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Engineering education for sustainable development: Bibliometric analysis

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***Abstract* - Bibliometrics is a tool to evaluate and comprehend work. Its usage is steadily spreading to various disciplines. The main aim of this research paper is twofold. Firstly, to use bibliometrix as an R package tool to provide bibliometric information on 1,995 publications considered from the Scopus database. Secondly, to serve as a source for finding answers to new scientific questions through further research on engineering education for sustainable development. It is not hard to understand that higher education, especially engineering education, has a more significant role in realizing the Sustainable Development Goals (SDG) 2030. A review of research papers on engineering education and sustainable development published between 2010 and 2023 was conducted. The bibliometrix analysis identified the current level of research on Engineering Education for Sustainable Development (EESD). Through the results of this study, we have broadened our understanding of who, which, and what aspects of EESD, as well as possible research areas in EESD to explore. This study presents implications and recommendations for the people at the helm of authority in engineering education institutions and policymakers. They can play an instrumental role in developing a society with a sustainable future.**

***Keywords*: Bibliometrics, Bibliometrix, Engineering Education, Sustainable development, R package tool, Sustainable development goals**

***JEET Category* - Research**

I INTRODUCTION

Scholars in the area of Sustainable Development (SD) have defined SD in several ways. However, at its core, sustainable development is about fulfilling the needs of society under the backdrop of environmental, economic, and social awareness. Living within our environmental boundary is one of the fundamental principles of sustainable development. Encouraging well-being, social inclusion, and creating equal opportunity are its hallmarks.

Higher education institutions (HEIs), such as engineering institutions, are among the different types of organizations governed by their boundaries but are responsible for creating a sustainable future (Wright & Horst, 2013). Engineering education is profoundly rooted in a framework that emphasizes at design and production of cost savings and technical efficiency products (Mohd-Yusof, Alwi, Sadikin, & Abdul-Aziz, 2015). Engineering education for sustainable development (EESD) is about developing future engineers who are conscious of building organizational capacity to address global issues and challenges. The 2000–2015 UN Millennium Development Goals (MDG) consist of 48 indicators measured by 18 quantifiable targets, belonging to 8 overall goals. To summarize global issues and challenges, 2.6 billion people do not have access to safe drinking water, 2.3 billion world population do not have improved sanitation, 1.6 billion people do not have access to electricity, 1.3 billion people live with less than 1$ per day, around 1 billion people live in slums, over 1 billion population do not have ICT connection. Unfortunately, around 852 million people worldwide go hungry daily (Christensen et al., 2015). We need robust engineering solutions to address at least some of the aforementioned issues and challenges. Engineering educational institutions of the world need to focus on developing curricula that can provide competencies to engineering graduates to address these pertinent world challenges and issues. We must be aware that engineering is at the core of sustainability, and up-keeping sustainability is a significant task for engineers.

The first industrial revolution mainly focused on the textile and related industries. The second revolution focused on steam engines. The third wave emphasized steel, heavy engineering, and electricity. The fourth industrial revolution focused on automobile engineering. The fifth wave was based on telecommunications and information technologies. For the sixth wave, thrust areas were on new knowledge production, biotechnology and materials. The seventh wave focused on sustainable ‘green’ engineering and technology. Green technology was emphasized at the Rio+20 conference in Rio de Janeiro, Brazil, on 20-22 June 2012. However, engineering has been ignored, unrecognized, and side-lined (Christensen et al., 2015). Research has revealed a lack of progress among organizations toward implementing sustainability initiatives (Puig et al., 2019). As de Paula Arruda Filho et al. (2019) stated, “a structural change is needed to [. . .] ensure educational institutions make sustainability an intrinsic value in their mission statement” (p. 859).

It is, therefore, appropriate to consider transformations based on greener technology for mitigating climate change, new knowledge production, innovation, and sustainability through engineering (Christensen et al., 2015). Considering the urgency to address the above-mentioned world challenges and issues, which directly impact the social and psychological well-being of the people, the literature related to these issues has been growing swiftly. Still, regrettably, there is a paucity of bibliometric studies investigating and reporting the advances made on EESD. To address the gap, this study will answer the following research questions.

- To understand the trends in scientific publications in the area of EESD across the globe.
- To provide bibliometric information on one thousand nine hundred and ninety-five studies conducted during 2010-2023 collected from the Scopus database.
- To identify leading authors in the EESD research area.
- To use a collaboration map to appreciate the networking in this domain.
- To know prolific institutions, countries, and journals in the area of EESD and
- To identify the potential research gaps on EESD.

The next part of the paper is organized as follows: Section 2 talks about the methodology adopted. Section 3 presents the results and also focuses on the discussion part. Section 4 presents Contributions, limitations, and directions for future research.

II. METHODOLOGY

The Scopus database is considered one of the most significant abstract indexing databases. It covers a wide range of topics and provides various search options to help researchers with accurate results. Since this paper aims to evaluate the level of knowledge that has been appended to the existing knowledge base on EESD, for this purpose, scholars opted for the bibliometric mapping method on the Scopus database to know the current trends, knowledge, and progress made in EESD. Bibliometric mapping is a tool to probe the developments happening in any discipline (Srisusilawati et al., 2021). A bibliometric approach is defined as "the measurement of all aspects related to the publication and reading of books and documents" (p. 218) (Rousseau 2014). Previous studies have effectively used bibliometric methods to evaluate many research domains such as entrepreneurship (Vallaster et al., 2019), diffusion of innovation (van Oorschot et al., 2018), operations research (Merigó & Yang, 2017), and big data (Mishra et al., 2016). The main steps in this methodology are study design, data collection, analysis, visualization, and interpretation (Aria & Cuccurullo, 2017). Relevant studies were searched within the Scopus database using the keywords: "Engineering Education" and "Sustainable Development", for this paper. Scholars have decided to choose studies classified as conference papers, articles, book chapters, review papers, and book publications from 2010 to 2023 in English, since it is the most used language in the Scopus database. After excluding the studies from arts & humanities, and psychology domains, the number of studies left was one thousand nine hundred and ninety-five. These relevant documents were selected for further analysis using a bibliometric tool by name bibliometrix. In particular, this paper used the biblioshiny module of the bibliometrix package. A few visualizations were prepared using Microsoft excel for better representation.

III. RESULTS AND DISCUSSION

This section presents the results and discusses the findings from the data analysis.

Table I presents the preliminary information from the Scopus dataset dealing with EESD. We can notice that 1,995 publications appear between the period 2010 and 2023. The most numbered documents are conference papers which are 1,518 in number. Each document was contributed by three (3.35) authors approximately. "Keywords Plus (ID)," meaning the total number of keywords commonly appearing in scientific publications is 9,232, is almost five times the number of documents. The average number of citations per document is 5.56.

Table I: Main information

Description	Results
Documents	1995
Sources (Journals, Books, etc.)	555
Keywords Plus (ID)	9232
Author's Keywords (DE)	3979
Timespan	2010:2023
Average citations per document	5.567
Authors	5413
Authors of single-authored documents	294
Single-authored docs	317
Co-authors per documents	3.35
International co-authorships %	16.54
Article	379
Book	25
Book chapter	43
Conference paper	1518
Review	30

Figure 1 shows the last fourteen years of scientific output. The first evident jump in EESD publications was in 2014, with 310 documents. Barring that, the trend in EESD publication has seen almost linear growth. One another significant observation is from the year 2022 when the number of publications has touched an all-time low. However, another four months are left in the year 2022 to complete as on the date of presenting these results. Following the trend for the first eight months of 2022, the total number of publications for 2022 can be projected to be approximately 125 documents. The number of publications in the last three years, i.e., from 2019, is 201, in 2020 is 227, and in 2021 it is 212. These numbers are above the average number of publications for the study period, i.e., from 2010 to 2023, which is 143 documents. To conclude, the year 2022 is not that encouraging for EESD publication.

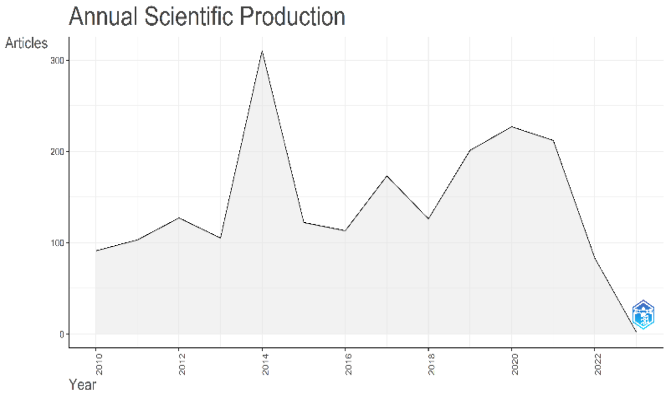

Figure 1: Annual scientific publication on engineering education and sustainable development.

During the study period, the annual average citations of all scientific documents on EESD have seen sharp linear growth. They align with the annual scientific publication trend (See figure 2).

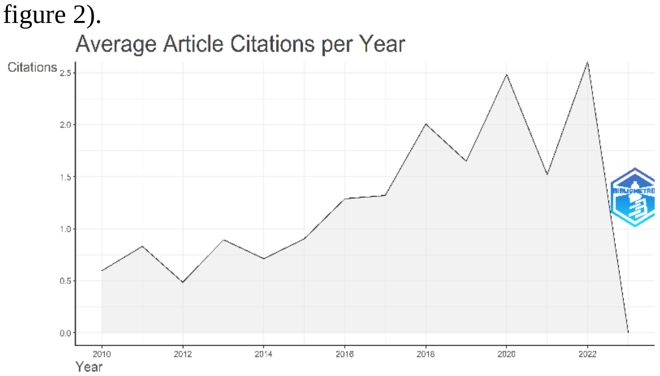

Figure 2: Annual average citations from 2010 to 2023

The distribution of the top 10 most relevant sources of EESD is shown in Fig. 3. It is evident that the ASEE annual conference and exposition conference proceedings top list with 307 documents published on EESD. IEEE global engineering education conference, EDUCON is second on the list with 244 documents. The above two conferences over-powered other sources for scientific publication in EESD. Hence, we could see a big difference in the number of conference papers published compared to other publications (See table I). Among the research articles, the top performing journal is "Journal of cleaner production," with 50 documents. The second top is "Journal of professional issues in engineering education and practice," with 41 documents. See figure 3 for more information.

Sources	Articles
ASEE ANNUAL CONFERENCE AND EXPOSITION, CONFERENCE PROCEEDINGS	307
IEEE GLOBAL ENGINEERING EDUCATION CONFERENCE, EDUCON	244
JOURNAL OF CLEANER PRODUCTION	50
JOURNAL OF PROFESSIONAL ISSUES IN ENGINEERING EDUCATION AND PRACTICE	41
PROCEDIA COMPUTER SCIENCE	37
PROCEEDINGS - FRONTIERS IN EDUCATION CONFERENCE, FIE	37
ACM INTERNATIONAL CONFERENCE PROCEEDING SERIES	35
SUSTAINABILITY (SWITZERLAND)	34
IOP CONFERENCE SERIES: EARTH AND ENVIRONMENTAL SCIENCE	33
PROCEEDINGS OF THE 45TH SEFI ANNUAL CONFERENCE 2017 - EDUCATION EXCELLENCE FOR SUSTAINABILITY, SEFI 2017	28

Figure 3: Top 10 most relevant source

The three-field plot (See figure 4) provides us with visualization of the main items, such as, in this case, affiliation (i.e., University), Country, and the journal and their relationship through a Sankey diagram. The visualization has surprised us with some interesting observations. The notable one is that all top ten Universities have paired with the USA to publish documents in all ten top journals. In conclusion, the USA stands tall among all other countries in EESD publication.

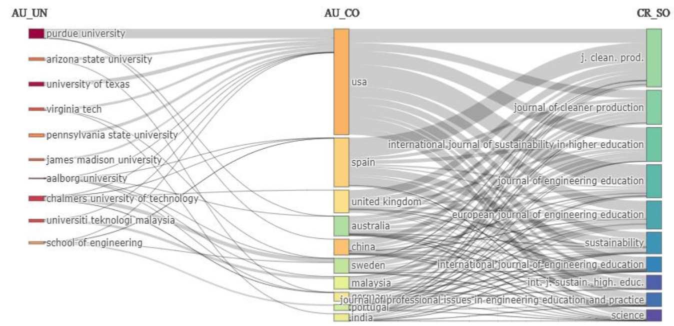

Figure 4: Three-field plot showing affiliation on the left field, countries in the middle field, and journals in the right field.

Figure 5 shows the source growth information on EESD published in the Scopus database. The top four sources were chosen to demonstrate growth dynamics. The top two are conferences and followed by top journals. All four sources experienced significant growth from the year 2010 to 2023.

Year	A	B	C	D
2010	29	0	3	4
2011	64	0	3	16
2012	110	0	3	17
2013	143	0	5	20
2014	174	197	6	23
2015	179	197	9	33
2016	183	200	15	33
2017	227	204	17	37
2018	228	210	31	39
2019	262	219	43	41
2020	274	228	45	41
2021	307	236	47	41
2022	307	244	50	41
2023	307	244	50	41
	A - ASEE annual conference and exposition, conference proceedings			
	B - IEEE global engineering education conference, EDUCON			
	C - Journal of cleaner production			
	D - Journal of professional issues in engineering education and practice			

Figure 5: Source growth dynamics based on cumulative occurrences

The top authors concerning the number of publications is shown in figure 6. We can see Bielefeldt AR leads with 15 articles. Penzenstadler B stands in the second position with 11 publications. Bilec MM and Ferreira P occupied third place with ten publications each. All influential authors have published nine articles each to secure the fourth position.

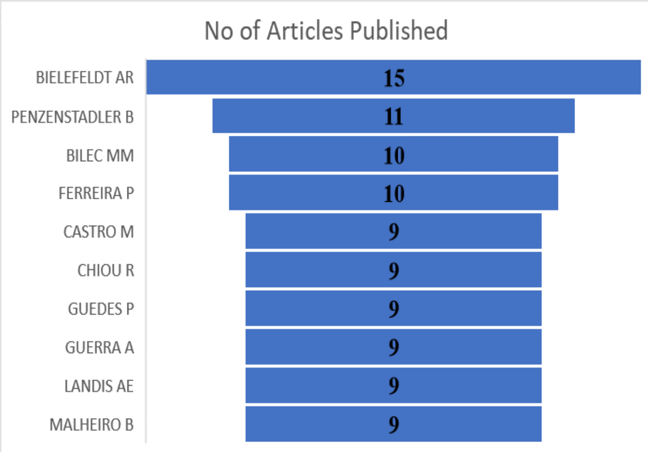

Figure 6: A funnel chart showing the most relevant authors in the field of EESD

The top three authors, as shown in figure 6, consistently produced scientific research at regular intervals starting from 2011 through 2021 (See figure 7). The size of the dot on the timeline corresponds to the number of publications.

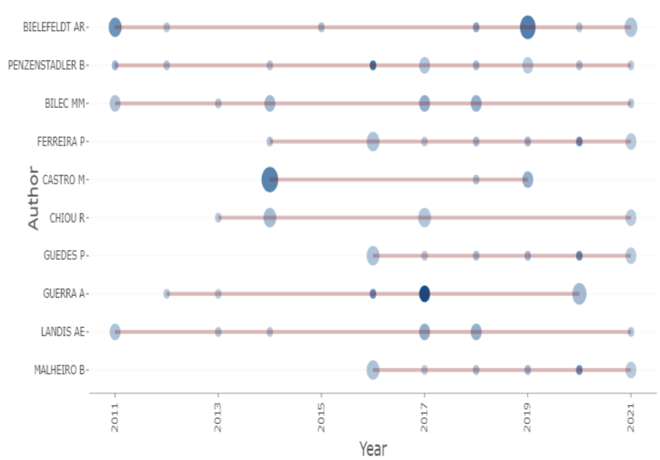

Figure 7: Authors' production over time

Figure 8 presents the top 10 relevant affiliations on EESD published in the Scopus database. The affiliation with the most significant number of articles goes to Purdue University with 52 documents. The University of Texas secures the second position with 34 publications on EESD. We can notice that almost all top ten affiliations come from the countries that are doing well on the overall economic front. One can get further clarity by understanding where most citations come from (See table II, figure 9). What is needed more is to work on engineering education with sustainability awareness from developing countries. However, the EESD topic should be of interest to countries from all over the world. Many countries face severe challenges such as clean drinking water facilities, good healthcare infrastructure, decent primary and higher education accessibility, holistic governance, etc. Unfortunately, we have not seen affiliations from such distressed parts of the world in the top 10 list.

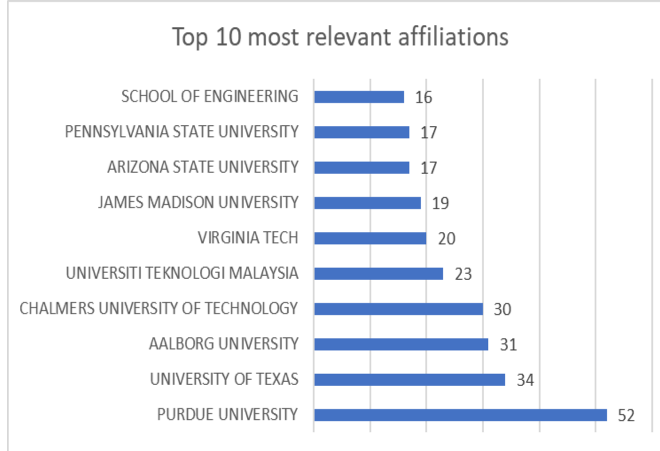

Figure 8: Showing the top 10 most relevant affiliations

Table II: Top 10 most cited countries of the world

Country	Total Citations	Average Article Citations
USA	2279	9.01
SPAIN	648	16.20
AUSTRALIA	417	12.64
UNITED KINGDOM	336	10.18
CHINA	286	4.21
GERMANY	279	8.72
ITALY	263	14.61
DENMARK	232	21.09
CANADA	224	16.00
SWEDEN	209	8.71

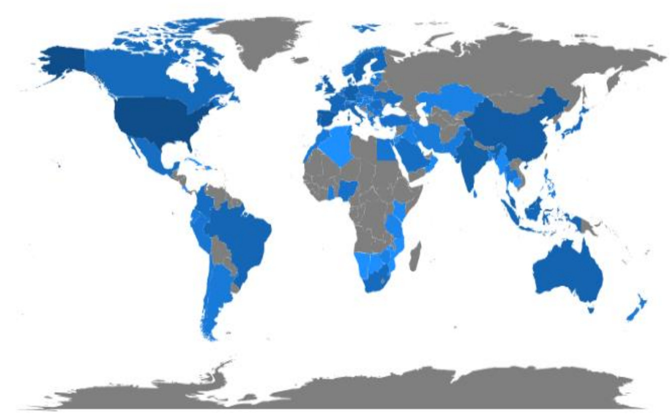

Figure 9: Showing countries' production. The darker blue colour indicates higher publications.

Figure 10 presents a wordcloud, and Table III presents the most frequent word occurrences related to EESD in the Scopus database. The wordcloud represents the frequent keywords used by authors and researchers in their publications. The word with the maximum occurrences was students (866). This demonstrates the importance of students in the framework of

EESD. The next word with the highest number of occurrences is curricula (552), followed by education (444). Teaching (429) and planning (286) occupy fourth and fifth positions. Unarguably *engineers* are solution providers for real-world challenges. Their contribution to addressing issues such as climate change mitigation, malnutrition eradication, portable drinking water provision, transportation facility, digital divide minimization, mass employment creation, waste recycling, etc., are the needs of the hour. To realize at least a few of the above exhaustive list of requirements, *engineering education* curricula should focus on the problem and project-based *teaching*. The entire teaching-learning *planning* should be *student*-centric, facilitating *student* interaction and serving engineering *education* as a rewarding career option (Beanland & Hadgraft, 2013), along with developing critical competencies of sustainable development.

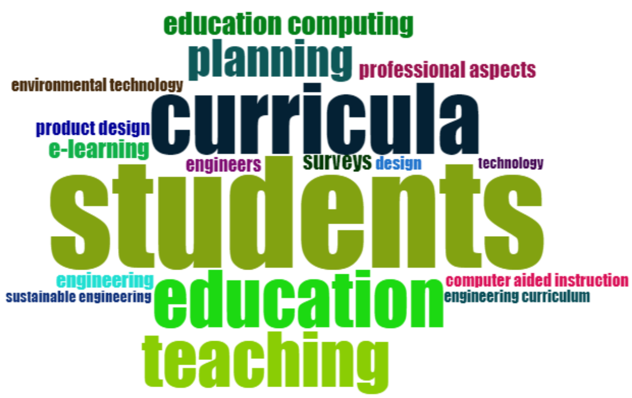

Figure 10: Worldcloud related to EESD

Table III: Most frequent words

Words	Occurrences
Students	866
Curricula	552
Education	444
Teaching	429
Planning	286
Education Computing	180
E-Learning	148
Surveys	135

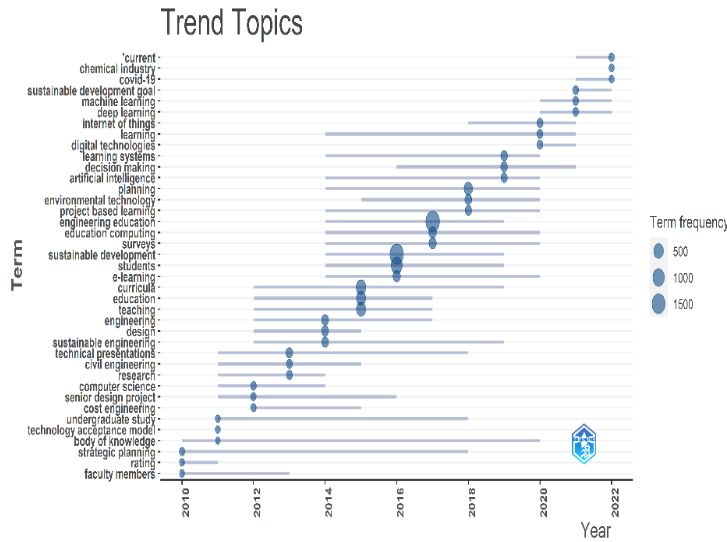

Figure 11: Trend topics

Figure 11 shows the progress of the "Engineering education" and "Sustainable development" theme between 2010 and 2022. From 2010 to 2012, engineering education and sustainable development were studied in the context of faculty members' involvement and strategic planning. From 2012 until 2018, a few dominant topics published in relation to engineering education and sustainable development were curricula, students, teaching, e-learning, and sustainable engineering.

From 2018 to 2022, new themes were explored; EESD is studied in digital technologies, the internet of things, deep learning, machine learning, sustainable development goals (SDGs), covid-19, and chemical industry domains. The trend can be matched with the observations of Christensen et al. (2015), which say that curricula need to reflect learning trends that use Information and Communication Technologies (ICT) resources for student-centric learning, with a combination of lectures and staff playing a role of learning facilitator.

Figure 12 presents the conceptual structure map on EESD. It characterizes the co-word analysis using the word co-occurrences from the EESD bibliographic data fetched from the Scopus database (Aria & Cuccurullo, 2017). Multiple Correspondence Analysis (MCA) helped us to identify two clusters of documents with similar concepts (Aria & Cuccurullo, 2017) (See Figure 12). Thus, it can be detected that the first cluster deals with the items related to the *administration* theme, such as information management, economics, higher education institutions, etc. In contrast, the second cluster is about the items related to theme *academics*, such as problem-solving, engineering research, learning systems, engineering curriculum, etc.

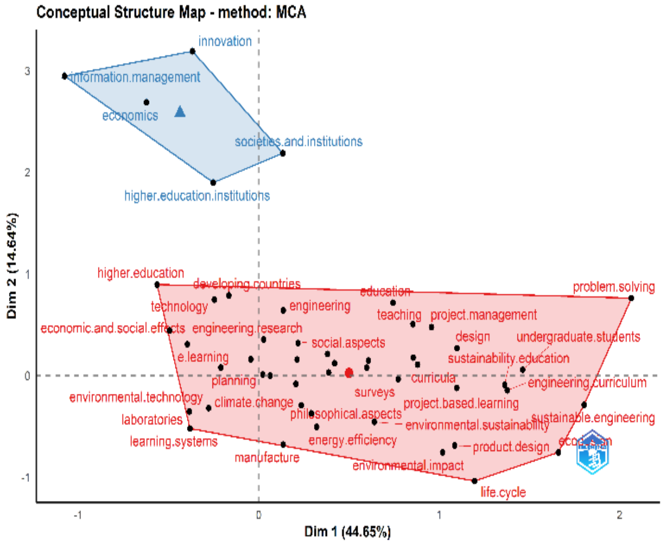

Figure 12: Conceptual structure map

The dendrogram in Figure 13 presents the hierarchical order and connections between the concepts, such as administration and academics, identified by the conceptual structure map (See figure 12). The plot allocates weight to each item based on the clusters and measures their connections.

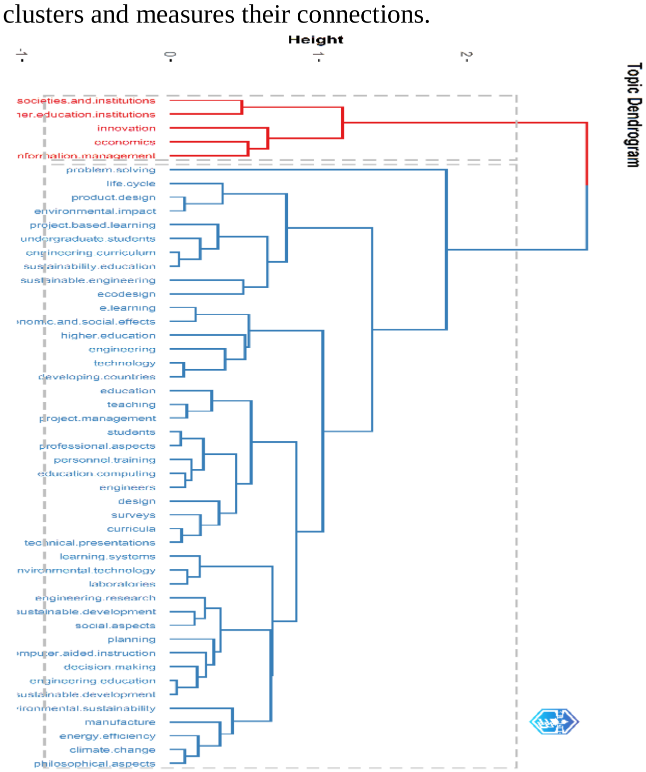

Figure 13: Topic dendrogram

Figure 14 shows the co-citation network. When both documents are cited in a third document, the co-citation of two documents happens. (Aria & Cuccurullo 2017). Co-citation helps to showcase the state of intellectual production in a given field (Batistiˇc & van der Laken, 2019). The present study on co-citation analysis shows two clusters, which are emphasized in Fig. 14. The contribution made by azapagic a. 2005 is significant in EESD.

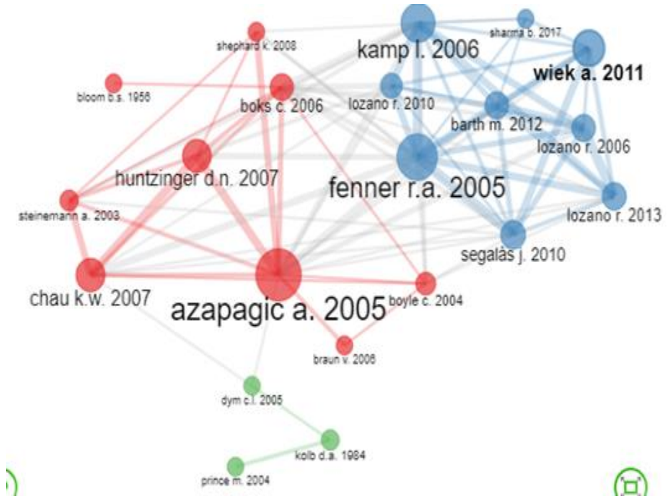

Figure 14: Co-citation network

Figure 15 shows collaboration between countries. The most substantial collaborations are being developed by scholars in the USA, followed by countries like the United Kingdom and Spain established strong publication links with various other countries of the world.

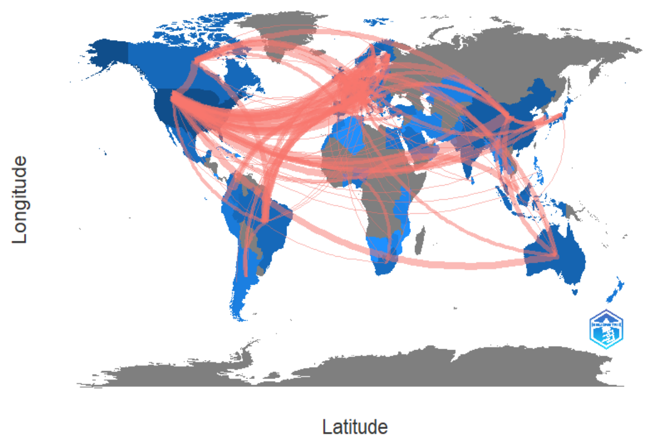

Figure 15: Collaboration worldmap

IV. CONTRIBUTIONS, LIMITATIONS, AND FUTURE OUTLOOK

The purpose of this study was to understand the developments taking place around engineering education for sustainable development (EESD). To achieve this task, scholars used R-Studio’s bibliometrix package and Scopus database of published work. A few essential observations have surfaced while performing the analysis. Firstly, the year 2022 was not great for EESD publications, especially compared to the past few years. On one hand, we have seen waves of technological growth and industrial revolution reflecting in the transformation of engineering education.
On the other hand, improving the quality of life (QOL) of the people, especially those who are living in poverty, encouraging sustainable development at every stage of innovation, and climate change mitigation and also adaptation, etc. are some of the pressing concerns being faced by engineering field on the whole. At this juncture, a severe challenge to capacity building

and addressing sustainable development goals is either a drop in EESD-related publications or a concentration of the majority of such publications to a few geographical areas. One reason for the drop can be attributed to the internal issues and challenges the engineering domain faces. In many countries, a shortage of engineers has been noted, and a decline in interest and enrolment of youth in engineering has been observed (Christensen et al., 2015). It is important to note that the most relevant affiliations, most productive authors, and countries come from developed countries of the world. Work on sustainability is the need of the hour for underdeveloped and developing countries. People or countries at the bottom of the development pyramid should be an area of focus to visualize the meaningful change. The conceptual structure map clearly shows that the workaround EESD is divided into two clusters. The proper names for these clusters can be academic and administration. Future research should focus on developing a single model with the themes coming from both clusters for extending novelty in the domain. It is an excellent sign to notice that the trending research on EESD is focusing on digital technologies, the internet of things, deep learning, machine learning, etc., to attain sustainable development goals (SDGs).

The study has considered only the Scopus database, limiting published papers' coverage. Hence the findings should be generalized with caution. Future studies can include publications from multiple databases to make them more comprehensive. Limitations can also appear in the choice of keywords selected for the study. Including more related keywords might end up in identifying more relevant publications. The limitations can also be in the form of the methodology adopted.

Further studies can combine various literature reviews with bibliometric tools to make new additions to the existing knowledge base. This study's findings benefit the policymakers of different countries, leadership in academic institutions, and individuals who keep an interest in sustainable development. Academic leadership should integrate pedagogical approaches that can develop competencies of sustainable development among young engineers. Policymakers should pay attention to introducing inter-disciplinary subjects in the engineering curriculum to produce, use and dispose of used products such as e-waste. Such steps would greatly aid in sustainable efforts.

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