

Review

Bibliometric Analysis of Specific Energy Consumption (SEC) in Machining Operations: A Sustainable Response

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Abstract: This paper's persistence is to make an inclusive analysis of 268 documents about specific energy consumption (SEC) in machining operations from 2001 to 2020 in the Scopus database. A systematic approach collects information on SEC documents' primary data; their types, publications, citations, and predictions are presented. The VOSviewer 1.1.16 and Biblioshiny 2.0 software are used for visualization analysis to show the progress standing of SEC publications. The selection criteria of documents are set for citation analysis. The ranks are assigned to the most prolific and dominant authors, sources, articles, countries, and organizations based on the total citations, number of documents, average total citation, and total link strength. The author-keywords, index-keywords, and text data content analysis has been conducted to find the hotspots and progress trend in SEC in machining operations. The most prolific and dominant article, source, author, organization, and country are Anderson et al. "Laser-assisted machining of Inconel 718 with an economic analysis", the Int J Mach Tools Manuf, Shin Y.C., from Purdue University Singapore, and United States, respectively, based on total citations as per defined criteria. The author keywords "specific cutting energy" and "surface roughness" dominate the machining operations SEC. SEC's implication in machining operations review and bibliometric analysis is to deliver an inclusive perception for the scholars working in this field. It is the primary paper that utilizes bibliometric research to analyze the SEC in machining operations publications expansively. It is valuable for scholars to grasp the hotspots in this field in time and help the researchers in the SEC exploration arena rapidly comprehend the expansion status and trend.

Keywords: specific energy consumption; machining; review; bibliometric analysis; sustainable machining; VOSviewer; Biblioshiny



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1. Introduction

Extraordinary conditions prevailed in 2020 due to the coronavirus pandemic. The situation was unparalleled. CO₂ emissions and energy use charted an unusual path. Worldwide energy demand weakened by 3.8% in the first quarter of 2020 compared with the first quarter of 2019. Annual energy demand in 2020 decreased by 6%. This is the largest ever decrease in energy requirement in the past 70 years. As a result, CO₂ releases fell by 8% nearly. In quantitative terms, the fall in emissions was 2.6 Gigaton (Gt) to reach 30.6 Gt for 2020. It is the lowest level since 2010 [1]. This was mainly due to the reduction in industrial production. This proves the fact that industrial production or manufacturing activity has a significant impact on CO₂ emissions. The fall in the emissions of 2020 may be temporary. Structural changes are required in environmental policies by all governments to sustain the reduction in CO₂ emissions [2]. The specific energy consumption (SEC) is one of the industrial manufacturing responses, especially in the field of machining operations. It is responsible for diminishing energy consumption and CO₂ emissions. This paper is

a step to review significant sustainable machining response SEC while considering its bibliometric analysis. SEC is defined as the ratio of energy consumed to produce one unit of product [3]. Some valuable researches conducted on SEC and energy responses in machining operations are presented here.

Balogun et al. [4] evaluated specific tip energy while considering the effect of un-deformed chip thickness, tool wear, tool geometry, and cutting environment in milling AISI 1045 steel alloy and turning EN8 steel alloy. In the shear dominated zone, the variation of nose radius of 0.4, 0.8, and 1.2 mm has no significant effect on the specific energy demand. When turning EN8 steel alloy, the tool wear can amplify the specific energy coefficient by 52% and total energy by 13%. The specific energy coefficient diminishes about 28% during the flood cutting environment as compared to dry cutting. For AISI 1045 steel alloy, the specific energy reduces from 5.34 to 1.47 J/mm³, increasing the feed from 0.01 to 0.55 mm/tooth. Total energy demand while selecting cutting fluids, tool wear and un-deformed chip thickness can be improved by 7%, 13%, and 18%, respectively, and can be taken as a benchmark. Balogun and Mativenga [5] also explored the deviation of specific energy coefficient for three different workpiece materials (aluminum AW6082-T6 alloy, AISI 1045 steel alloy, and titanium 6Al-4V alloy). They modeled its liaison to a thickness of material removed. The power function follows the same fashion for specific energy with un-deformed chip thickness for three materials. Balogun et al. [6] conducted high speed turning experiments on Nitronic 33 steel alloy under diverse cutting environment and cutting speed, and investigated tool life and wear, Ra, cutting forces and power demand. The tool life of 5.167 min. was highest at 90 m/min., with an uncoated carbide insert under a dry coolant flow condition. The optimum conditions for surface roughness (Ra), cutting force and power also achieved at 90 m/min., with a dry cutting environment.

The power consumption investigated of three machine tools; the Hitachi Seiki VG-45 91 (Machine-1), Roeders RFM 760 high-speed milling (Machine-2) and Mikron HSM 400 machining center (Machine-3) at zero cutting and cutting load capacities. The machine start-up (basic and idle states) and auxiliary units consumed a large amount of the electrical energy of 80.2%, 79.9%, and 69% of the total electrical energy demand on (Machine-1), (Machine-2), and (Machine-3), respectively. Simultaneously, their corresponding tooltip energy demands were 19.8%, 20.1%, and 31%, respectively. Consequently, at zero loads, i.e., when cutting is not taking place, machine tools should not be left in running condition for a substantial amount of time. With the variation of cutting variables and machining load, the electrical energy for machining processes varies from 0 to 48.1%. This needs to be optimized [7]. A new power measurement system presented allows recording the power consumption profile related to all the controlled axes of hard turning with a variation of cutting parameters; cutting speed from 150 m/min. to 300 m/min., feed rate from 0.1 to 0.2 mm/rev., and the depth of cut has fixed at a value of 0.3 mm and ball burnishing operations under variable machining conditions; burnishing speed (30 m/min.) and burnishing feed (0.05–0.15 mm/rev.). They explained how the sequential process's machining conditions influence power and energy consumption, and reported that power components consume 20% of the total power in turning operation. In the burnishing process, power components consume 3% of the total power. The burnishing process's energy consumption is higher than that of the hard-turning process compared to the power consumption. The most energy-efficient process is performed at the maximum feed rate because the total energy consumption decreases [8]. Paul et al. [9] studied the effect of the depth of cut (0.5–2 mm), feed (0.08–0.2 mm/rev.), nose radius (0.8–1.2 mm), cutting velocity (90 m/min.), and principal cutting edge angle or tool cutting edge angle (45°, 60°, and 75°) on turning of AISI 1060 medium carbon steel. The machining process was performed with un-coated carbide inserts under a dry machining environment. The objective was the minimization of back force and specific cutting energy. It was observed that the principal cutting edge angle and nose radius did not have much effect on specific cutting energy.

The effects of process parameters; cutting speed (40–80 m/min.), feed rate (0.1–0.2 mm/rev.), and cutting depth (0.75–1.25 mm) investigated on SEC consumption

and processing time by using the Taguchi method while turning of AISI 5140 with carbide insert. The optimum specific energy consumption was achieved at 80 m/min. cutting speed, 0.2 mm/rev. feed rate, and 1.25 mm depth of cut, and optimum processing time was achieved at cutting speed of 60 m/min., feed rate of 0.2 mm/rev., and depth of cut 0.75 mm [10]. Warsi et al. [11] developed and analyzed the SEC map for high-speed machining of Al 6061-T6 alloy and reported that it could be used effectively to decide the most energy-efficient cutting parameters for given work material. Cai et al. [12] illustrated the concept, content and scope of the energy benchmarking rules for machining operations research. The machining operation's power efficiency is defined as the processing power ratio to total power consumption and compared the power efficiency of brushing, conventional milling, and microscale drilling employing experimental results. The power efficiency of brushing, traditional milling, and microscale drilling was 23.8%, 7.6%, and 1%, respectively [13]. The authors [13] compared the results reported by Zhao et al. [14], i.e., the energy efficiency comparison of conventional turning process with laser-assisted turning operation, this process at first considered by Skvarenina and Shin [15], performed to study the variations of cutting speed (1.36–2.04 m/sec.), depth of cut (0.5–1 mm), feed (0.075–0.125 mm/rev.), and material removal temperature (26.85–76.85 °C) on tool wear, cutting forces, specific cutting energy, and surface roughness. The laser-assisted turning was performed on a turret lathe with a 1.5 kW CO₂ laser. The SEC by the laser-assisted turning operation was 0.85 J/mm³ less as compared to the conventional turning process. The tool life, SEC, and surface roughness were improved by 60%, 25%, and 5%, respectively. Balogun et al. [16] anticipated the methodology used to assess machining efficiency based on maximum specific shear energy and derive the specific ploughing energy for minimum tip energy demand. The shearing dominated machining should be utilized to enhance the process efficiency in mechanical machining. Park et al. [17] applied RSM and TOPSIS method to optimize the machining variables; cutting speed (60–300 m/min.), feed rate (0.10–0.16 mm/rev.), nose radius (0.2–0.6 mm), edge radius (20–100 µm), and rake angle (−10° to 0°) of the turning operation for hardened AISI 4140 steel to diminish the cutting energy consumption and to get better energy efficiency. The sustainable machining output parameters, power factor, energy consumption, and energy efficiency were optimized with the Taguchi method. ANOVA was utilized to assess the impact of turning cutting variables. The results reveal nose radius does not impact too much on energy responses [18]. The sustainable responses were also optimized simultaneously along with material removal rate, surface roughness, and power consumption of the CNC turning machine while utilizing different weight assigned with Entropy and AHP methods [19]. The active power consumption of the CNC turning machine while machining alloy steel has been optimized with the Taguchi method [20]. Li et al. [21] incorporated Taguchi, RSM, and particle swarm optimization to optimize energy saving parameters in vertical milling of AISI 1045 steel. The response specific energy consumption was picked to assess energy efficiency along with processing time. The energy efficiency of finish turning of EN 353 alloy steel was investigated during turning operation [22]. The sustainable machining responses were optimized, such as machining time [23], active power consumption [24], active cutting energy [25].

Kara and Li [26] presented an empirical model of the specific energy consumption; the model was developed based upon eight dissimilar milling and turning machines. Energy consumption while machining was fixed at 1 cm³. The developed empirical model anticipates the energy consumption with correctness of more than 90%. A model validation test was conducted on brass and mild steel. The accuracy of the model for brass and mild steel was 91.06% and 95.59%, respectively. Suresh et al. [27] used RSM to develop models of specific cutting force, Ra, power, and wear of tool, although turning of hardened AISI 4340 steel with coated carbide insert. They optimized cutting parameters with the Taguchi method. The ANOVA results revealed that the feed rate has the superior impact on the machining force (53.38%), specific cutting force (70.55%), and Ra (83.79%). The cutting speed has a superior effect on the power consumption (77.67%) and tool wear

(75.75%). To diminish the specific cutting force, upper values of feed rate are required, tool wear and power has a linear relation with cutting speed and feed rate. Guo et al. [28] applied a two-step approach to determining the optimal cutting state with a deviation of speed (60–800 m/min.), feed (0.05–0.3 mm/rev.), and depth of cut (0.5–2 mm) of steel and aluminum with the coated carbide tool under dry conditions. They developed a model for total specific energy consumption and surface roughness with the least square curve fitting method. With a rise in feed rate, the total specific energy consumption declines, smaller diameter yields higher energy consumption because higher RPM requires more power consumption. The total specific energy consumption lowers with increasing depth of cut. The R-square 0.995 and 0.943 for total specific energy consumption and R_a , respectively. They represent the capability of the models developed for steel. Li et al. [29] presented a modified energy consumption model of the milling operation. The statistic modeling was used to obtain the model coefficients based on trial information. The improved model offered a reliable prediction of energy consumption with an accuracy of around 96%. R-square value for specific energy consumption, total power during cutting, ideal power demand and air cutting power of 99.98%, 99.45%, 97.80%, and 96.18%, respectively, shows the reliable prediction accuracy of the improved model terms. The new lubricant is used under minimum quantity lubrication for grinding of material Ti-6Al-4V. The authors claim that palm oil containing 0.1% by weight of Graphene nanoplatelets can reduce the specific cutting energy to the extent of 80.25% as compared with conventional cutting fluid LB2000. This is achieved due to reduced cutting forces due to decreased friction because GNP increases contact angles and a viscosity [30]. The authors utilize nitrogen gas as a coolant in turning stainless steel 304 grade on CNC machine tool. They claim that surface finish gets better. There is an increase in material removal rate and a decrease of 2.7% of specific cutting energy at lower speeds [31].

Peng and Xu [32] critically reviewed the energy-efficient machining system by grouping it into four categories, i.e., theoretical, empirical, discrete event-based, and hybrid models. They suggested that it requires an inclusive understanding, as well as optimization of energy consumption. A thorough study of the literature revealed that the SEC stood for the mapping association among energy consumption and process conditions, representing industrial machinery energy efficiency to improve input and output effectiveness [33]. To clarify the concept of development in machining energy, the relevant literature is described using a systematic approach, accompanied by qualitative and content analysis [34]. A thorough review of conceptual and empirical energy models for industrial machinery was carried out. Optimization of cutting parameters has been described as a critical technique for industrial machinery energy efficiency [35]. Yoon suggested a new hierarchical structure for energy management strategies for a machine tool focused on process stages, applicability, and strategic thinking. Yoon [36] proposed a novel hierarchical model for energy efficiency strategies based on process levels, ease of applicability, and decision making for a machine tool.

The bibliometric analysis has been successfully applied to find the research hotspots in many fields including, optimization techniques in metal cutting operations [37], sustainable development research [38], plasma spray coating techniques [39], green manufacturing [40], global carbon footprint [41], industry 4.0 and sustainability [42], managing for sustainability [43], circular economy, and internet of things [44].

The review of literature of SEC in machining operations and review studies on energy in machining reveals that the SEC is a significant sustainable response in machining operations. However, the review studies did not adequately characterize the overall framework of SEC analysis. Therefore, visualization methods are needed to investigate SEC in machining operations. This is necessary to illustrate the progression of the SEC in the machining literature. Two-level research, which included bibliometric and visualization review, has been used to bridge that gap. This study's general intent is to use bibliometric and visualization analysis to investigate the selected literature's options and strategies on SEC in machining operations from 2001 to 2020.

2. Materials and Methods

To analyze the research trends, keyword and content analysis, etc., of SEC in machining operations, VOSviewer 1.6.16 and Biblioshhiny 2.0 software are used.

2.1. Research Data Collection Methodology on Specific Energy Consumption (SEC)

The research data were collected on Scopus as it is an appropriate search engine containing primary citation sources and publishes peer-reviewed journals and conferences. The data collection process was completed on the first of April of 2021. The keywords utilized to collect information of SEC in machining operations are shown in Table 1. Search step 1 in Table 1 shows the keywords searched on the Scopus search engine, and step 2 indicates that data collection was limited to 2001 to 2020. Search step 3 shows the excluded keywords that are not relevant to the machining operations investigated for SEC. The final collected most relevant documents on SEC in machining operations comes out to 268.

Table 1. Data collection steps on Scopus.

Search Steps	Query on Scopus	Description	Number of Documents
1	TITLE-ABS-KEY	((“Specific cutting energy”) OR (“Specific energy consumption”) OR (“Specific power consumption”) OR (“Specific cutting power”) AND (“machining”))	528
2	OR LIMIT-TO PUBYEAR	(2001 to 2020)	477
3	AND EXCLUDE (EXACT KEYWORD)	(“Particle Size”, “Grinding (comminution)”, “Ball Mills”, “Cements”, “Comminution”, “Grinding Mills”, “Particle Size Analysis”, “Forecasting”, “Ternary Alloys”, “Size Determination”, “High Pressure Grinding Rolls”, “Reinforcement”, “Grinding Machines”, “Size Effect”, “Biomass”, “Vertical Roller Mills”, “Minerals”, “Moisture”, “Wood”, “Additives”, “Cement Grinding”, “Cement Industry”, “Computer Control Systems”, “Fine Grinding”, “Grinding Characteristics”, “Operating Parameters”, “Rollers (machine Components)”, “Stirred Media Mill”, “Dry Grinding”)	268

2.2. Features of Data Collected on SEC: Publications, Yearly Prediction and Citations

The primary information extracted from Scopus on SEC research data are shown in Table 2. The SEC databases consist of 268 documents from 2001 to 2020 published in 122 different sources. The collected papers have 5.87 average years from publication, 16.88 average citations per article, and 2.288 average citations per year article. All the sources on SEC have 6708 references. The extracted data have 186 articles, two book chapters, 77 conference papers, one erratum paper, and two review papers. In addition, the 268 documents on SEC have 1863 index-keywords or keywords plus, 719 author-keywords, 719 authors, and 962 author appearances. Of the extracted articles from the Scopus database, 11 articles written by a single author and 708 authors appeared in multi-authored documents.

From 2001 to 2020, there are 268 documents published on SEC in machining operations and the year-wise distribution is shown in Figure 1. During the first five years, 15 papers published on SEC in machining operations. Since 2011, the article publication rate on SEC increased at a faster pace. Overall, the annual article publications on SEC in machining operations shows a quickly rising trend since 2015. To better understand SEC in machining operations documents changing trend, a curve is fitted between time and documents published annually using an exponential function. The equation presented in Figure 1. can

predict the documents published yearly having an R-square of 86%. The article's mean citations per article and year are shown in Figure 2.

Table 2. Key evidence of specific energy consumption review Scopus database.

Description	Results
Timespan	2001:2020
Sources (Journals, Books, etc.)	122
Documents	268
Average years from publication	5.87
Average citations per documents	16.88
Average citations per year per doc	2.288
References	6708
Document types	
Article	186
Book chapter	2
Conference paper	77
Erratum	1
Review	2
Document contents	
Keywords plus or index keywords	1863
Author's keywords	719
Authors	
Authors	719
Author appearances	962
Authors of single-authored documents	11
Authors of multi-authored documents	708
Authors collaboration	
Single-authored documents	13
Documents per author	0.373
Authors per document	2.68
Co-authors per documents	3.59
Collaboration index	2.78



Figure 1. Distribution of specific energy consumption documents yearly and prediction.

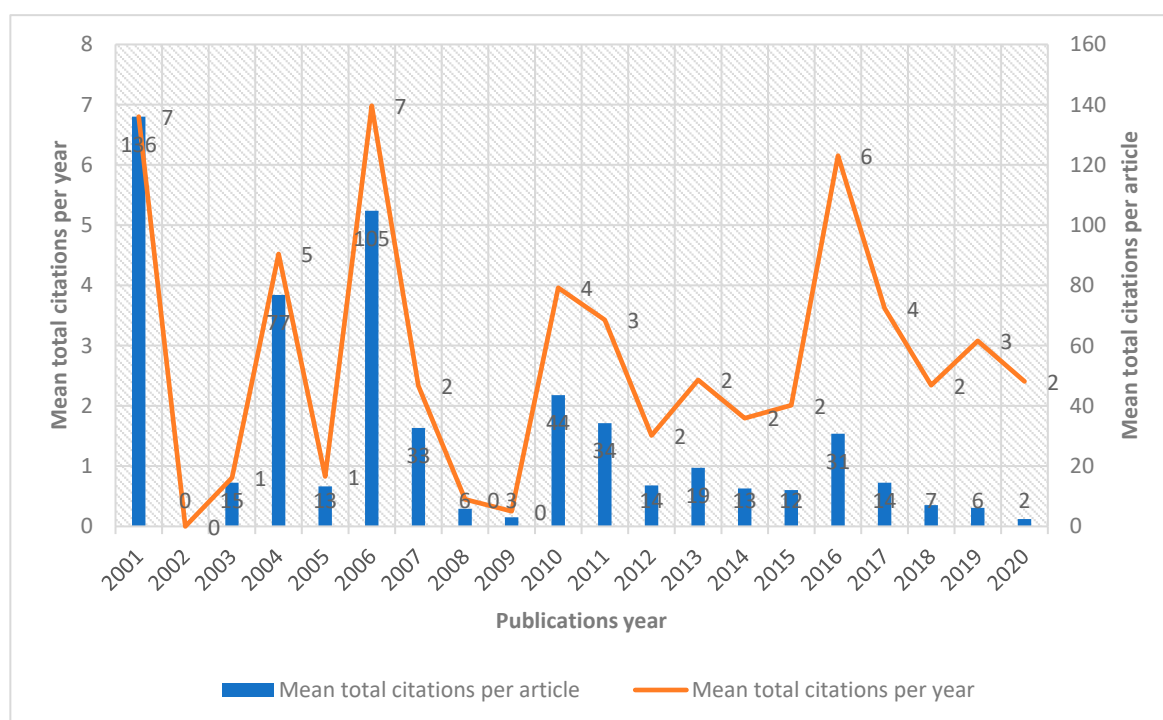


Figure 2. Distribution of mean citations of documents yearly.

3. The Most Prolific and Dominant Articles, Sources, Authors, Institutions and Countries in SEC of Machining Operations

3.1. The Most Prolific and Dominant Article-Citation Analysis

This section explains and analyses the most cited articles of SEC in machining operations [45]. A total number of 268 documents of SEC in machining operations. The most extensive set of related items consists of 112 articles divided into 17 clusters. Cluster-1 consists of 12 documents, cluster-2, 3, 4 of 11 authors' documents, cluster-5 of 10 documents, cluster-6 of eight documents, cluster-7 of seven, cluster-8 of six, cluster-9, 10, 11, 12, 13 of five documents, cluster-14, 15, 16 of three, and cluster-17 of two documents. The network visualization of connected documents based on citations by association strength method is shown in Figure 3.

The node size signifies the frequency of occurrence. The line between two nodes specifies that there is a co-occurrence association amid them. The thickness of the lines directs the strength of co-occurrence.

The total citations are picked as one criterion for ranking, followed by the strength of links and total citations per year, and the top 10 articles are shown in Table 3. The document of Anderson et al. (2006) [46] ranked at one, as the article has 246 citations, 13 links, and 17.57 total citations per year. So, the title "Laser-assisted machining of Inconel 718 with an economic analysis" in "International Journal of Machine Tools and Manufacture" becomes the most prolific and dominant article in the field of SEC in machining operations. Dandekar et al. (2010) [47], with 213 citations ranked second, has nine total link strength and 21.30 total citations per year. The document of Zhou et al. (2016) [33] ranked first based on total citations per year. All the top nine papers cited more than 100 times, and the top four more than 200.

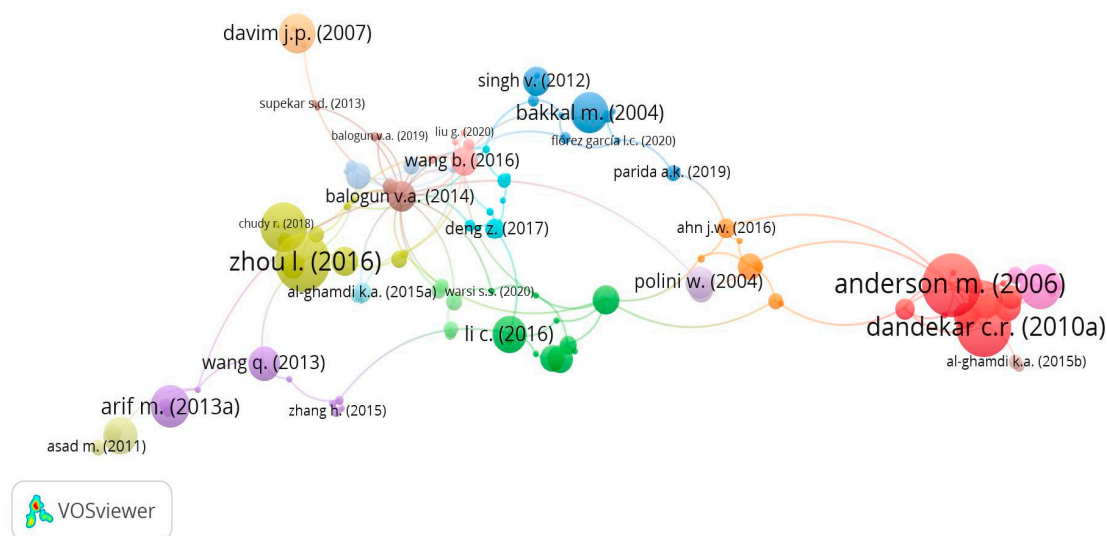


Figure 3. Document network visualization based on citations.

Table 3. Top 10 Documents or articles of SEC in machining operations based on total citations.

Rank	Document	TCi	Rank on TCi	TLS	Rank on TLS	SYoA	CiY	TCi/y	Rank on TCi/y	Ref.
1	Anderson M. (2006)	246	1	13	1	2006	14	17.57	4	[46]
2	Dandekar C.R. (2010)	213	2	9	2	2010	10	21.30	3	[47]
3	Zhou L. (2016)	211	3	6	4	2016	4	52.75	1	[33]
4	Rahim E.A. (2011)	200	4	2	7	2011	9	22.22	2	[48]
5	Chou Y.K. (2004)	148	5	3	5	2004	16	9.25	6	[49]
6	Gente A. (2001)	136	6	0	10	2001	19	7.16	9	[50]
7	Pfefferkorn F.E. (2004)	123	7	9	2	2004	16	7.69	7	[51]
8	Arif M. (2013)	111	8	3	5	2013	7	15.86	5	[52]
9	Bakka M. (2004)	104	9	2	7	2004	16	6.50	10	[53]
10	Davim J.P. (2007)	97	10	2	7	2007	13	7.46	8	[54]

Total citations: TCi, total link strength: TLS, start year of article: SYoA, citable years: CiY, total citations per year: TCi/y.

3.2. The Most Prolific and Dominant Source-Citation Analysis

In source citation analysis, the minimum number of documents set at one and total citations at two. Out of 122 sources, 84 meet the threshold criteria. The sources with the greatest total link strength are 41. The 41 items divided into 10 clusters. Cluster-1 consists of six sources, cluster-2, 3, 4 of five sources, cluster-5, 6, and 7 of four sources, cluster-8, 9 of two sources, and cluster-10 of two sources. The network visualization of five clusters with different colors is shown in Figure 4.

The top 10 sources based on the total citations, number of articles, total link strength, and average article citations are shown in Table 4. The Int J Mach Tools Manuf ranked first when the total citations, total link strength, and average articles citations are selected as an index to the journal's impact and have 903 total citations. The first article published in 2004 SEC in machining. The Int J Adv Manuf Technol also ranked first based on a number of documents 28. The J. Clean. Prod. ranked second with 639 total citations and 13 papers. The h-index, g-index, and m-index of the top 10 journals also shown in Table 4. The time zone of the source imitates the articles that appear in a specific period is shown in Figure 5.

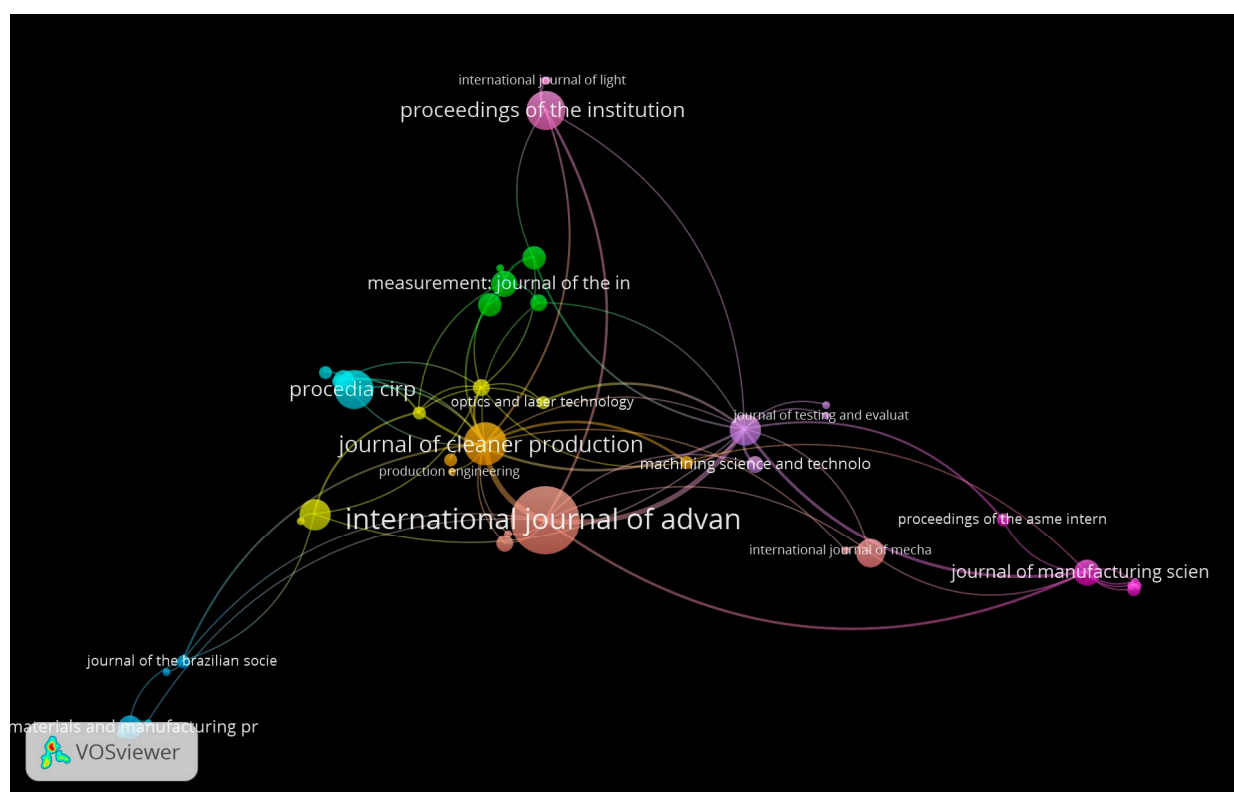


Figure 4. Source citation network visualization based on two citations and a single document.

Table 4. Top 10 sources based on total citations, number of articles, total link strength, and average article citations.

Rank	Source	TCi	Rank on TCi	NoA	Rank on NoA	TLS	Rank on TLS	AACi	Rank on AACi	h_Index	g_Index	m_Index	PSY
1	Int J Mach Tools Manuf	903	1	8	4	36	1	112.88	1	8	8	0.44	2004
2	J. Clean. Prod.	639	2	13	2	36	1	49.15	4	11	13	1.22	2013
3	Int J Adv Manuf Technol	428	3	28	1	36	1	15.29	9	13	20	1.18	2011
4	J Manuf Sci Eng Trans ASME	257	4	6	6	14	4	42.83	5	4	6	0.22	2004
5	J Mater Process Technol	230	5	7	5	4	7	32.86	7	6	7	0.33	2004
6	Tribol Int	215	6	3	9	2	9	71.67	2	3	3	0.27	2011
7	CIRP Ann Manuf Technol	179	7	3	9	0	10	59.67	3	2	2	0.50	2018
8	Mater Manuf Process	167	8	5	8	3	8	33.40	6	5	5	0.33	2007
9	Meas J Int Meas Confed	148	9	6	6	7	6	24.67	8	5	6	1.00	2017
10	Proc Inst Mech Eng Part B J Eng Manuf	145	10	11	3	9	5	13.18	10	8	11	0.53	2007

Total citations: TCi, number of articles: NoA, total link strength: average article citations: AACi, TLS, publication start year: PSY.

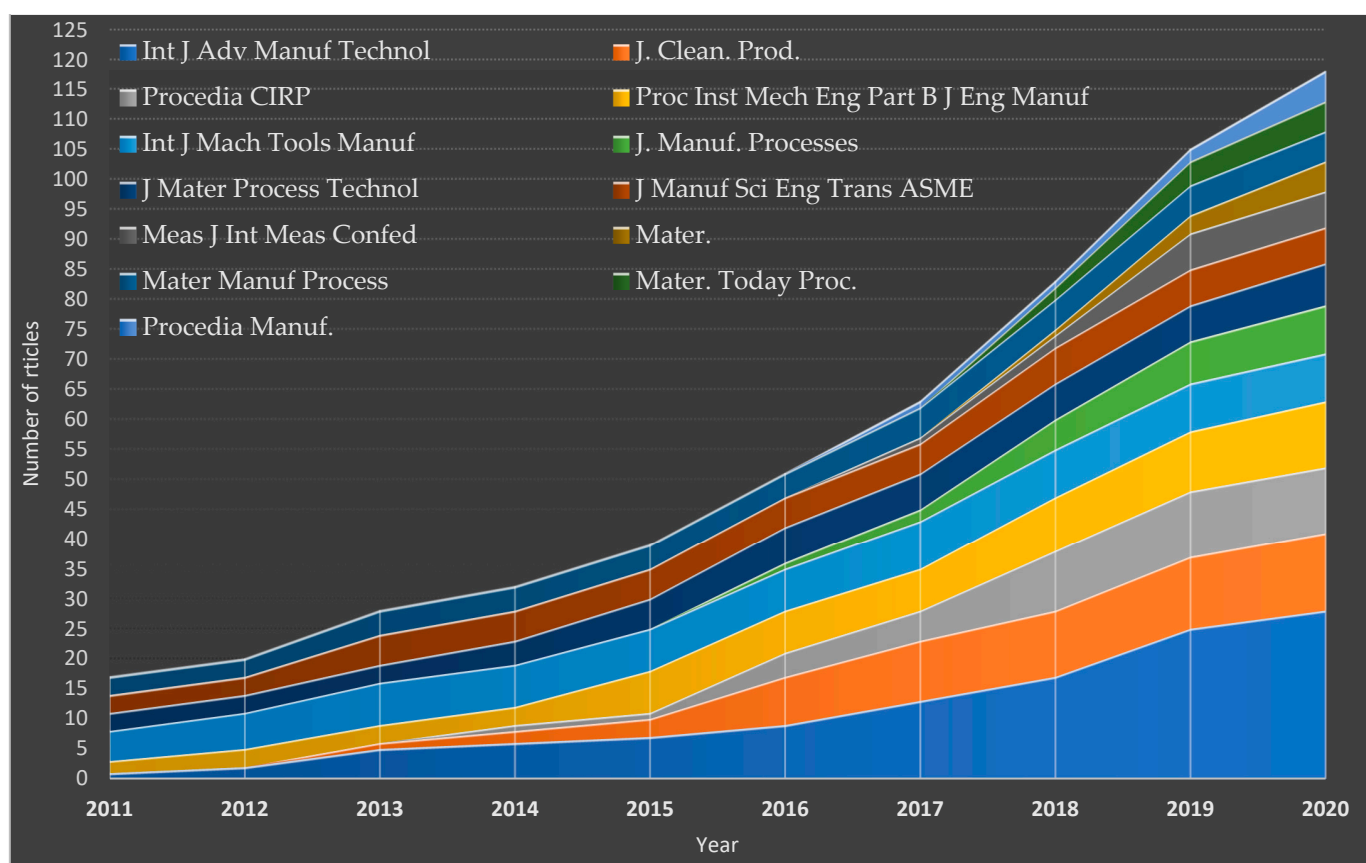


Figure 5. Top 10 source dynamics from 2011 to 2020.

3.3. The Most Prolific and Dominant Author-Citation Analysis

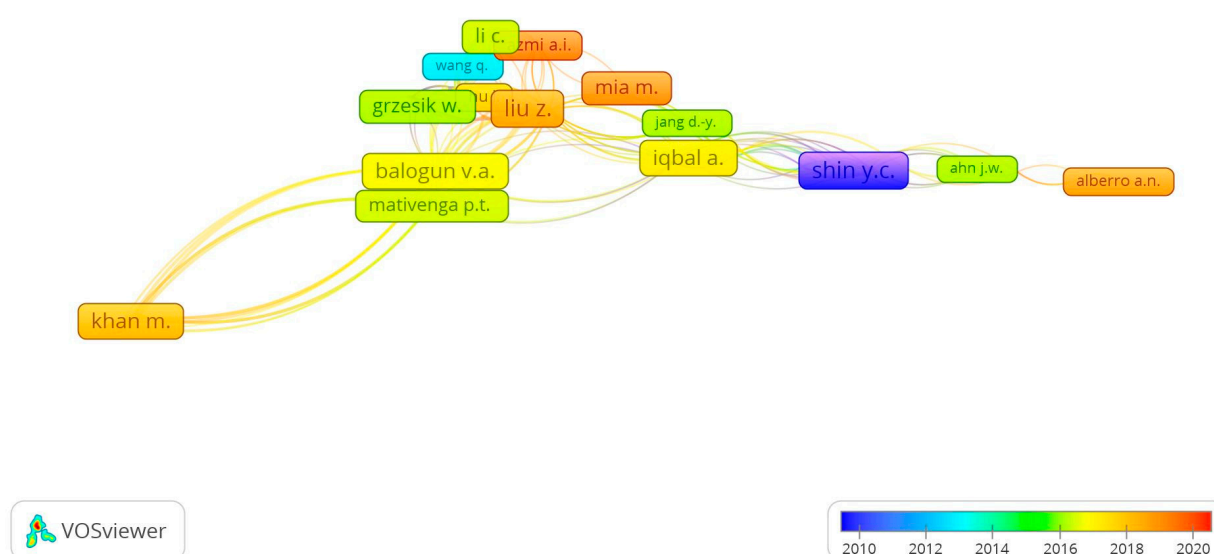
This subsection explains the visual reflection of the author productivity and their impacts based on citations. Table 5 shows the total link strength, total citations, number of articles, and average article citations of top authors having one article and 10 citations. There are 719 authors; out of this, 297 meet the threshold. The most extensive set of related authors consists of 132 items. The 132 authors divided into 10 clusters. Cluster-1 consists of 25 authors, cluster-2 of 24 authors, cluster-3 and 4 of 22 authors, cluster-5 of 11 authors, cluster-6 of nine, cluster-7 of seven authors, cluster-8 of five, cluster-9 of four, and cluster-10 of three authors. The network visualization of nine clusters with different colors is shown in Figure 6.

The authors' rank is assigned based on total citations, number of articles, total link strength, and average article citations, as shown in Table 5. The first rank goes to Shin Y.C., based on total citations of 810, number of articles nine and total link strength of 109 and have the fifth rank based on average article citations of 90. Shin Y.C. belongs to the center for Laser-based Manufacturing, School of Mechanical Engineering, Purdue University Singapore and has an h-index of 8, a g-index of 9 and an m-index of 0.44. Shin Y.C. started publishing on SEC in machining operations in 2004, and the year-wise publication and citation growth can be seen from Figure 7. The second most prolific and dominant author is Dandekar C.R., based on total citations of 302, number of articles four, and total link strength of 52. Finally, Anderson M. is the most prolific and dominant author based on average article citations of 246.

Table 5. Top 10 authors based on total citations, number of articles, total link strength, and average article citations.

Author	TCi	Rank on TCi	NoA	Rank on NoA	TLS	Rank on TLS	AACi	Rank on AACi	h_Index	g_Index	m_Index	PSY	Ref.
Shin Y.C.	810	1	9	1	109	1	90	5	8	9	0.44	2004	[15,46,47,51,55–59]
Dandekar C.R.	302	2	4	2	52	2	75.5	7	3	4	0.23	2009	[47,55,57,59]
Anderson M.	246	3	1	9	32	6	246	1	1	1	0.06	2006	[46]
Patwa R.	246	3	1	9	32	6	246	1	1	1	0.06	2006	[46]
Li F.	240	5	4	2	35	4	60	8	3	4	0.50	2016	[33,60–62]
Li J.	240	5	4	2	40	3	60	8	3	4	0.50	2016	[33,61–63]
Zhou L.	240	5	4	2	35	4	60	8	3	4	0.50	2016	[33,60–62]
Rahim E.A.	231	8	2	7	4	9	115.5	3	2	2	0.18	2011	[64,65]
Sasahara H.	231	8	2	7	4	9	115.5	3	2	2	0.18	2011	[48,65]
Xu X.	231	8	3	6	30	8	77	6	2	3	0.33	2016	[33,60,62]

Total citations: TCi, number of articles: NoA, total link strength: average article citations: AACi, TLS, publication start year: PSY.

**Figure 6.** Author network visualization based on 10 citations and one document per author.

3.4. The Most Prolific and Dominant Organizations Citation Analysis

There are 486 organizations involved in the research of SEC in machining operations. The ranks are assigned while considering a minimum number of one document only for each organization, and each document must have five citations. Out of 486 organizations, only 276 meet the threshold. The organizations rank is assigned based on total link strength, total citations, number of articles, and average article citations, as shown in Table 6. School of Mechanical Engineering, Purdue University, United States ranked first based on total citations 459, the number of articles two, and ranked fifth based on total link strength of five. The School of Mechanical Engineering, Shandong University, China, ranked second based on total citations of 220.

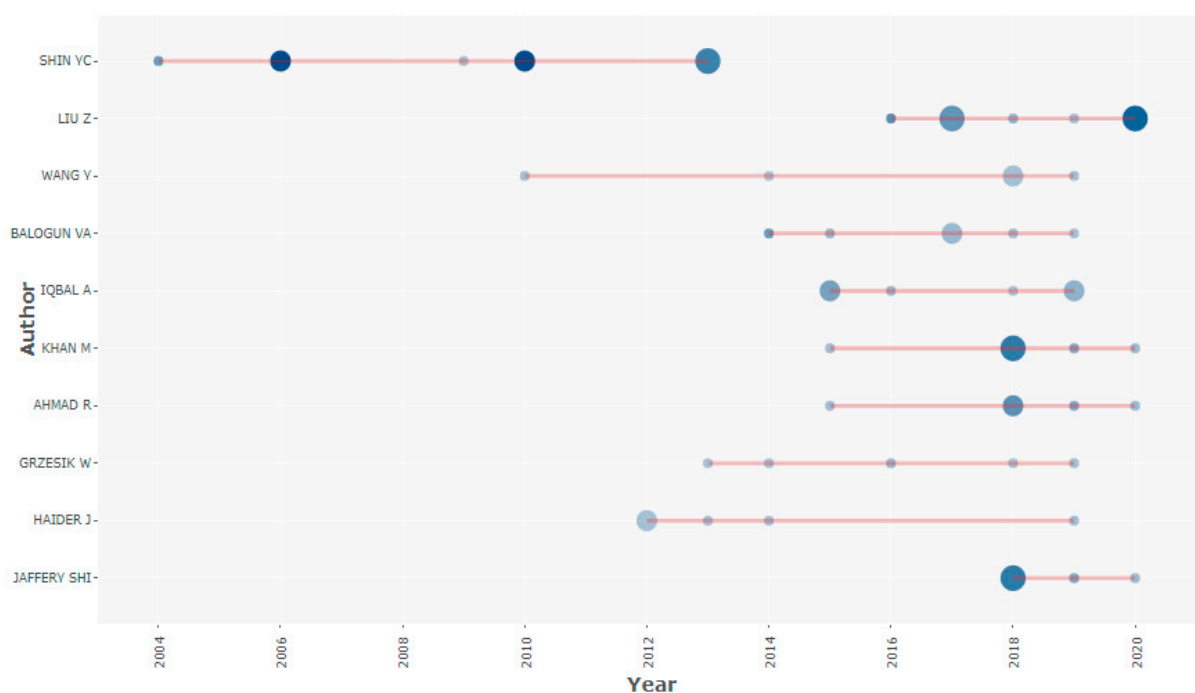


Figure 7. Top authors article publication yearly (dark blue bubble is the number of articles and a light blue bubble is total citations per year).

Table 6. Top 10 organizations based on total citations, number of articles, total link strength, and average article citations.

Organization	NoA	Rank on NoA	TCi	Rank on TCi	TLS	Rank on TLS	AACi	Rank on AACi
School of Mechanical Engineering, Purdue University, United States	2	1	459	1	27	5	230	1
School of Mechanical Engineering, Shandong University, China	2	11	220	2	14	3	110	9
Advanced Development Programs, United States	1	11	213	3	13	13	213	2
Tokyo University of Agriculture and Technology, Japan	1	11	200	4	8	9	200	3
Universiti Tun, Hussein Onn Malaysia, Malaysia	1	11	200	5	8	8	200	3
University of Alabama, United States	2	8	148	6	1	19	74	10
Technical University of Braunschweig, Germany	1	8	136	7	0	1	136	5
University of Notre Dame, United States	1	11	123	7	10	17	123	6
Purdue University, United States	1	2	123	9	10	5	123	6
National University of Singapore, Singapore	1	6	111	10	5	13	111	8

Total citations: TCi, number of articles: NoA, total link strength: TLS, average article citations: AACi.

3.5. The Most Prolific and Dominant Country-Citation Analysis

There are 52 countries involved in SEC in machining operations research, and the ranks are assigned while considering a minimum of one document for each country and five citations. Out of 52 countries, 40 meet the threshold. Therefore, the country with the greatest total link strength of 34 is connected. The 34 countries divided into nine clusters. The cluster-1 consist of seven countries, cluster-2 of five, cluster-3, 4, 5 consists of four countries, cluster-6 and 7 of three countries, clusters-8, and 9 of two countries. The density visualization of nine clusters is shown in Figure 8.

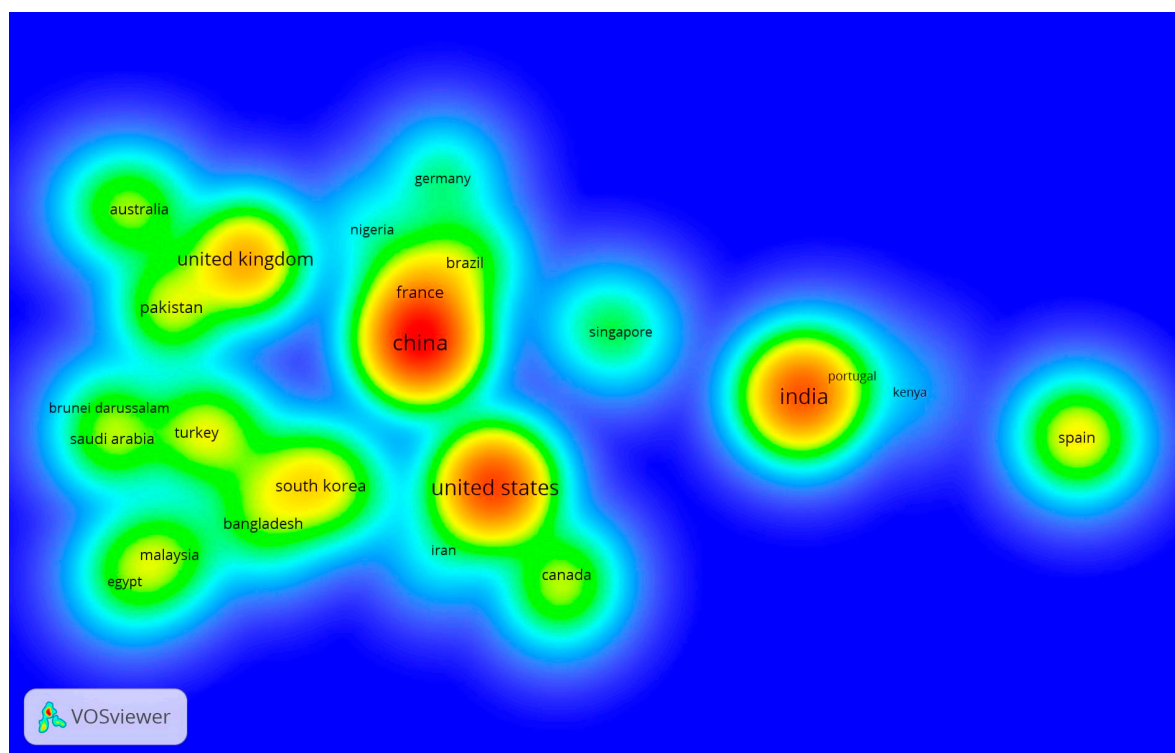


Figure 8. Country-citation density visualization of countries.

The country rank is assigned based on total link strength, total citations, number of articles, and average article citations, as shown in Table 7. The most prolific and dominant country is the United States, based on total citations of 1386. The United States ranked second based on a number of articles 43 and total link strength of 42. China is a prolific and dominant country based on a number of articles 55 and total link strength of 52. Japan stands at a first position based on average article citations of 57.40.

Table 7. Top countries based on total citations, number of articles, total link strength, and average article citations.

Country	TCi	Rank on TCi	NoA	Rank on NoA	TLS	Rank on TLS	AACi	Rank on AACi
United States	1386	1	43	2	42	2	32.23	5
China	776	2	55	1	52	1	14.11	8
India	515	3	38	3	29	4	13.55	9
United Kingdom	334	4	23	4	35	3	14.52	7
Malaysia	289	5	7	6	9	6	41.29	2
Japan	287	6	5	9	7	7	57.40	1
Italy	212	7	6	7	3	9	35.33	4
Germany	181	8	5	9	1	10	36.20	3
South Korea	175	9	13	5	11	5	13.46	10
Bangladesh	160	10	6	7	4	8	26.67	6

Total citations: TCi, number of articles: NoA, total link strength: TLS, average article citations: AACi.

3.6. Co-Authorship Versus Authors Analysis of SEC in Machining Operations

There are 719 authors involved in SEC in machining research writing. The network visualization was seen while setting minimum documents two and citations at five. A total of 124 co-authors were meet the threshold, and the most extensive set of connected authors is 21. The 21 authors divided into five clusters. Cluster-1, 2, 3, 4, and 5 consists of 7, 4, 4, 3, and 3 authors. The density visualization of five clusters is shown in Figure 9.

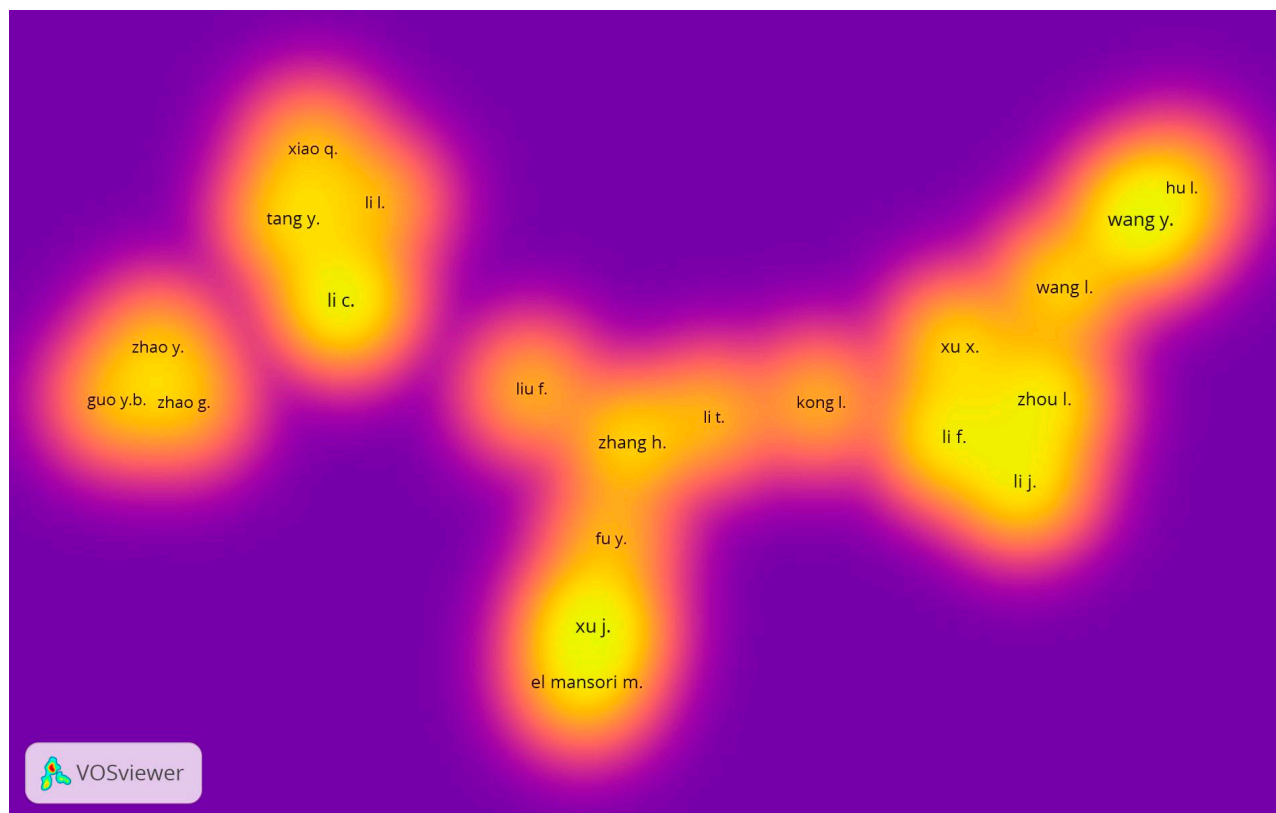


Figure 9. Density visualization of co-authorship-authors.

4. Co-Occurrence of Keyword and Content Analysis

Some items, like keyword or index words or feature entities pronounced in an article, appear simultaneously called co-occurrence phenomenon. The feature entities consist of organizations, title, author, or keywords, and so on in the literature. It is a quantifiable study of the co-occurrence phenomenon to disclose the content connotation of the evidence and the acquaintance disguised by specific items. Keywords can acme the exploration boundaries in studying and regulating research hotspots and growth trends [45].

4.1. Co-Occurrence Analysis of Author Keywords of SEC in Machining Operations

This section explains and analyzes the author keywords co-occurrence in SEC in machining operations Scopus databases from 2011–2020. The keywords on SEC in machining operations are selected based on two author-keywords co-occurrences. A total number of 719 author keywords appear on SEC in machining operations, and 138 meet the two author-keyword co-occurrences threshold. The most extensive set of related items consists of 137 author-keywords divided into 14 clusters. The author keyword network visualization of co-occurrences is shown in Figure 10. Different clusters consist of various author keywords are given below:

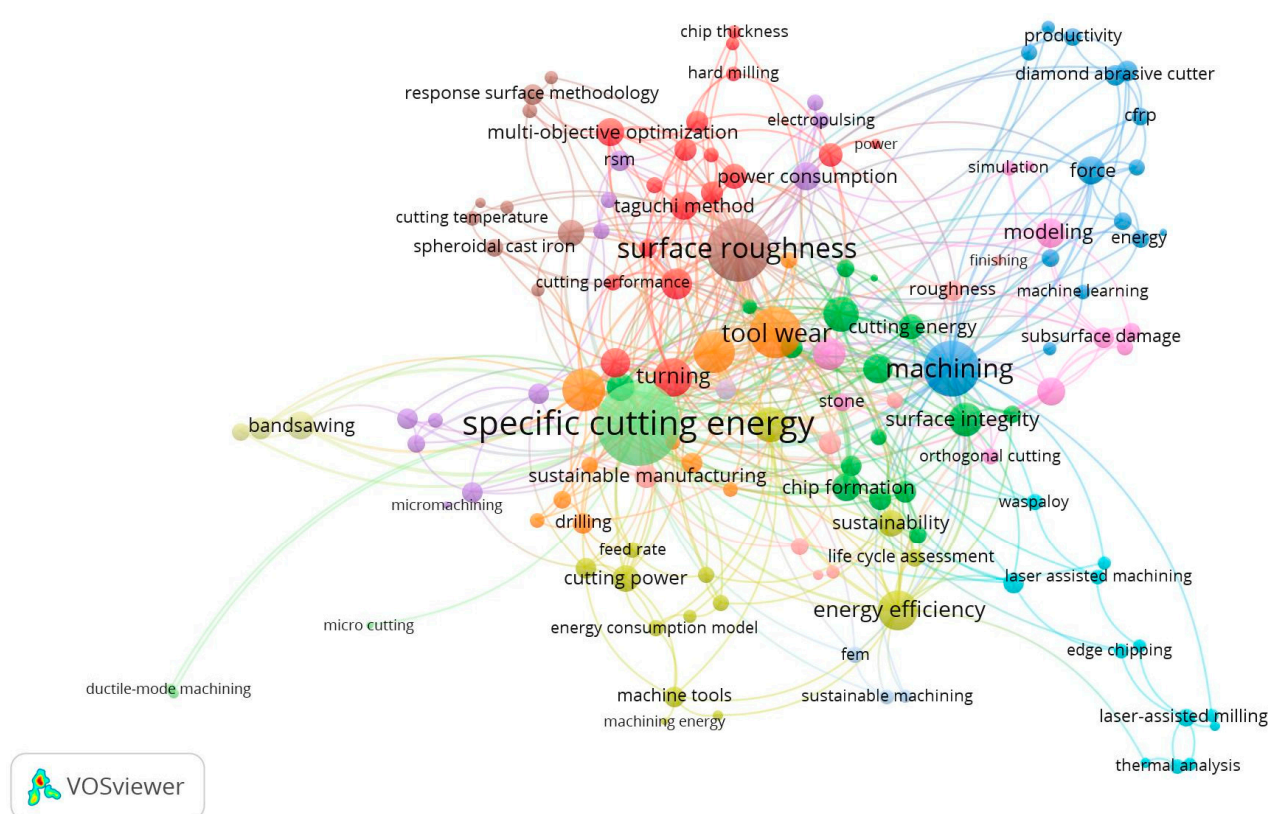


Figure 10. Author keyword network visualization based on co-occurrences.

- The cluster-1 of maroon color consists of 18 author-keywords such as “chip thickness”, “cutting conditions”, “cutting parameters”, “cutting performance”, “cutting speed”, “energy consumption”, “grey relational analysis”, “hard milling”, “machining parameters”, “material removal rate”, “multi-objective optimization”, “optimization”, “power”, “Taguchi”, “Taguchi method”, “TOPSIS”, “tungsten carbide composite”, and “turning”;
- The cluster-2 of bottle green color consist of 16 author-keywords such as “chip formation”, “chip morphology”, “cutting energy”, “die steel”, “finite element analysis”, “grinding”, “hardened steel”, “high speed machining”, “Inconel 718”, “laser-assisted machining”, “machinability”, “process mechanism”, “specific energy”, “surface finish”, “surface integrity”, and “titanium”;
- The cluster-3 of royal blue color consists of 15 author-keywords such as “bead milling”, “big data”, “CFRP”, “diamond abrasive cutter”, “electric handpiece”, “energy”, “force”, “grooving”, “machine learning”, “machining”, “milling”, “productivity”, “temperature”, “tool life”, and “trimming”;
- The cluster-4 of yellow color consists of 14 author-keywords such as “cutting edge radius”, “cutting power”, “energy assessment”, “energy consumption model”, “energy efficiency”, “feed rate”, “green manufacturing”, “life cycle assessment”, “machine tools”, “machining energy”, “nose radius”, “specific energy consumption”, “sustainability”, and “ultra-precision machining”;
- The cluster-5 of purple color consists of 12 author-keywords such as “ANOVA”, “built-up edge”, “electro pulsing”, “energy map”, “finite element method”, “high-speed machining”, “micromachining”, “orthogonal machining”, “plastic side flow”, “power consumption”, “RSM”, and “specific cutting energy consumption”;
- The cluster-6 of blue color consists of 12 author-keywords such as “alumina”, “design of experiments”, “difficult-to-cut material”, “edge chipping”, “laser assisted machining”, “laser-assisted milling”, “machining characteristics”, “micro-milling”, “Nickel alloy”, “silicon nitride”, “thermal analysis”, and “waspaloy”;

- The cluster-7 of orange color consists of 11 author-keywords such as “bulk metallic glass”, “cutting force”, “cutting forces”, “drilling”, “friction”, “metal cutting”, “milling process”, “stainless steel”, “titanium alloy”, “tool geometry”, and “tool wear”;
- The cluster-8 of black color consists of 10 author-keywords such as “cutting temperature”, “end milling”, “micromilling”, “minimum quantity lubrication”, “neural network”, “response surface methodology”, “single crystal silicon”, “specific power”, “spheroidal cast iron”, and “surface roughness”;
- The cluster-9 of pink color consists of 10 author-keywords such as “anisotropic machinability”, “cutting”, “finite element method (fem)”, “modeling”, “MQL”, “orthogonal cutting”, “process characterization”, “simulation”, “stone”, and “subsurface damage”;
- The cluster-10 of peach color consists of eight author-keywords such as “finishing”, “laser cladding”, “manufacturing sustainability”, “process parameters”, “roughness”, “surface quality”, “sustainable manufacturing”, and “un-deformed chip thickness”;
- The cluster-11 of red color consists of four author-keywords such as “ductile-mode machining”, “edge radius”, “micro cutting”, and “specific cutting energy”;
- The cluster-12 of sky blue consist of three author-keywords such as “fem”, “lubrication”, and “sustainable machining”;
- The cluster-13 of parrot green color consists of three author-keywords such as “band-sawing”, “ti-17 alloy”, and “wear”;
- The cluster-14 of navy blue color consists of only “artificial neural network” author-keyword.

The tree plot of leading 30 author-keywords used in SEC in machining operations documents are shown in Figure 11. The SEC in machining operations documents used the author-keyword “specific cutting energy” 62 times and have 19% contribution in the top 30 author-keywords. The author-keyword “surface roughness” is used 27 times and contributes 8%, followed by “machining” 23 times with 7% contribution and “tool wear” nine times and contributes 6%. The author-keywords “energy efficiency”, “specific energy consumption”, “cutting force”, “machinability”, “cutting forces”, and “turning” are used more than 10 times.

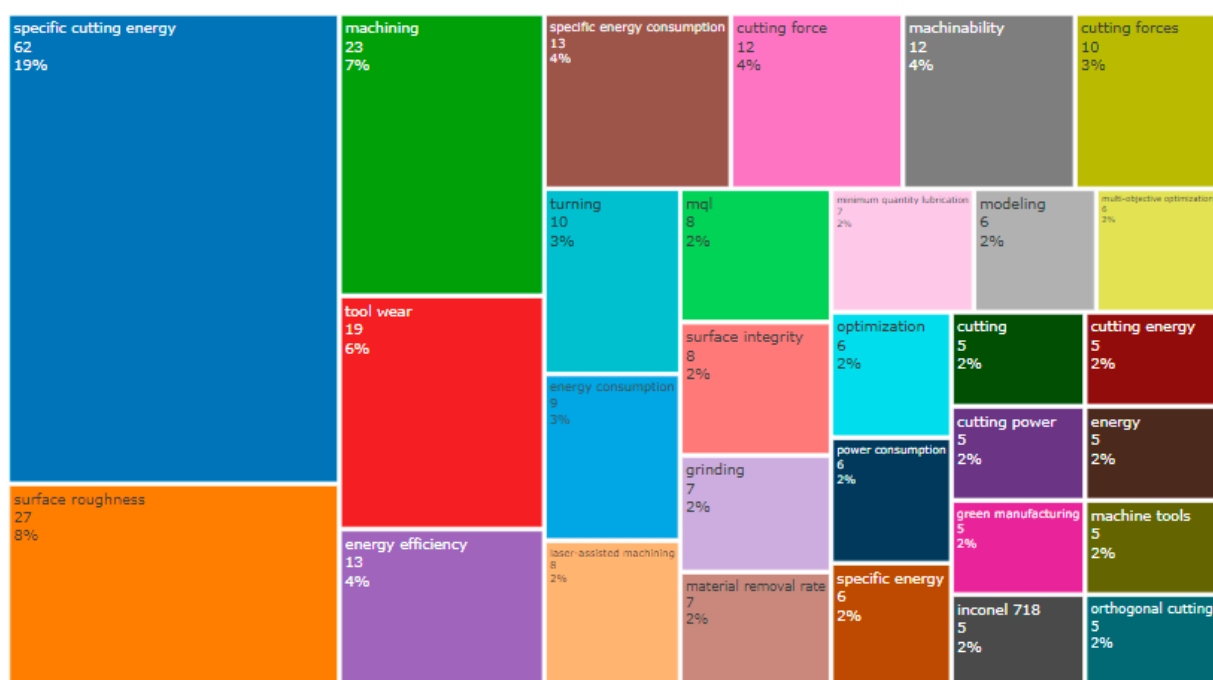


Figure 11. Tree plot of top-30 author-keywords.

- Cluster-3 consist of 23 index-keywords such as “carbon dioxide”, “chip thickness”, “electric discharge machining”, “electric power utilization”, “energy conservation”, “energy consumption model”, “energy utilization”, “environmental impact”, “green manufacturing”, “industrial research”, “life cycle”, “machine tools”, “machining”, “machining centres”, “machining process”, “manufacture”, “manufacturing process”, “specific energy”, “specific energy consumption”, “sustainable development”, “sustainable manufacturing”, “tool steel”, and “workpiece materials”;
- The cluster-4 of orange color consists of 22 index-keywords such as “analysis of variance (ANOVA)”, “ceramic materials”, “design of experiments”, “economic and social effects”, “energy efficiency”, “genetic algorithms”, “laser-assisted machining”, “laser-assisted millings”, “machinery”, “machining characteristics”, “machining conditions”, “machining parameters”, “minimum quantity lubrication”, “multi-objective optimization”, “optimization”, “quality control”, “regression analysis”, “response surface methodology”, “surface roughness”, “Taguchi methods”, “thermoanalysis”, and “turning”;
- The cluster-5 yellow color consists of 15 index-keywords such as “aluminium”, “atmospheric temperature”, “conventional machining”, “cutting conditions”, “cutting parameters”, “cutting speed”, “finite element method”, “laser assisted machining”, “material removal”, “material removal rate”, “materials”, “metallic matrix composite”, “sub-surface damage”, “surface properties”, and tool life”;
- The cluster-6 consist of 12 index-keywords such as “allot steel”, “cooling”, “cryogenics”, “difficult-to-cut materials”, “experiments”, “grinding (machining)”, “lubrication”, “process parameters”, “productivity”, “sintering”, “surface integrity”, and “titanium alloys”;
- Cluster-7 consist of three index keywords of “aluminium alloys”, “high speed machining”, and “speed”.

The tree plot of the foremost 30 index-keywords or keywords-plus used in SEC in machining operations documents is shown in Figure 13. The SEC in machining operations documents used the index keyword “specific cutting energy” 138 times and have 13% contribution in the top 30 index keywords. The index keyword “energy utilization” is used 81 times and contributes 7%, followed by “cutting tools” 76 times of 7% contribution. The index keywords “milling (machining)”, “cutting”, “surface roughness”, “machining”, “specific energy consumption” are utilized more than 50 times and have 5% or more contribution in the top 30 index keywords.

Similarly, as done for author or index-keywords, a tree plot of the top 30 title keywords is shown in Figure 14. For example, the SEC in machining operations documents used the title keyword “machining” 99 times and have 11% contribution in the top 30 title keywords. The title keyword “cutting” is used 96 times and contributes 11%, followed by “energy” 94 times with 11% contribution and “milling” 53 times and contributes 6%, followed by “specific”, “process”, and “consumption”.

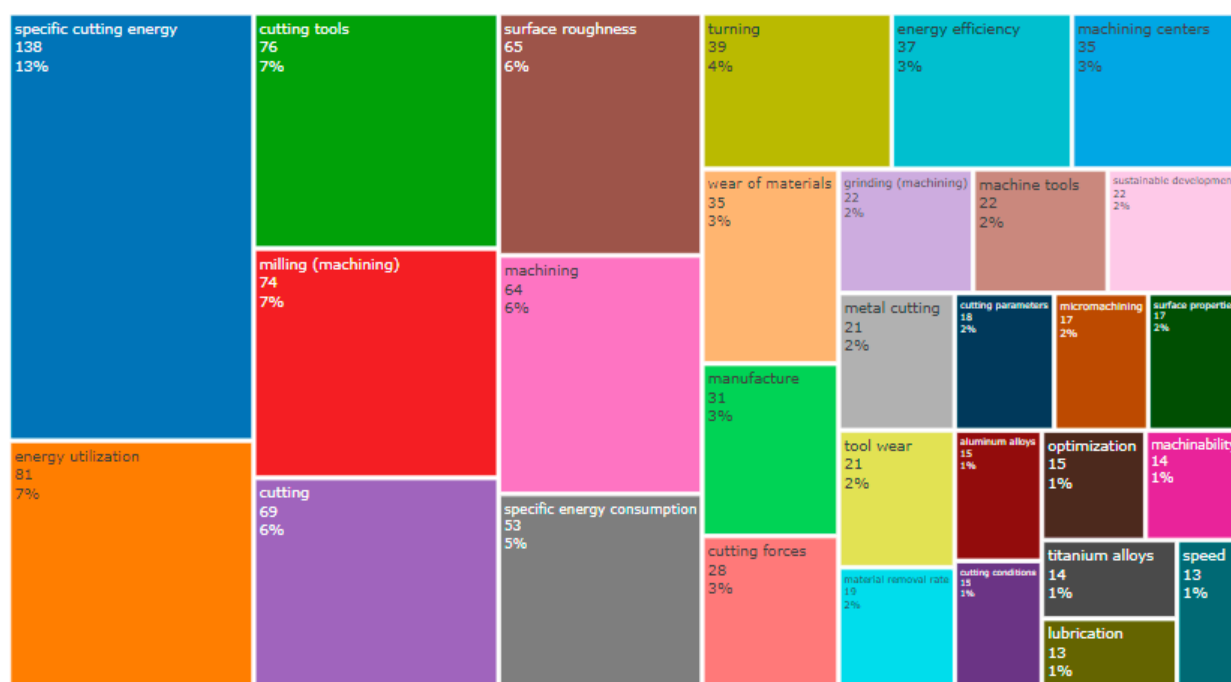


Figure 13. Tree plot of top-30 index keywords.

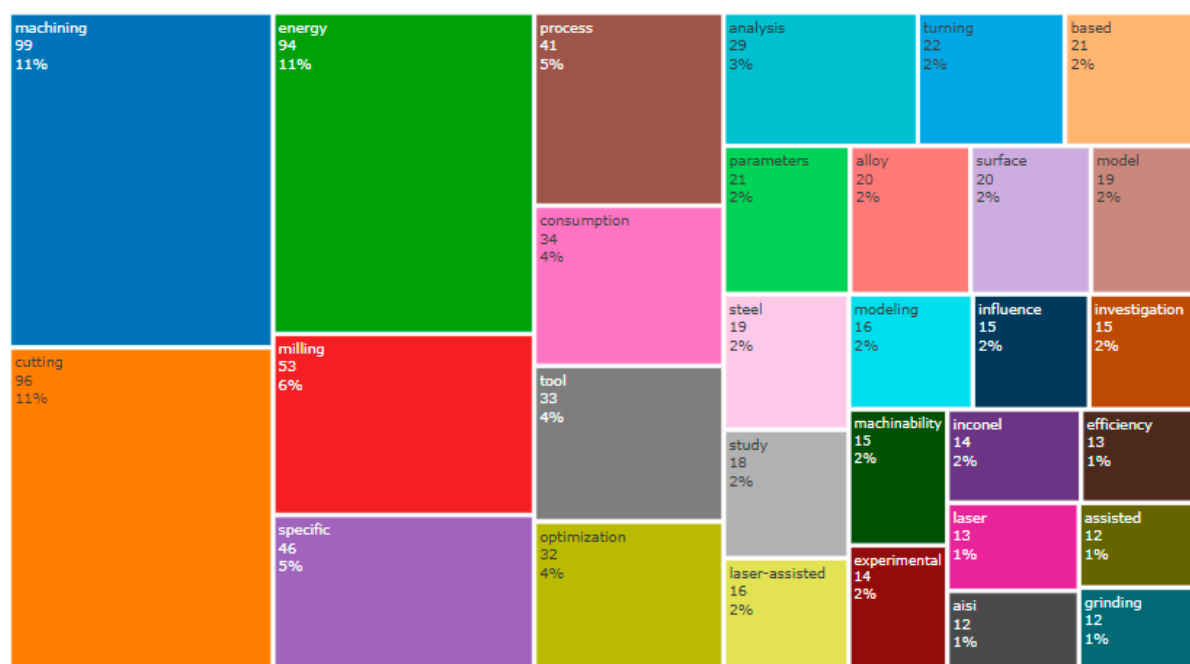


Figure 14. Tree plot of top-30 title words.

4.3. Text-Data Analysis by VOSviewer

The VOSviewer software 1.16.6 performs an exclusion procedure in a text-data analysis and computes each term's relevance score. In the text data extraction process, the words with a higher relevance score are inclined to signify explicit themes covered by the text information. The text-data extraction terms have a low relevance score incline to be general and do not represent any specific theme. An insufficient relevance score data extracted terms are sieved out, and the main focus on explicit and informative pieces. Around 40% of data extracted terms with low relevance score are excluded [45]. In a text-data analysis, the terms from the title and abstract of the document are extracted. The document's title

Table 8. Top 20 text-data terms based on an occurrence and relevance score.

Rank	Term	Occurrences	Relevance Score	Rank	Term	Occurrences	Relevance Score
1	Consumption	66	0.3804	1	Optimal combination	5	3.1753
2	Specific energy consumption	57	0.7001	2	RSM	7	2.9339
3	Optimization	46	0.9216	3	Response surface methodology	9	2.9264
4	Tool wear	45	0.5272	4	Multi objective optimization	9	2.8559
5	Machinability	43	0.4807	5	Taguchi	6	2.7537
6	Temperature	36	0.4222	6	Grey relational analysis	5	2.6301
7	Formation	31	0.3439	7	Material removal temperature	11	2.5555
8	Laser	31	1.4546	8	Mechanical machining process	5	2.3462
9	System	29	0.5531	9	Tool wear rate	5	2.3061
10	Machine	28	0.3554	10	Micro machining	6	2.2469
11	M min	25	0.4139	11	Laser assisted machining	13	2.2285
12	Response	24	1.1249	12	Taguchi method	11	2.0718
13	Machine tool	22	0.9897	13	Sustainable manufacture	5	1.9545
14	Machining parameter	22	0.7547	14	Genetic algorithm	8	1.927
15	Tool life	22	0.8989	15	Microstructure	11	1.7553
16	Chip thickness	20	0.7097	16	Conventional machining	17	1.7418
17	Improvement	20	0.5595	17	Sec	13	1.7309
18	Inconel	20	0.3357	18	Room temperature	7	1.7193
19	Manufacturing	20	0.6485	19	T6 alloy	5	1.7114
20	Modeling	20	0.66	20	Diamond tool	7	1.7006

4.4. Sankey Diagrams: Three Field Plots on SEC in Machining Operations

Sankey diagrams are conventionally utilized to represent the flow of energy or materials in several networks and procedures. They represent flows, associations, and their transition with quantitative details. Sankey diagrams reflect guided and weighted graphs with features of weight that fulfil flow preservation. At each node, the amount of the influx weights is identical to its outgoing consequences. The processes with Sankey diagrams are envisioned, and communications can be explored [67]. The three-field plot in Biblioshiny 2.0 is utilized to visually assess the relationship between sources, countries, affiliations, keyword, leading authors, cited source, and author-keywords, etc.

The diagrams of rectangular shape are used to represent pertinent elements with various colors. The rectangle's height indicates the relationship among multiple features such as countries, sources, prominent authors, and author-keywords, etc. The larger the size of the rectangle, means more relationships between various components.

Figure 16 shows the diagram for research in SEC in machining literature on the relation between author keyword (left), author (middle) and source (right). The analysis established that which SEC keywords in machining operations had used most frequently by different authors and journals. The study of the top keywords, authors and sources indicated that

there are keywords, i.e., “specific cutting energy”, “surface roughness”, “laser-assisted machining”, “energy efficiency”, and “tool wear”, and authors Shin Y.C., Iqbal A., Balogun V. A., Khan M., mainly used these keywords, published in sources such as International Journal of Advanced Manufacturing Technology, and Journal of Cleaner Production.

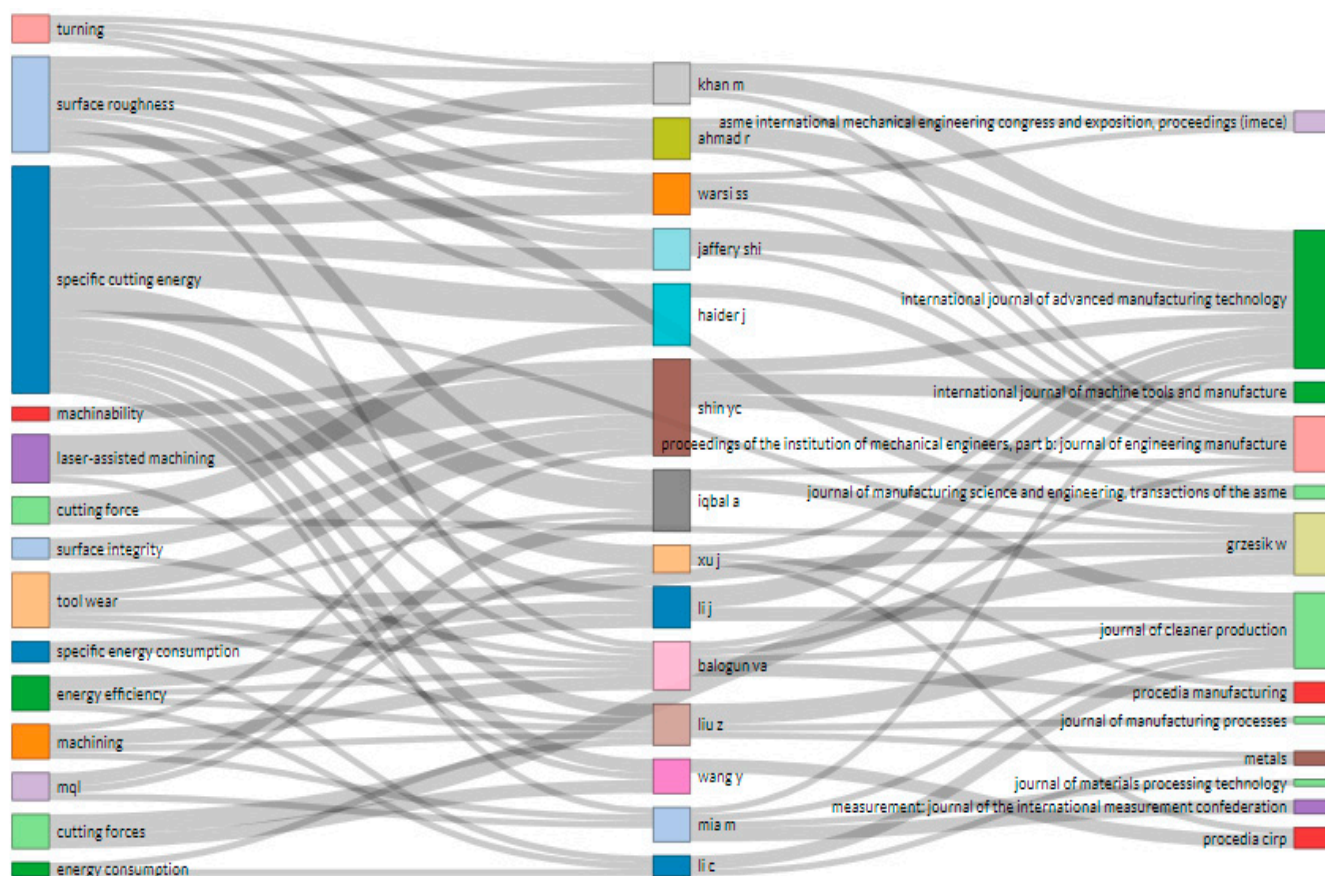


Figure 16. Three field plot author keyword (left), author (middle) and source (right).

Figure 17 shows the diagram for research in SEC literature in machining operations on the relation between index keyword or keyword-plus (left), author (middle), and source (right). The analysis established which keyword-plus of SEC literature in machining operations were used most frequently by different authors and journals published. The study of the top keyword-plus, authors and sources indicated that there were six keywords, i.e., “specific cutting energy”, “cutting” and “cutting tools”, “energy utilization”, “surface roughness”, “machining” and six authors Khan M., Ahmad R., Warsi S.S., Iqbal A., Liu Z., and Wang Y., published in source International Journal of Advanced Manufacturing Technology, and Journal of Cleaner Production.

Figure 18 shows the relationship between countries (left), author (middle) and source (right). It shows how different authors from various countries published in different journals. For example, it is revealed that the author’s Khan M., Ahmad R., Warsi S.S., and Jaffey Shi published their research in source International Journal of Advanced Manufacturing Technology. China is another major contributor, and their researcher published in different sources and in a similar way the USA, authors also published in different sources.

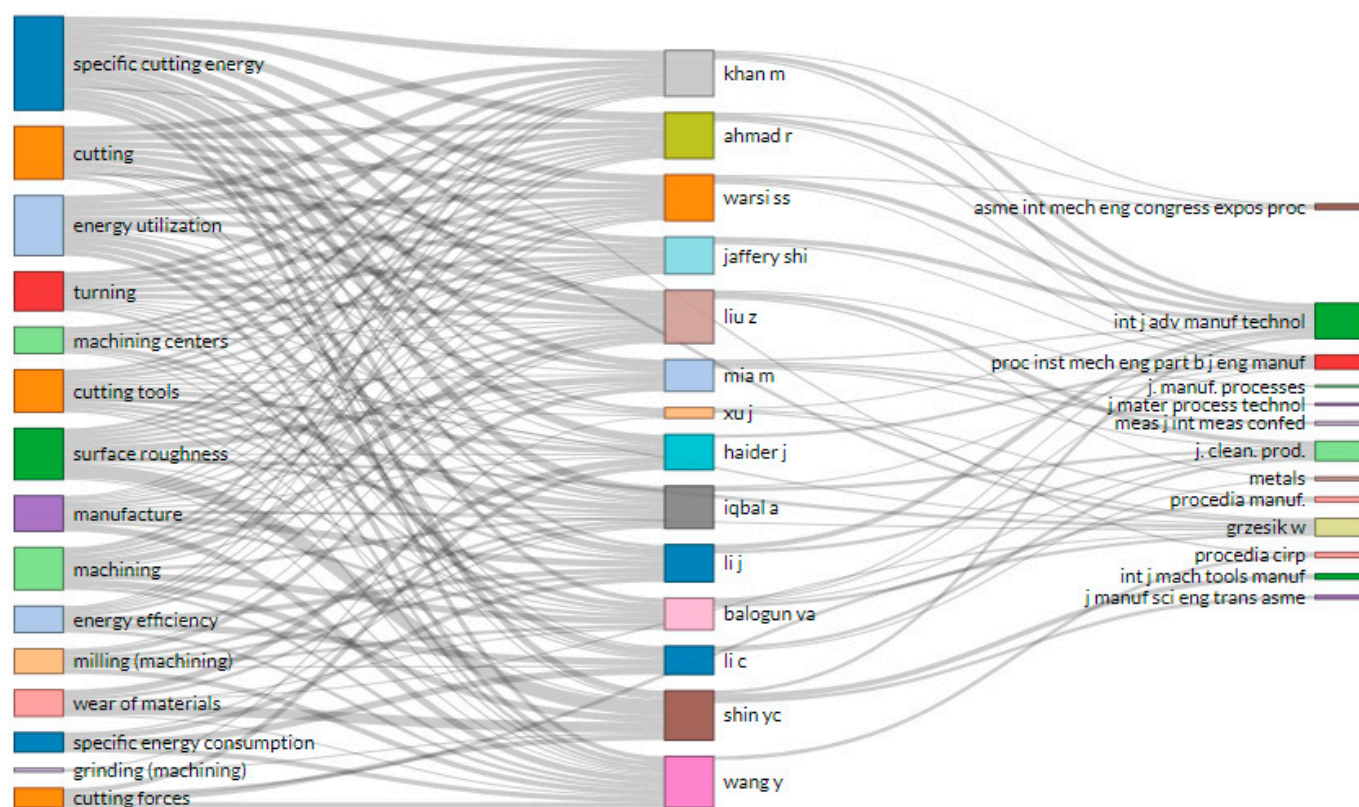


Figure 17. Three field plot index-keyword (left), author (middle) and source (right).

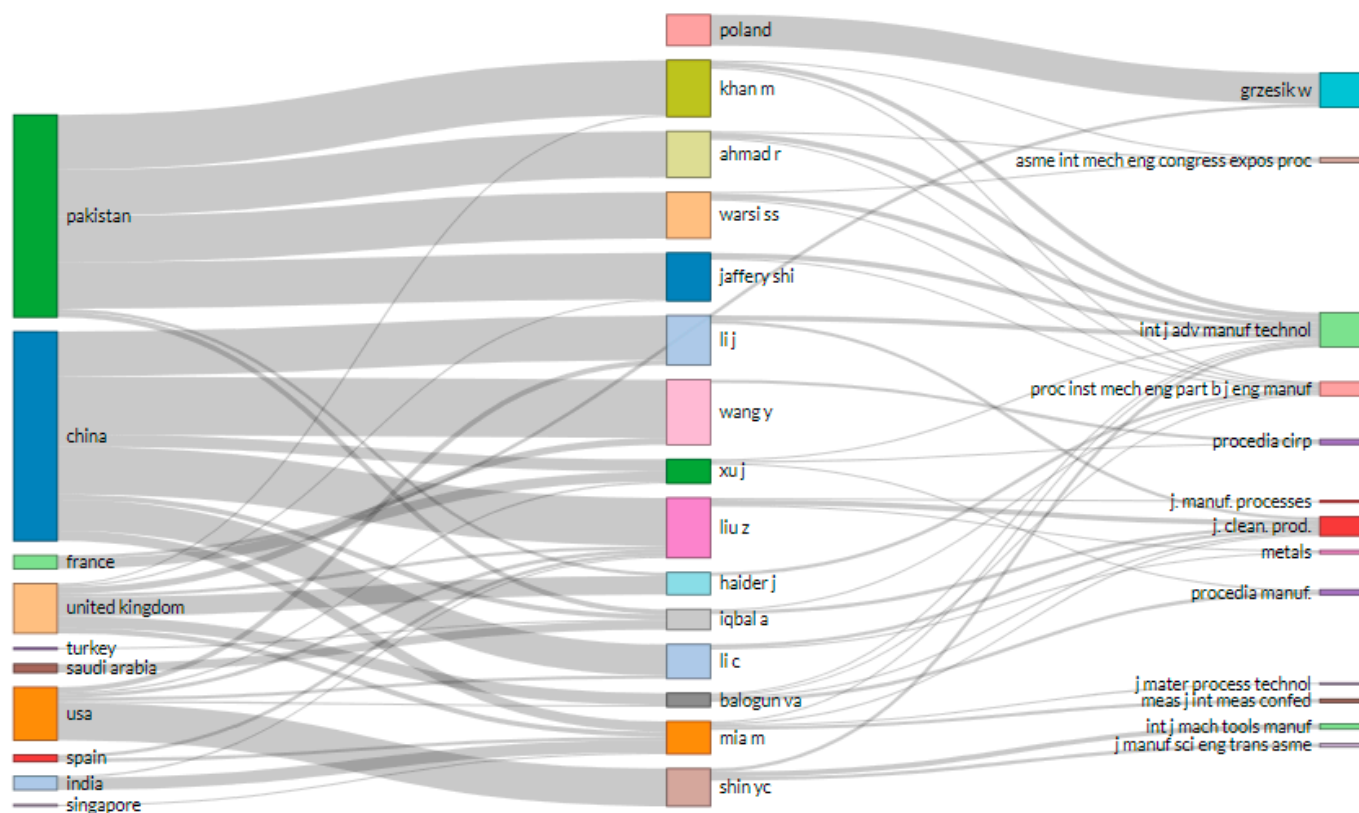


Figure 18. Three field plot countries (left), author (middle) and source (right).

Figure 19 shows the relationship between authors (left), title-terms (middle), and source (right). It shows authors Balogun VA, Wang Y, Liu Z, Khan M utilizing most frequently used title terms like Cutting, energy, machining, specific. Their works being published in journals like the International Journal of Advanced Manufacturing Technology, Journal of Cleaner Production, Procedia manufacturing.

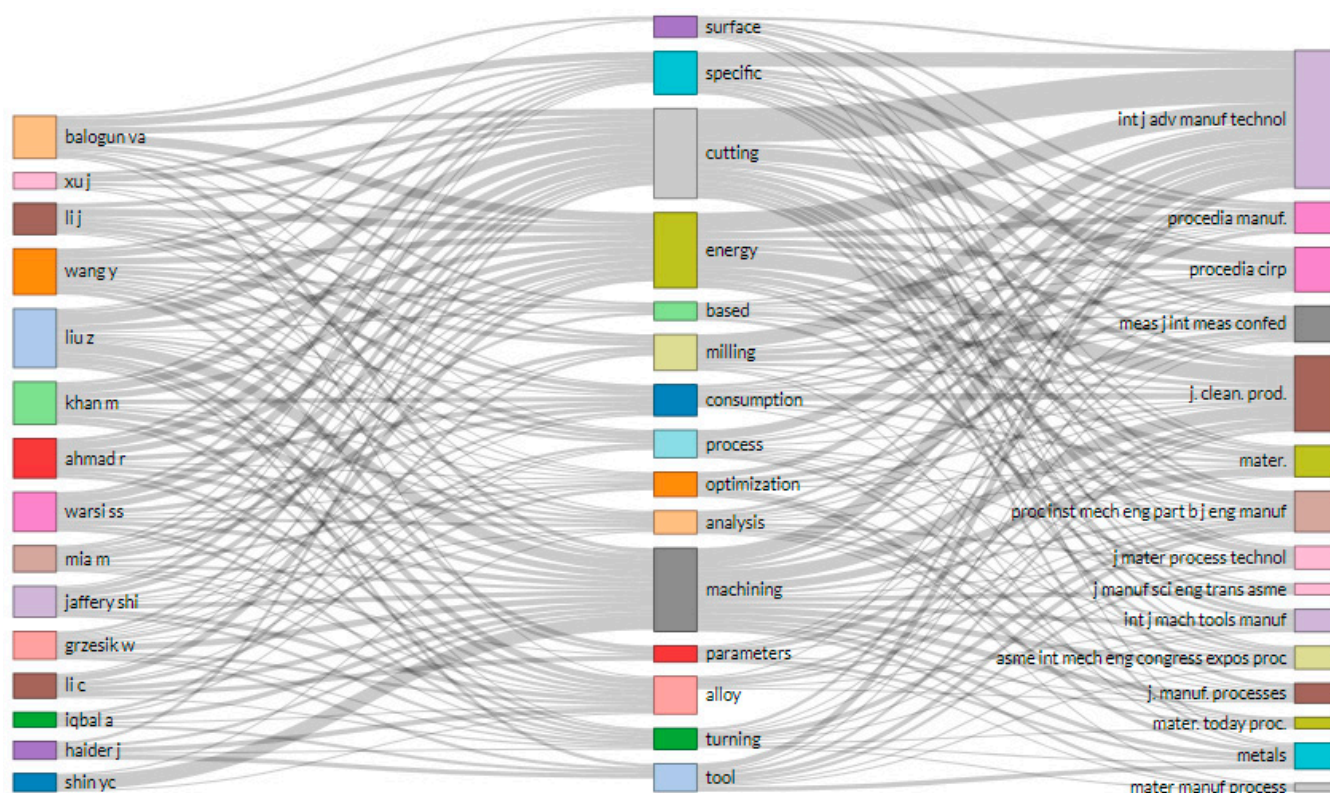


Figure 19. Three field plot authors (left), title-terms (middle), and source (right).

5. Thematic Areas and Research Hotspots of SEC in Machining Operations

5.1. Thematic Areas of SEC in Machining Operations from 2001 to 2020

The thematic areas belong to article classification, as shown in Figure 20. It is observed that the extent of knowledge of Engineering is the first one, with 217 articles of 43% and 69 articles with 14% belongs to Material Science, followed by Computer Science, with 62 papers and Physics and Astronomy 31 articles with 6% contribution. Varied classification of themes such as Business, Management, and Accounting, Decision Sciences, Energy, and so on have a contribution of around 5%.

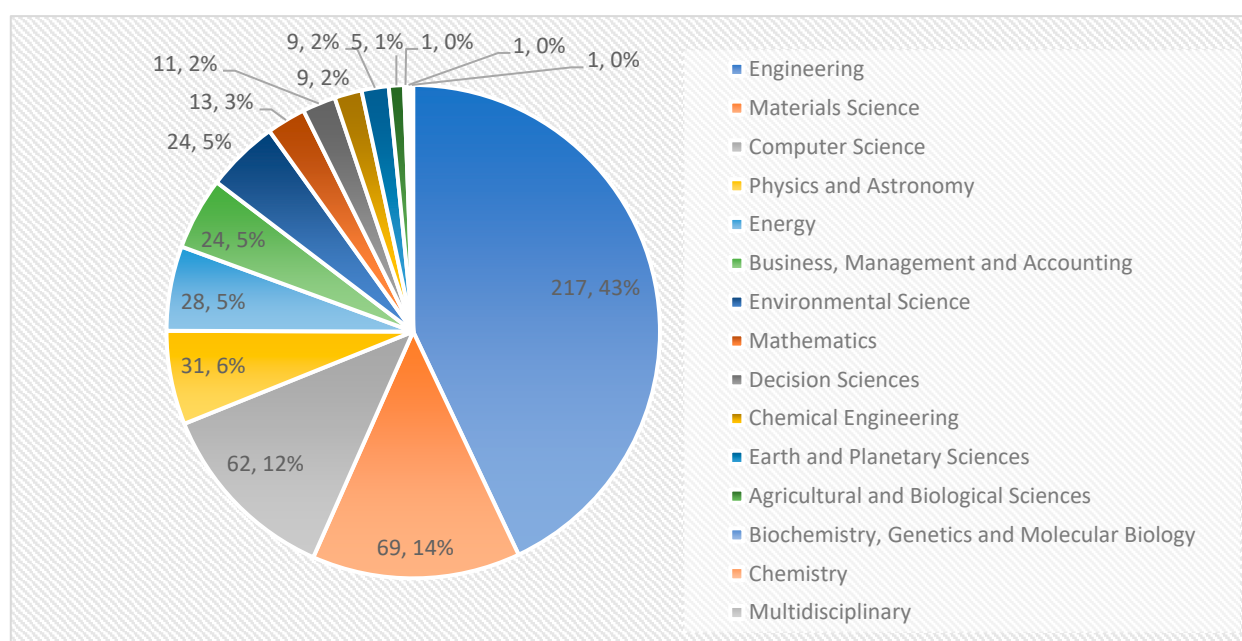


Figure 20. Classification of articles on thematic area.

5.2. Research Gaps and Hotspots

SEC publications in machining operations have become progressively popular in recent years. However, there are still many research gaps in the machining operations where SEC is anticipated to be addressed in subsequent years. The author's keyword network visualization based on co-occurrences from Figure 10 reveals that the machining operation laser-assisted milling has a smaller node size that signifies the occurrence frequency. The line between two nodes specifies that there is a co-occurrence association amid them, and the thickness of the lines directs the strength of co-occurrence. So, the laser-assisted milling operation was not investigated from the SEC viewpoint largely. It indicates that there exists a gap in the research while investigating SEC in laser-assisted milling operation.

Similarly, the other keywords signify the research gaps. For example, chip thickness, grooving, hard milling, micro-cutting, drilling, lubrication, and micromachining have smaller nodes, and the thickness of the lines refers to Figure 10. It indicates that more research needs to be conducted on "micro-cutting" and "micromachining", these two keywords have the same meaning, but researchers used them differently. SEC analysis needs to be addressed in these operations, such as drilling and hard milling, similarly chip thickness, grooving, and lubrication also have research gaps. Grooving also belongs to machining operation, chip thickness to output response and lubrication to input parameters. The SEC and surface roughness have a larger node size, indicating these two responses are investigated the maximum number of times in turning operation. The decision-making, response surface methodology, and optimization keywords smaller node size suggest that the blend of responses needs more inquiry. As temperature, force, cutting energy needs to consider while exploring SEC in machining operations. Electric discharge machining's process appears very little, and still, a gap exists in advanced or non-conventional machining operations. The slight use of keywords "decision making" and "optimization" indicates that a gap exists in decision-making methods and optimization of parameters while taking SEC as a response in machining operations. The aids of entropy weights methods in machining operation identified only two conventional turning papers that involve SEC in a multi-objective optimization model. However, the review identified 19 traditional and non-conventional machining operations [68]. This indicates a clear research gap of decision making and optimization in machining operations, considering SEC as

one of the sustainable machining response. More research work using decision-making techniques can be regarded as in SEC analysis [69–73].

Similarly, research hotspots can be identified from index keywords Figure 12. as it is scholarly articles' content and is picked from the pre-decided information. It is revealed that the machining operations of laser-assisted milling and laser-assisted machining have smaller node size. The output responses such as hardness, tool wear, cutting force need to be inspected alongside SEC. The smaller node size of the Taguchi method, ANOVA, and multi-objective optimization indicates that the minimum use of experiments and experiments is mainly designed based on conventional methods. The smaller node size of the index keyword "geometry" and "tool wear" states that tool geometry is not considered too much while designing experiments, and tool wear is a response parameter. Another smaller node size of the effective term "life cycle" reveals that the SEC was not considered while doing life cycle analysis of machining operations. So, for the life cycle analysis of machining operations, there is a necessity to consider SEC. Specific cutting energy, energy utilization, and surface roughness are dominating in milling operations. The content text analysis also indicates research gaps can be seen from Table 8 based on relevance score and occurrence.

5.3. Managerial Implications of the Review

The review has tried to bring out a new connotation to the emerging SEC concepts in machining operations. The SEC state of the art and bibliometric analysis is beneficial for engineering researchers, societies, and the industry. Legal restrictions and stricter emissions norms are forcing enterprises to adopt sustainable manufacturing norms. The recent review assists an engineer working in an enterprise to quickly identify the quantum of research already carried out in the field of concern. Moreover, the SEC depicts how much energy is used for manufacturing a unit of an item and is convenient to find the quantity of energy. Thus, SEC is one of the energy efficiency indicators and is a good measure able to meet the objective to diminish greenhouse gas emissions by 80–95% by 2050 compared to 1990 levels.

Furthermore, SEC is one of the approaches for energy benchmarking at the multi-national, national and regional, location, and process levels, most commonly utilized in process-level benchmarking [3]. The review identified the energy-intensive machining process. Therefore, the researcher, practitioner, or industry engineer can take benefit from the presented visualizations networks. Besides, it indicates the volume of research already conducted on that process. Thus, it immediately decides whether the topic of his concern is a hot spot where additional research is required, or the existing research data will suffice. The present bibliometric review and analysis have brought a new idea and aspect that earlier reviews might have ignored unknowingly.

6. Concluding Remarks

This paper aims to shed light on the research of specific energy consumption in machining operations. Furthermore, it offers a groundwork for imminent research. The exploration tactic directed the assortment of 268 documents from 2001 to 2020 in the Scopus repository. A systematic bibliometric analysis and visualization review is carried out to bridge the gap and identify the hot spots in research.

The citation analysis results revealed that the most productive and leading article on SEC in machining processes is by Anderson et al. (2006) [46] titled "Laser-assisted machining of Inconel 718 with an economic analysis" in "International Journal of Machine Tools and Manufacture". The most prolific and dominant source is the "International Journal of Machine Tools and Manufacture", followed by the "Journal of Cleaner Production". The author Shin Y.C. has the maximum number of citations and articles published in the SEC field. School of Mechanical Engineering, Purdue University, United States, emerges as the topmost organization. The most upstanding country is the United States of America, followed by China and then India.

The “specific cutting energy” emerges as an author keyword with a contribution of 19%, followed by “surface roughness.” The “specific cutting energy” also appears 138 times as an index keyword followed by “energy utilization” and “cutting tools”. The “Machining” has been used 99 times in the Title words, followed by “cutting” and “Energy.” The terms “consumption”, “specific energy consumption”, “optimization”, “tool wear”, and “machinability” appeared more than 40. The terms or words “optimal combination”, “RSM”, and “conventional machining” are top-ranked based on relevance score. The Shankey diagrams, the three-field plot presented a valuable relationship among authors, keyword, source, and countries.

The research hotspots indicate that the responses hardness, tool wear, cutting force need to be inspected together with SEC. The smaller node size of the Taguchi method, ANOVA, and multi-objective optimization indicates that the minimum use of experiments and experiments is mainly designed based on conventional methods. The study suggests that much research potential exists in the machining processes like laser-assisted milling, Electric discharge machining, hard milling, micro-cutting, drilling, micro-cutting, micromachining, grooving, chip thickness, lubrication. This research paper is a boon for a researcher willing to work in the field of SEC for machining operations. The network visualizations help to identify the research gaps termed Hotspots. Future research can be conducted in these areas, which allows the researcher to minimize the time spent determining the exact topic and field of the study.

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