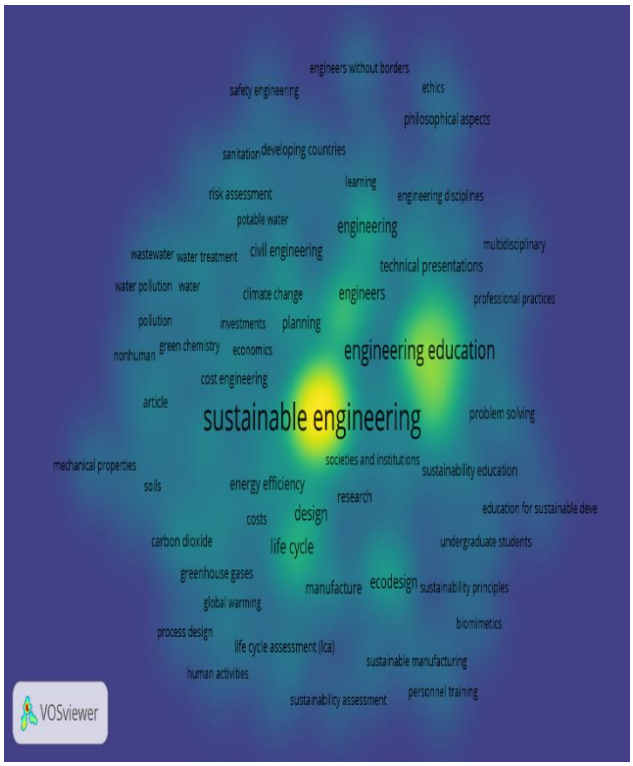

Figure 5. Keyword occurrence analysis.
Source: Created by the authors using VOSviewer software

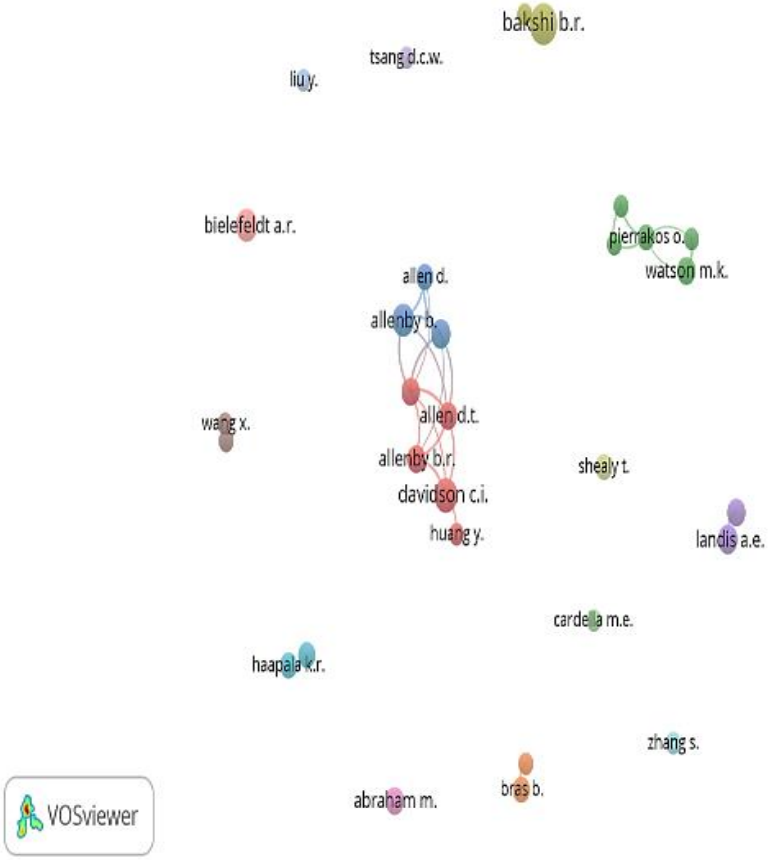

Figure 6. Co-authorship network analysis.
Source: Created by the authors using VOSviewer software

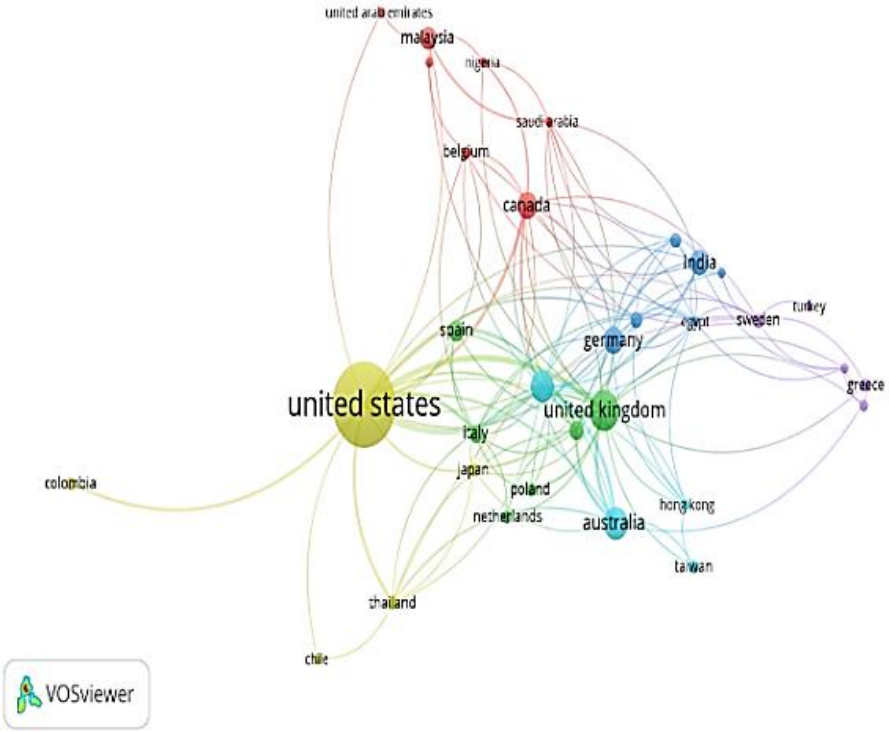

Figure 7. Intercountry Co-authorship network analysis.
Source: Created by the authors using VOSviewer software

Intercountry Co-Authorship Network Analysis

This section discusses the analysis of the international co-authorship network. The goal of this study is to identify which writers from which countries have worked together the most. Fig. 7 shows a map of the international co-authorship network. The data collection considers a nation to have a minimum of five documents. The VOSviewer tool found that 33 items make up the greatest group of connected things. Following the inter-country co-authorship network analysis, six clusters were formed: cluster-1 (Belgium, Canada, Iraq, Malaysia, Nigeria, Saudi Arabia, United Arab Emirates); cluster-2 (France, Italy, Netherlands, Poland, Spain, United Kingdom); cluster-3 (Brazil, Egypt, Germany, India, Portugal, South Korea); cluster-4 (Austria, Greece, Ireland, Sweden, Turkey); cluster-5 (Sweden, Finland, Norway, Denmark, and Sweden) and cluster -6 (Australia, China, Hong Kong, Taiwan).

CONCLUSION

The present article explores sustainable engineering research from the year 1991-2021 through bibliometric analysis. Under this, the most prolific authors from various countries were taken into consideration along with the prominent journals from various disciplines, and the most cited articles related to the aforesaid topic were taken into consideration. The total number of documents during this period are 778 in number, the first paper related to sustainable technology appeared in the year 1991 and gained familiarity from the year 2005. Arizona State University has the maximum number of publications with 21 in number, the most prolific author comes out to be B.R. Bakshi, from Ohio State University, Columbus, USA. The country with the maximum number of articles in the field of sustainable engineering is the U.S. with 321 articles. The journal which contributed the most is the Journal of Cleaner Production with 24 publications, the journal is from Elsevier with an 11.072 impact factor. The topmost article cited 221 times is “Clean production and properties of geopolymer concrete; A review” published by the Journal of Cleaner Production and the most frequently appeared keyword is Sustainable Engineering which is 437 times. In a similar vein, the keyword co-occurrence item density visualization map portrayed synonyms terms, while intercountry co-authorship network analysis and co-authorship network analysis identifies 6 clusters and 15 clusters with an overall link strength of 85 respectively.

Nowadays, the environment is one of the most sensitive issues, especially after COVID-19. The issues like global warming and other environmental issues were regularly discussed even on global platforms. The earth is left with very limited resources but with the growing population, the demands are also increasing rapidly. Engineers are supposed to satisfy all such human requirements as they are the building blocks for a nation, but it is a challenging time for them as they must understand the need for an hour to maintain sustainability. The engineering graduates must be conditioned in a way that they must focus on the sustainability of resources.

At the same time, educational institutes also understand their responsibilities towards the environment by revising the courses and curricula and preparing future engineers in such a way that they can face challenges. For this, educators must be equipped with training, workshops, and new educational material on sustainable engineering so that the teaching staff will be able to facilitate the budding engineers. The students must learn various novel techniques related to sustainable engineering. Embracing Circular and Green Polymer Science, alongside other sustainable engineering practices, offers innovative solutions to address these challenges effectively. By nurturing a generation of engineers attuned to sustainability principles, we lay the foundation for a more resilient and environmentally conscious future.

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