Green manufacturing literature during three decades: A scientometric approach

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Abstract. The research aimed to map the global green manufacturing academic literature indexed by Scopus by using a scientometric approach and analysis was done by using the analysis search results service from Scopus and the VOSviewer application. The research data consisted of 1,386 academic literature published from 1993 to 2019 were obtained from the Scopus database. The results show that the most productive countries, research institutions, and individual researchers in green manufacturing literature were China; Chongqing University; and Liu, F. The most intensive subject areas and sources of publications in green manufacturing literature are engineering and the Applied Mechanics and Materials. There are six collaborative researchers' group patterns. The research proposes a convergence axis classification consisting of green manufacturing literature to characterize the body of knowledge generated from three decades of publications: machining, environment, sustainable development, energy, manufacture, computer science, and tools.

Keywords: green manufacturing issues, green manufacturing literatures, scientometric approach

1. Introduction

Green manufacturing is increasingly needed by industrial areas and society. More and more stakeholders are expecting entrepreneurial and business organizations to be more environmentally responsible concerning the work of their products and business processes [1] for more than a decade [2]. The evolution of manufacturing systems has a function in several internal and external factors. Industrial manufacturing systems are transformed into a new paradigm because of the need to excel through efficiency and current global awareness of environmental risks [3]. Current manufacturing conditions, changes in consumer behavior, increased ecological awareness, and rising energy prices are increasingly driving business decision-makers to prioritize the implementation of the green manufacturing concept [4]. Growing pressure is placed on businesses to recognize environmental concerns in certain manufacturing actions. Also, the need for optimizing their supply chain base. Various studies have sought to link performance with Green
manufacturing abilities including reducing emissions and handling the green supply chain. However, some companies still have difficulty developing supply chains and implementing green manufacturing [5].

Green manufacturing is growing rapidly as a solution for the sustainable manufacturing industry. This is because Green manufacturing covers the whole life cycle of the product, from concept design to environmentally sustainable and innocuous waste management. Thus, the industry is expected not to cause negative impacts or minimize risks to the environment with optimized resource use and waste management and emissions. 4R - reuse, reduce, recycle, remanufacture. Gradually embraced and welcomed around the nation as a model of development and sustainability [6]. Energy is money, time is money, and consumables are money. Producing the same commodity with less capital and/or energy is a successful money-making technique. To put it another way, productivity by waste management is both efficiency and money efficiency. Manufacturing processes and products generally produce a lot of waste. Green manufacturing as a strategy to reduce waste with material that can be decomposed [3]. Green manufacturing in the industrial area can be developed based on a sustainable entrepreneurial spirit.

Green manufacturing reflects a new manufacturing paradigm that combines a variety of green strategies including driving the critical success factors, principles, goals, and techniques in the form of technology and innovation to become more environmentally friendly [3]. Green manufacturing helps create goods that are economically feasible by reducing the social and environmental impacts [7]. Green manufacturing involves mechanisms that use inputs with the lowest impact on the environment possible [8]. Green manufacturing is also recognized as a mixture of initiatives, activities, and methods that potentially improve economic, environmental, social quality and contribute to the triple bottom line reduction of the impact of company operations [9]. Green manufacturing is necessary to ensure the non-hazardous and safe development of the product to have a minimum impact through the use of the best resources [10].

In general, the study of green manufacturing academic literature is limited to one research focus. One example of the results of a study by Abhijeet has been to measure the performance of green manufacturing in India with empirical investigations [11]. Green manufacturing research is generally limited to an institution [12], aspect [13], country [14], or within a period [15]. There is no academic literature on green manufacturing that shows the big picture visualized from year to year with data from all countries. Also, there is no academic literature in the field of green manufacturing that specifically discusses the relationship between affiliates, authors, the most cited, and the impact of their research. Therefore, the research aims to map the global green manufacturing academic literature indexed by Scopus using a scientometric approach.

2. Methodology

The research maps academic literature in the field of green manufacturing at the international level. Research data were obtained from the Scopus database using document search services in April 2020 with a scientometric approach [16]. Scientometrics is the study of the measurement and analysis of literature on research, science, and technology. Scientometrics is a Bibliometrics subfield [17]. Analysis and visualization of data using the analyze search results feature on the Scopus service and VOSViewer application [18]. VOSviewer tool was used to visualize and build bibliometric or scientometric networks, network visualization can be in the form of researchers, countries, academic affiliations, growth in the number of studies, keywords, author collaboration, and research that is the most cited [19]. The research identifies keywords related to green manufacturing to identify and search for related academic literature in the Scopus database with 1,386 academic literature documents published from 1993 to 2019 at the global level. The query command that is applied when mining data on Scopus is TITLE-ABS-KEY ("green manufacturing") AND (PUBYEAR <2020)). Theresearch limits data retrieval to 2019 without looking at 2020 (exclude 2020) so that the annual data obtained illustrates the condition of the publication of academic literature in one whole year from January to December.
The research conducts an analysis of co-authorship with units of analysis of authors and full counting methods using VOSViewer to get the author's collaboration network. It carries out an analysis of co-occurrence by analysing keywords and a full calculation method using VOSViewer to obtain a network of keywords.

3. Results and discussions

3.1 Most frequent country affiliation of green manufacturing literatures

Figure 1. Country Number of Green Manufacturing Per Year

Figure 1 presents the country that has the largest contribution in the academic literature in the field of green manufacturing was China with 520 documents. Followed by the United States with 192 documents, India with 165 documents, the United Kingdom with 58 documents, Taiwan with 54 documents, Malaysia with 46 documents, South Korea with 44 documents, Germany with 42 documents, Japan with 40 documents, Canada with 28 documents, Spain with 24 documents, France with 23 documents, Indonesia with 23 documents, Australia with 20 documents, and Brazil with 18 documents. Green manufacturing research in China drives the acceleration of the growth of the manufacturing industry.

3.2. Most frequent institution affiliation of green manufacturing literatures

Figure 2 shows the top 15 research institutions in the academic literature in the field of green manufacturing are Chongqing University with 59 documents. Then, followed by Wuhan University of Science and Technology with 46 documents, Chinese Ministry of Education with 27 documents, Birla Institute of Technology and Science, Pilani with 24 documents, Tsinghua University with 21 documents, Chinese Academy of Sciences with 20 documents, Nanjing University of Aeronautics and Astronautics with 18 documents, Huazhong University of Science and Technology with 17 documents, Northeastern University, China with 16 documents, The University of Texas at El Paso with 14 documents, Soochow University with 14 documents, Drexel University with 14 documents, University of California, Berkeley with 13 documents, Beihang University with 11 documents and Xi'an Jiaotong University with 11 documents. This shows that research institutions in China dominate green manufacturing publications.
3.3. Most individual authors of green manufacturing literatures

The author with the most academic literature publications in the field of Green Manufacturing is Liu, F., with 38 documents. Followed by Zhang, H., with 32 documents, Sangwan, KS, with 21 documents, Cao, H., with 20 documents, Mittal, VK, with 14 documents, Li, C., with 13 documents, Then, Chiou, R., with 11 documents, Jiang, Z., with 10 documents, Tseng, TLB, with 10 documents, He, Y., with 9 documents, Ray, A., with 9 documents, Shrivastava, RL, with 9 documents, Ahn, SH, with 8 documents, Xiao, M., with 8 documents and Zhao, G., with 8 documents. This shows that researchers in China dominate green manufacturing publications, as shown in Figure 3.
3.4. Most frequency of green manufacturing literatures by subject area

Figure 4. Most Frequency of Green Manufacturing Literatures by Subject Area

Figure 4 shows the most subject area in green manufacturing literature was Engineering with 999 documents (36.7%). Followed by Computer Science with 285 documents (10.5%), Business, Management and Accounting (10.3%) with 280 documents, Other (9.7%), Materials Science (9.0%) with 244 documents, Environmental Science (6.2%) with 170 documents, Energy (5.0%) with 137 documents, Decision Science (4.2%) with 115 documents, Mathematics (3.2%) with 86 documents, Physics and Astronomy (2.8%) with 75 documents, Chemical Engineering (2.5%) with 67 documents. Green manufacturing as part of manufacturing tends to be an engineering study.

3.5. Documents per year based on sources of green manufacturing literatures

Figure 5. Number of Documents Per Year Based on Sources of Green Manufacturing
The number of literature documents per year based on sources in academic literature in the field of green manufacturing was Applied Mechanics and Materials with 67 documents. Followed by the Journal of Cleaner Production with 52 documents, Advanced Materials Research with 51 documents, International Journal of Advanced Manufacturing Technology with 30 documents, Key Engineering Materials with 27 documents, International Journal of Precision Engineering and Manufacturing with 26 documents, Zhongguo Jixie Gongcheng China Mechanical Engineering with 25 documents and International Journal of Production Research with 23 documents, as presented in Figure 5.

3.6. Literature documents per year from green manufacturing literatures

![Number of Literature Documents Per Year from Green Manufacturing](image)

In general, the number of academic literature documents on green manufacturing has increased every year. This can be seen in Figure 6, the highest publication peak in 2019 with 177 documents. Academic literature on Green Manufacturing has been published since 1993. The number of documents per year in Green Manufacturing publications is in 2019 as many as 177 documents, in 2018 there were 144 documents, in 2017 there were 106 documents, in 2016 there were 109 documents and in 2015 there were 88 documents.

3.7. Literature document cited of green manufacturing literatures

The academic literature that has been published internationally in green manufacturing with the most citations as a form of academic impact was Maria-Magdalena Titirici, Robin J. White, Nicolas Brun, Vitaliy L. Budarin, Dang Sheng Su, Francisco del Monte, James H. Clark, and Mark J. MacLachlang titled Sustainable Carbon Materials in Chemical Society Reviews in 2015 cited 543 documents.

3.8. Map of literature themes

The construction of keyword networks for the literature themes map was compiled with the VOSViewer tool. The criterion for a minimum number of literature documents related to keywords was seven repetitions. Thus, from 8,869 keywords, 347 keywords met the thresholds. There were seven clusters of literature themes based on research keywords related to the field of green manufacturing literatures as presented in Figure 7.
1. Machining cluster (Red). This cluster is dominated by the keywords such as machining, grinding, milling, welding, cutting fluids, cutting forces, dry cutting, gear cutting, surface roughness, material removal rate, mechanical properties, yarn, energy, and cooling.

2. Environment cluster (Green). This cluster is dominated by the keywords such as green manufacturing, life cycle, environmental impact, green production, product design, green design, manufacturing process, engineering education, and ecodesign. Most of these keywords relate to the environment theme.

3. Sustainable development cluster (Dark Blue). This cluster is dominated by the keywords such as sustainable development, sustainability, decision making, environmental protection, environmental management, green supply chain management, human, supply chain, and green product. Most of these keywords relate to the sustainable development theme.

4. Energy cluster (Yellow). This cluster is dominated by the keywords such as energy consumption, energy efficiency, energy utilization, optimization, job shop scheduling, carbon emissions, costs, energy management, and reducing energy consumption. Most of these keywords relate to the energy theme.

5. Manufacture cluster (Orange). This cluster is dominated by the keywords such as manufacturing industries, sustainable manufacturing, lean manufacturing, lean production, agile manufacturing system, value stream mapping, and efficiency.

6. Computer science cluster (Purple). This cluster is dominated by the keywords such as simulation, computer simulation, decision support system, internet, internet of things, computer aided design, database system, fuzzy logic, industrial research, and key technologies. Most of these keywords relate to the computer science theme.

7. Tools cluster (Light Blue). This cluster is dominated by the keywords such as machine tools, planning, computer control system, index system, and evaluation index system. Most of these keywords relate to the tools theme.

Figure 7. Map of Literature Themes
3.9. Author collaboration networks
The criteria for the minimum number of literature documents per author were five literature documents. Thus, from 3,016 authors, 74 authors were found who met the thresholds. There was a collaborative pattern of six groups between researchers in the green manufacturing literature as shown in Figure 8.
1. Red Cluster: li, J., Chen J., Chen, Y., liu, Y., Xu, X., Huang, S., liu, Z., Wang, J., liu, L. and Wang, W.
2. Green Cluster: Zhang, H., Zhao, G., Jiang, Z.G., Xiao, M., Xiu, S., Wang, Y., Jiang, Z., Wang, X., Zhang, X., Yue, W. and Gao, D.
3. Light Blue Cluster: Zhang, Z., Jiang, G., Zhong, K.M., Zhang, C. and He, T.
4. Dark Blue Cluster: li, X. Gao, L., Li, Z., Li, L., Zhang, L., Zhou, Y., Xue, L., Wang, H., Liu, Q. and Li, Y. Cluster
4. Yellow Cluster: Wu, X., Wang, Z., Sun, L., Zheng, K., Yuan, C., Zhang, T. and Dornfeld, D.
5. Orange Cluster: Wu, J., Zhang Y., Li, B. and Zhou, M.
6. Purple Cluster: Reb, F., Tan, X., Liu, F. Li, C., Cao, H. and Wang, Q.

Figure 8. Author Collaboration Network

4. Conclusion
The results of the research showed that there were a map and an increasing trend in the number of academic literature in green manufacturing at the international level. The most productive countries, research institutions, and individual researchers in academic literature in the green economy were China with 520 documents, Chongqing University with 59 documents, and Liu, F. with 38 documents. The most intensive subject area in academic literature in green manufacturing was engineering with 999 documents (36.7%). The source of academic literature in green manufacturing with the highest number of documents was the Applied Mechanics and Materials with 67 documents. The highest academic literature in green
manufacturing was achieved in 2019 with 177 documents. There were six collaborative researchers' patterns in green manufacturing literature.

In terms of contributing implications to knowledge, the research proposes a convergence axis classification consisting of green manufacturing literature to characterize the body of knowledge generated from three decades of publications: machining, environment, sustainable development, energy, manufacture, computer science, and tools. As implications for practical, identifying key themes in the green manufacturing sector leads to understanding the development of publications to understand common topics and contexts, as well as the research gaps. With all of this, new studies can be led to address a lack of study and advance knowledge in the areas. The themes most researched also demonstrate green manufacturing contribution to environment and manufacturing practice.

Limitations of this research related to scientometric analysis tend to simplify the complexity of green manufacturing literature to provide a clear and simple picture. Also, researchers chose to limit the collection of data in the Scopus database because it provides a collection of papers with peer review, and can be extracted for scientometric studies. Green manufacturing keyword data mining is limited based on what appears in the title, abstract, and keywords in a manuscript.

The future opportunity for green manufacturing research is to analyze the contribution and impact of green manufacturing literature based on an integration of data obtained from Scopus, Web of Science, EBSCO, and SciELO.

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