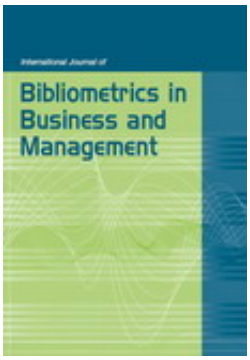

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Green manufacturing practices: a bibliometric and thematic analysis

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Green manufacturing practices: a bibliometric and thematic analysis

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Abstract: Green manufacturing provides cost-effective ways to address environmental concerns. This study discusses the significant facets and current practices of green manufacturing. Between 1995 and the early 2020s, a bibliometric analysis of 300 studies was conducted to identify research activity on green manufacturing practices. The data is then analysed using the bibliometrix R package. Our study employed scientific methods to comb through a large body of literature. To determine influence, we look for highly cited articles and authors. The paper examines the literature on current topics, impediments to literature growth, and potential future research areas. Green manufacturing has grown steadily. JCP and JMTM are the top contributing journals. Most influential authors in this field are Ramayah and Sarkis. Thematic analysis reveals the importance of emphasising 'green', 'performance', and 'sustainability' in research design. These findings can be used by educators, researchers, and stakeholders to promote green manufacturing.

Keywords: green manufacturing; practices; Scopus; bibliometric analysis; thematic analysis.

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1 Introduction

Environmental degradation, resource depletion, and population growth are serious problems facing the world, threatening human survival and development. The production of products using resources results in the release of harmful environmental pollutants. With the ever-increasing concerns regarding resource scarcity and environmental degradation, several initiatives are in place to promote green practices within the industrial sector (Yacob et al., 2019; Kumar et al., 2022a). The goal is to develop and promote sustainable manufacturing practices. Although manufacturing is essential for global economic growth, creating jobs, and generating wealth, it will continue to do so for years. Due to this, the integration of green practices in manufacturing has been a widely discussed topic in recent years (Pang and Zhang, 2019).

Green initiatives have become more common in the past decade. Environmental management systems, green supply chain practices, environmental accountability, and new circular economy practices can contribute to green industry policy implementation (Phurita and Chanathip, 2021). The term 'green manufacturing' (GM) refers to an emerging approach to production that embraces environmentally friendly practises in order to improve efficiency (Ariffin, 2015). GM, as described by Dornfeld et al. (2013), is a process or system that maximises sustainability and minimises environmental impact through the reuse of materials and the development of environmentally friendly new products. Deif (2011) said that GM is representative of a new manufacturing paradigm that incorporates a wide range of environmentally friendly tactics, drives, and procedures to maximise resource efficiency. GM incorporates green product design and green technology, and it must be explicitly implemented throughout the manufacturing process (Belhadi et al., 2020; Kumar et al., 2022b). Many firms have embraced GM adoption or are preparing to do so (Shohan et al., 2020; Gandhi et al., 2018; Ahmad and Wong, 2019; Roschangar et al., 2017).

The public is in agreement that we must take action to preserve our planet's natural resources; therefore, companies may boost their image by switching to environmentally friendly production methods. Through the introduction of more effective systems and the promotion of a company culture committed to innovation in procedures, this method may also save expenses for the firm over the long run. The trash that a company generates may also decrease as a result of these more effective procedures (Bass, 2017).

In contrast to the previous reviews, no bibliometric and thematic analysis of the expression 'GM practices', has yet to be conducted. Thus, through a bibliometric analysis, this paper aims to discover the current state of this field of research in times of

increased recognition of significant global challenges. Thus, the following research questions will be studied:

RQ1 What are the developments of GM practices articles?

RQ2 Which are the most well-known journals in this area and what impact factors do they have?

RQ3 Who are the most influential authors?

RQ4 Which institutions and countries have published more about the topic of GM practices, and what is a cooperation network between countries?

RQ5 What is the intellectual structure of this field of study?

RQ6 What is the common focus of this research among researchers in this field?

We used bibliometric network analysis to answer the questions mentioned above. Compared to traditional narrative reviews of the literature based on the researchers' knowledge, the bibliometric analysis provides an easily extended perspective from micro to macro levels (Wang et al., 2020). Bibliometric analysis is a highly effective technique for performing quantitative analyses of scientific results (Li et al., 2020). A bibliographic analysis is the most effective method for determining the conceptual structure of a field of study (Castriotta et al, 2019; Sharma et al., 2023).

The remainder of the paper is organised as follows: The current literature is defined in Section 2. The methodology flow is defined in Section 3. The results of our research are shown in Section 4. Section 5 discusses the essential findings and criticises them. Section 6 concludes with a study that considers present implications and proposes future paths for research.

2 Prelude to the literature review

The concept of GM first surfaced in the early 1990s, and its inception was motivated by human concerns over the natural environment (Rehman and Shrivastava, 2013). At first, GM was solely process-oriented, with the goal of minimising manufacturing waste. From then on the emphasis shifts to the finished product, with measures taken to conserve energy, water, and other natural resources. Within a very narrow context, GM is generally viewed as referring to the production of green products, like those utilised in renewable energy systems and equipment for clean technology (Sharma et al., 2021). However, in a much broader context, GM is commonly thought of as being about implementing green strategies, like waste and resource reduction strategies (Pang and Zang, 2019). While the concept is indeed challenging in a broad sense, it is still universal in application. Indeed, green products include those manufactured using environmentally friendly manufacturing processes (Shrivastava and Shrivastava, 2017). The existing research usually focuses on the whole concept of the greening of manufacturing processes. In an economic sense, 'GM' strives to reduce or eliminate the negative impacts of 'externalities' on the environment. GM practises are considered an advantage for companies (Afum et al., 2020).

Herva et al. (2008) created a technique to assess the environmental impact of a cotton jacket manufacturing plant in continuation of their GM experiments. Deif (2011) offered

a GM system model. The model shows plans for a greener, more eco-efficient manufacturing process. The methodology developed by Bigliardi and Bottani (2012) suggests that enterprises' GM practises may be validated based on their strategic aims, behaviour towards stakeholder demands, and stakeholder interests. Rehman and Shrivastava (2013) analysed the GM literature review research in adequate depth in 2013. They concluded that research on GM was divided into distinct sections. GM incorporates a comprehensive set of processes into all company activities with an environmental impact. Shrivastava et al. (2013) verified the GM framework for sustainable development in the Indian steel sector. The research described the company's GM implementation strategy and its impact on organisational performance. Mittal and Sangwan (2014) identified and ranked motivations or motivators for industrial GM implementation. It was determined that government incentives and firm GM policies may help industries implement GM. Arulrajah et al. (2016) provided an insight that urges academics to evaluate the human component of a company to determine whether or not it engages in green practises.

Due to the success factors and technical and management concerns, there have been several attempts to put it in place. In the last few years, GM has emerged and encompasses all stages of the product life cycle, from the design to the end-use phases (Digalwar et al., 2017). It refers to the specifics of manufacturing activities that do not harm the environment, such as recycling, conservation, waste management, environmental protection, regulatory enforcement, and pollution control, among others (Seth et al., 2016). Green practices are essential in almost all manufacturing activities (Pathak et al., 2021).

2.1 Research gap

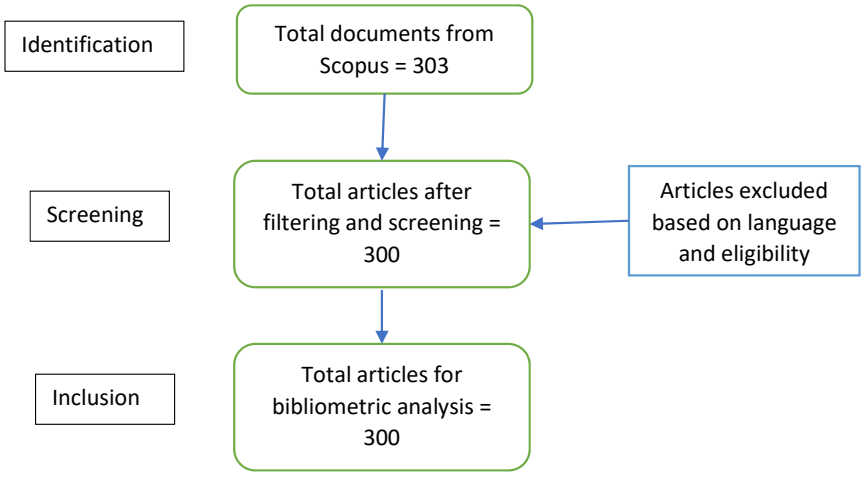
Much scientific research has been done on GM. Researchers have performed many detailed reviews and surveys on GM. The review papers provide the basic terminology, theoretical foundations, definitions, and methodologies (Rehman and Shrivastava, 2013; Paul et al., 2014; Shrivastava and Shrivastava, 2017). Setyaningsih et al. (2018) performed bibliometric analysis using Google Scholar. The study has two significant limitations: one, the approach is based mainly on a small sample of keywords, and two, the analysis is based on only a small sample of articles (76).

To fill the aforementioned research gap, this study used a bibliometric analysis of SCOPUS to determine the present condition of this field of study in an era of heightened awareness of critical global concerns.

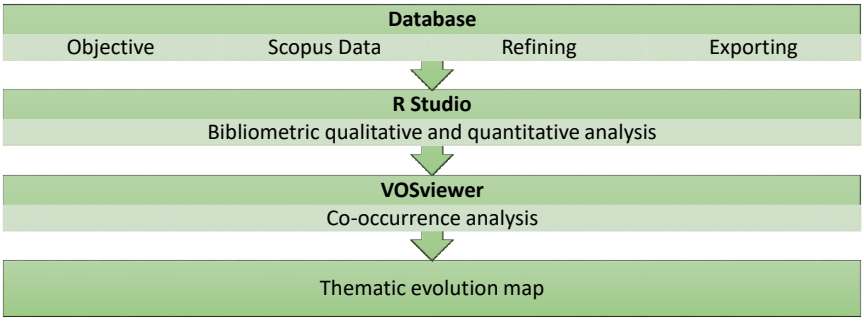
3 Method

The first step in the bibliometric analysis is to identify databases that help the study (Albort-Morant and Ribeiro-Soriano, 2016). This article is based on information taken from the Scopus database as of December 30, 2020. The Scopus database has been used as the most comprehensive citation and literature search abstract source and the highest searchable citation resource (Chadegani et al., 2013). Scopus's coverage is 60% more than that of Web of Science (Zhao and Strotmann, 2015).

Figure 1 (a) Search flow diagram (b) Analysis flowchart (see online version for colours)



(a)



(b)

The theme 'GM practices' consists of two terms – 'GM' and 'practices.' To ensure both terms are included in the results, we searched the two terms separately. The first included all possible keywords associated with GM, while the second included all practices associated with keywords. Finally, our search string was [('GM' Or 'Sustainability') and ('Practices' Or 'Implementation' Or 'Application')]. This search produced a total of 303 documents. Next, the non-English languages were removed. Finally, for bibliographic analysis, a set of 300 papers was obtained. Our analysis is based on an emerging and continuously evolving field of research; therefore, we have focused on all references in the database, including peer-reviewed journal articles and conferences. We began the analysis by retrieving relevant bibliometric qualitative and quantitative data, such as articles written, authors, citations, country of origin, or keywords, using a statistical package available on R-Studio (Aria and Cuccurullo, 2017). Bibliometix is an R-based package for bibliometric analysis. R is an ecosystem program, which means it functions in a unified setting provided by a collection of open-source components, including open-source libraries, algorithms, and graphics programs. Figure 1(a) shows the Scopus database search flow diagram, and Figure 1(b) shows the analysis flow chart followed by the authors.

4 Analysis and findings

Data from the Scopus database was used to examine publication trends by year, country, journal, contributor, and organisation, using total publications in GM practises.

4.1 Descriptive analysis

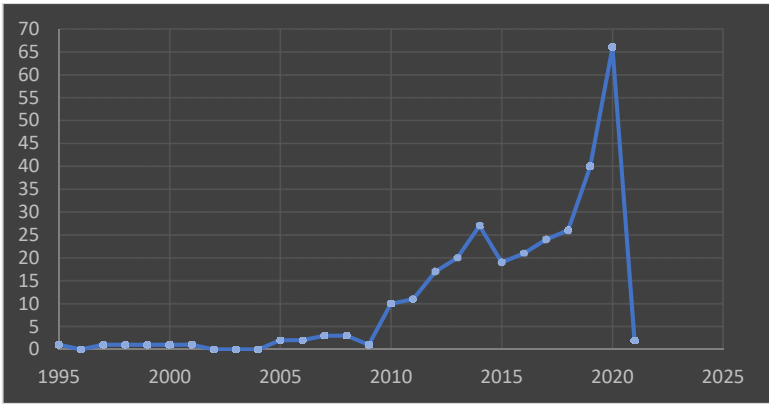
Figure 2 depicts the annual publication trend. The articles identified spanned the years 1995 to 2020. Publications began to become systematic only in 2010; the number of publications also grew consistently and steadily. According to Nag (2019) article, investment in GM is the most significant advantage for industry. Machines and equipment are becoming much more energy-efficient and can permanently affect the bottom line of a manufacturer.

Table 1 Main data information summary

Variables	
Source (journal, conferences, etc.)	191
Articles	300
Average years from publication	5.2
Average citations per documents	23.03
Average citations per year per document	3.43
Documents contents	
Keywords plus (ID)	1473
Author's keywords (DE)	774
Authors	
Authors	793
Authors of single-authored documents	30
Authors of multi-authored documents	763
Authors collaborations	
Single-authored documents	52
Documents per author	0.382
Authors per document	2.62
Co-authors per documents	3.18
Collaboration index	3.04

A total of 300 research articles published in 191 different sources by 793 authors. The average number of publications per year is 5.2, and the average number of citations per document is 23.03. The average number of citations per document is 3.43. Also, there have been 1473 keywords and 774 of the author's words found so far. Finally, the collaboration index is 3.04 according to the number of authors per document, which is around 2.62. This data can be seen in Table 1.

Figure 2 Year wise publication (see online version for colours)



4.2 Sources

The top 12 journals contributing to this field of research are shown in Table 2; each contribution is at least four articles. The *Journal of Cleaner Production* is the field's leading contributor, with 25 articles and 1349 citations. In addition, the *Journal of Manufacturing Technology Management*, listed second in the list, included ten articles and 154 citations. 85 articles out of the total set of 300 are included in the top 12 journals. Numerous journals have contributed to this area on a sporadic basis.

Table 2 Top contributing journals

Journal	*Articles*	*H-Index*	*Citations*
Journal of Cleaner Production	25	18	1,349
Journal of Manufacturing Technology Management	10	6	154
Applied Mechanics and Materials	6	1	4
Benchmarking	6	5	69
International Journal of Production Research	6	5	757
International Journal of Supply Chain Management	6	2	25
International Journal of Production Economics	5	5	205
Lecture Notes in Mechanical Engineering	5	0	0
Clean Technologies and Environmental Policy	4	3	71
IOP Conference Series: Materials Science and Engineering	4	1	1
Supply Chain Management	4	4	620
Sustainability (Switzerland)	4	2	6

Figure 3 shows the development of sources in the field. The chart depicts the number of documents published by 12 of the most abundant sources over the 1995–2020 time period. The scientific community has hailed the *Journal of Cleaner Production* for containing an increased number of publications. New researchers who employ GM practices are more likely to publish in *The Journal of Cleaner Production*, as demonstrated by the publication of approximately four related papers in 2020. Some

more sources, such as the *Journal of Manufacturing Technology Management* and the *Lecture Notes in Mechanical Engineering*, have developed rapidly since 2013.

Figure 3 Annual occurrences (see online version for colours)

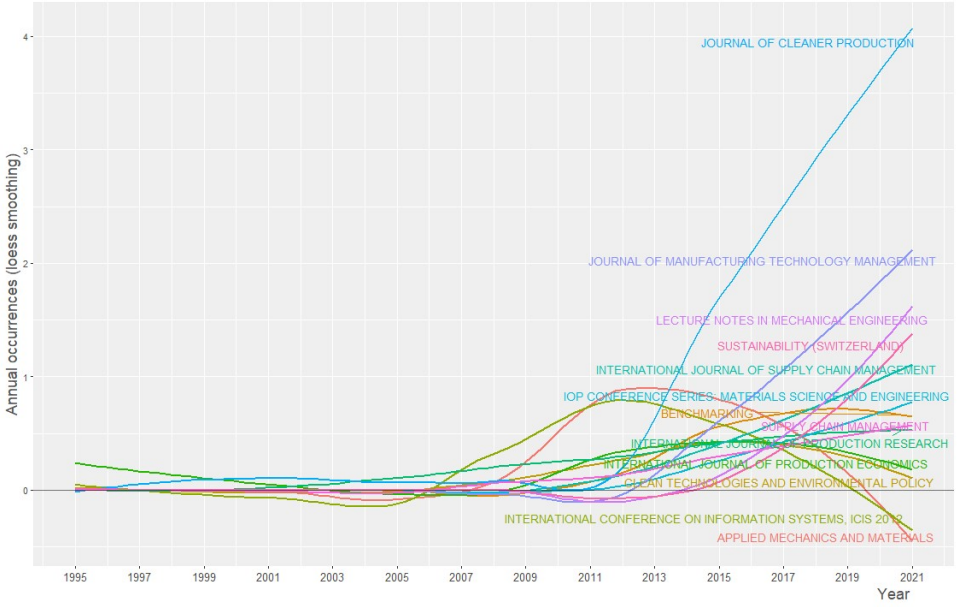


Table 3 Top productive authors

Author	*Articles*	*H-index*	*Citations*	*First article year*
Ramayah, T.	6	3	25	2012
Sarkis, J.	6	6	616	2008
Geng, Y.	5	5	632	2008
Zhu, Q.	5	5	786	2008
Ali, S.M.	4	2	13	2020
Govindan, K.	4	4	312	2014
Green, K.W.	4	4	96	2015
Kumar, P.	4	4	316	2015
Lai, K-H.	4	4	639	2008
Mangla, S.K.	4	4	339	2015
Shrivastava, R.L.	4	2	59	2011
Zailani, S.	4	4	43	2010
Zelbst, P.J.	4	4	729	2012

4.3 Authors

Table 3 represents the top 13 authors contributing to this research area, with an average of four articles each. Ramayah and Sarkis have published the highest number of articles

(6). According to the authors who have the most significant number of citations, Zhu and Zelbst respectively have the highest numbers of citations, with 786 and 729.

Figure 4 emphasises the connections among primary authors, their countries, and their sources. The analysis determined which sources were most commonly emphasised by GM authors.

Figure 4 Three field plots for relationship between journals, writers, and countries (see online version for colours)

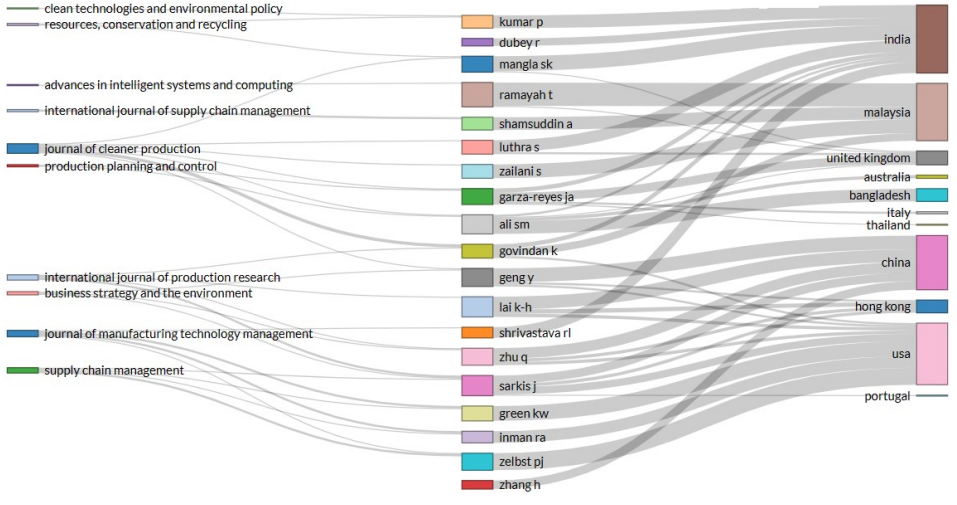


Table 4 Publications by institutions

Institutions	*Articles*
International Space University	37
Universiti Sains Malaysia	13
Universiti Teknikal Malaysia Melaka	13
Indian Institute of Technology	11
University of Malaya	11
Bangladesh University of Engineering and Technology	10
Universiti Teknologi Malaysia	10
Universiti Tunku Abdul Rahman	10

4.4 Institutions

A total of 290 institutions have published articles on this topic. The institution shall mean the one with which the researcher is affiliated at the time of publication of the article. We excluded the author affiliations to see which institutions are the top contributors. Table 4 depicts the top accounting institutions that publish ten or more papers. The International Space University, France, is the leading contributor to the university, with 37 articles, followed by the Universiti Sains Malaysia and the Universiti Teknikal Malaysia Melaka, with 13 articles each. Next on the list are the Indian Institute of Technology in India and

the University of Malaya. A university must have active authors in order to have the most affiliations. The other institutions typically have only nine or fewer articles.

4.5 Countries

From a total of 32 countries, researchers have published at least one article on this topic. Figure 4 illustrates the scientific collaboration network of the top 17 countries in this research field. The size of the coloured lines and the strength of international cooperation between connecting countries are shown. India, which ranks as the most productive country, had 183 published documents. The UK and Denmark collaborate mainly on these publications. Malaysia was ranked second overall with 143 papers submitted. The USA and China collaborate on a significant number of publications. The different colours in Figure 5 show the different research areas internationally developed through cooperation. After this analysis, we can conclude that two main country clusters exist: 'India, Malaysia, the UK, Denmark' and 'China, the USA, Hong Kong'. The two smaller clusters at the bottom right represent 'Australia, Bangladesh', and 'Sweden, France, Spain'. These professional networks help researchers around the world establish more collaborations with colleagues and sources of funding. The country collaboration map is located in Figure 6.

Figure 5 Network structure of top 17 countries collaboration (see online version for colours)

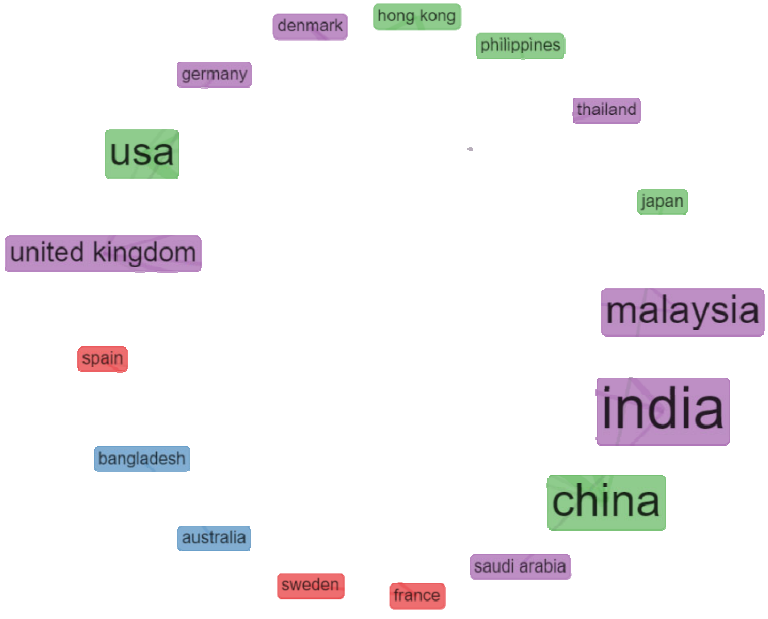


Figure 7 illustrates the number of multiple and single publications. Countries were culled based on the author's nationality. There are 17 articles indicated by corresponding Indian authors, including four multi-country publications (MCPs) and 13 single-country publications (SCPs). The corresponding authors of Malaysia have 12 articles with five MCPs and seven SCPs. The corresponding American authors have 11 articles with two MCPs and nine SCPs. The corresponding Chinese author has ten articles with seven

MCPs and three SCPs. Figure 7 shows that authors inscribe most documents published in peer-reviewed journals from the same country, which betokens that authors frequently collaborate with their national peers.

Figure 6 Country collaboration map (see online version for colours)

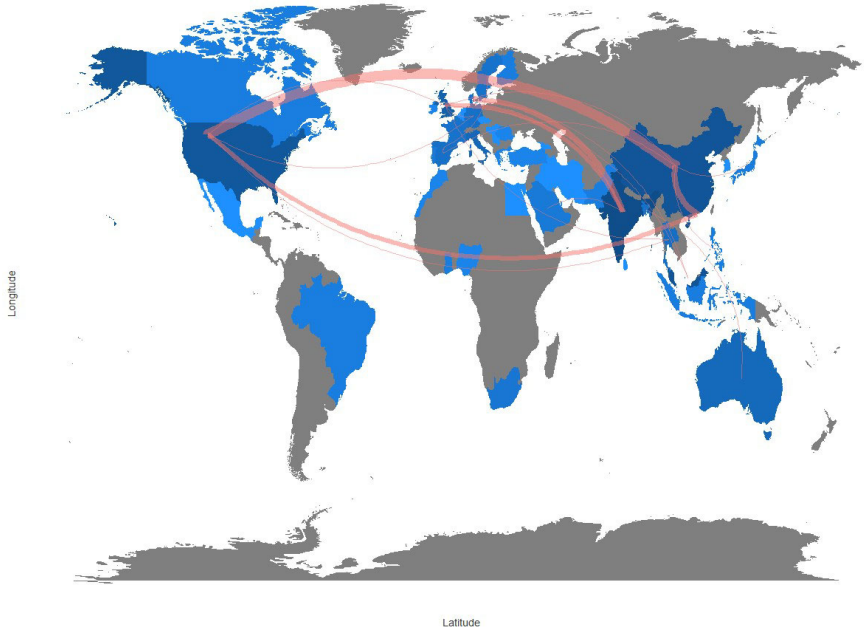


Figure 7 Multiple country publication and single country publication by corresponding author's countries (see online version for colours)

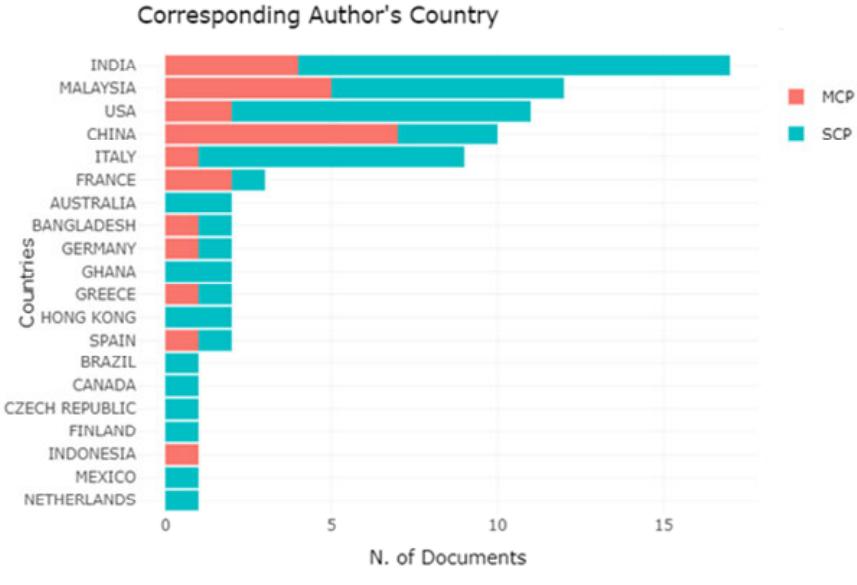
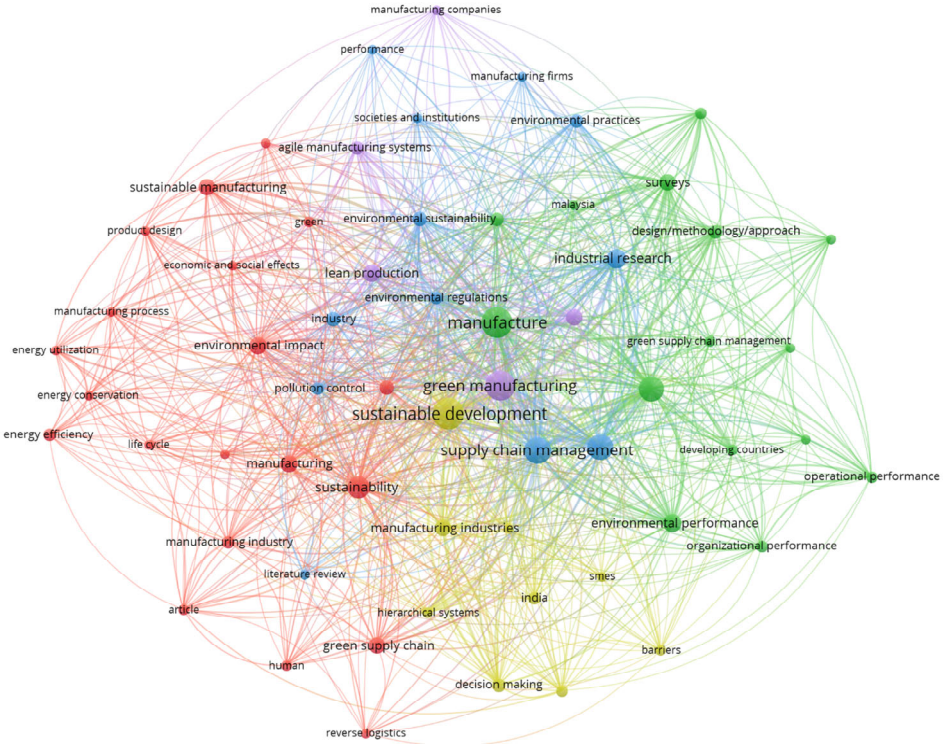


Figure 8 Co-word networks (see online version for colours)



4.6 Co-word analysis

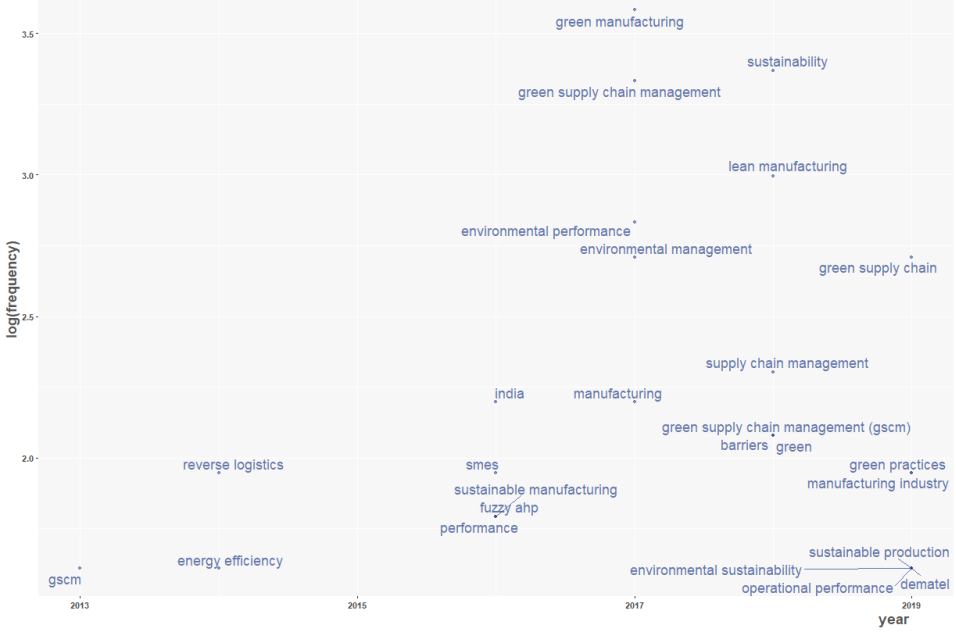
The co-occurrence of keywords is analysed with the help of a network analysis performed with VOSviewer. The minimum occurrence keyword is set for seven occurrences. Sixty-one meet the threshold. A total of five clusters of 61 keywords are finalised. A total of 20 keywords are found in cluster 1. In which 'sustainability' is the main keyword with maximum node strengths. A total of 15 keywords are found in cluster 2. In which 'manufacturing' is mainly used keyword with the maximum strength of the nodes. A total of 12 keywords are found in cluster 3. In which 'Supply chain management' is mostly used keyword with the maximum strength of the nodes. A total of nine keywords are found in cluster 4. In which 'sustainable development' is mostly used as a keyword with the maximum strength of the nodes. A total of five keywords are found in cluster 5. In which 'GM' is mostly used as a keyword with the maximum strength of the nodes. The relationship between the keywords is shown in Figure 8. Also, the occurrence of keywords is identified. 'Sustainable development' is found to have a maximum keyword occurrence with 68 occurrences, followed by 'GM' (65), 'supply chain management' (54), and 'Environmental management' (46). The cluster I keywords have been given more attention in this field of research.

4.7 Trends and thematic analysis

Examining the text's thematic evolution enables one to identify the conceptual subdomains of the text (Cobo et al., 2011). There are various themes discussed in this field of study, and these can be interpreted as semantics /conceptual classes (Aparicio et al., 2019). This section encourages the study of topics related to the general thematic field.

Figure 9 shows an example of the trending topics based on keywords plus. These are words or phrases that frequently appear in the references to an article's title but not in the title itself. Keywords plus is just as powerful as the author keywords in the bibliometric study (Zhang et al., 2016). Figure 9 shows that there has been a change in the trend of issues in the analysed period; in 2013 and 2014, researchers focused their studies on green supply chain management, energy efficiency, and reverse logistics; from 2015 to 2017, they focused on environmental management and performance; and recently, they focused on environmental sustainability, GM practices, green supply chain, and lean and sustainability in GM practices.

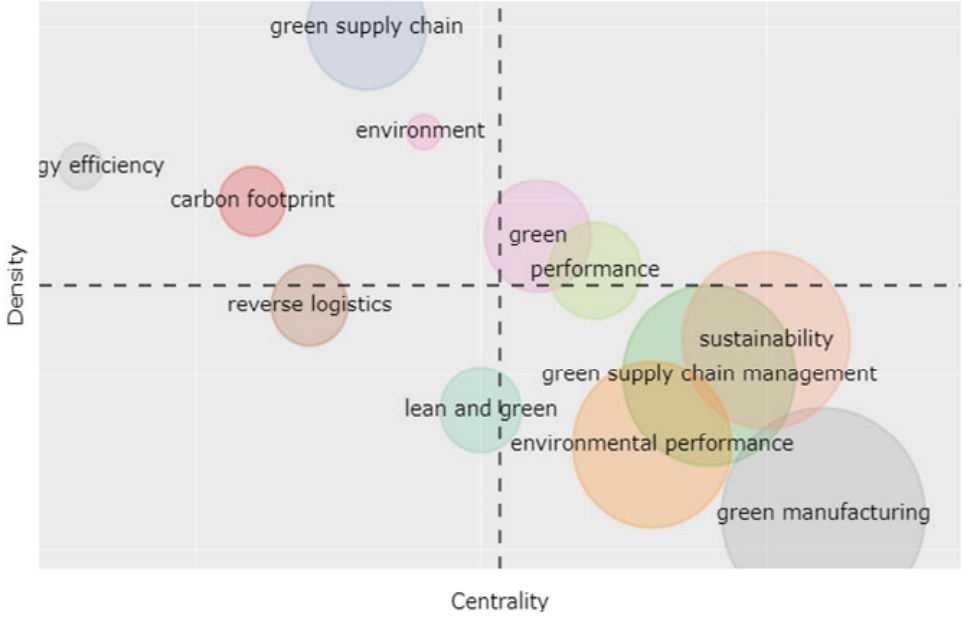
Figure 9 Trend topics (see online version for colours)



Lastly, the strategic field diagram is presented (see Figure 10). This thematic map shows the two-dimensional space in which the axes illustrate each keyword. The scale of the points is proportional to the cumulative input for each keyword. Centrality can be regarded as the focus theme of the field, and density is a measure of how the theme grows in the field. The size of the spheres is the number of occurrences of these keywords. The first quadrant (upper-right) is a motor theme; the second quadrant (upper-left) is a very specialised theme; the third quadrant (lower-left) appears or disappears; and the fourth quadrant (lower-right) is a basic theme.

Themes in the fourth quadrant will provide valuable insights into this research. These general themes are appearing in this quadrant, including 'GM', 'environmental performance', 'green supply chain management', 'sustainability'. Themes in the third quadrant are weakly developed and marginal, mainly representing emerging or vanishing themes. 'Lean and green' can be seen as emerging themes due to its centrality. The 'reverse logistic' theme occupied a position between emerging themes and isolated themes. Themes in the second quadrant, such as the 'carbon footprint,' and the 'green supply chain', have well-developed internal ties but few external ties. However, they are an insignificant aspect of the field. 'Environment', due to its centrality and density, will become the focus of various motor themes in the future. 'Green' and 'performance' are themes in the first quadrant that are both relevant and well developed for structuring this field of research. The analysis of themes demonstrates that a better focus on combining research with 'green' and 'performance' with 'sustainability' will improve results.

Figure 10 Thematic map (see online version for colours)



5 Discussion

The purpose of the study was to investigate the authors, citations, journals, and topics. Some intriguing issues were ascertained. We summarised this study and discussed the findings cognate to the six research questions.

The analysis revealed the publication trends in this research area. We picked out prominent authors and journals through bibliometric analysis. Citations show the trend of a research area and the top papers in the area. Co-citation network analysis and content analysis found the ascendant areas of research in the field.

From analysing this study on the six research questions, the following conclusions can be drawn for each question:

1 The descriptive analysis has reinforced the trends in publishing in this field. It can be assumed that the growth and expansion of GM practices have been consistent over time. In the past decade, we have seen an increase in the number of published papers. 2019 and 2020 are essential in this field. In general, the amount of academic documents pertaining to GM has grown annually. This may be observed in Figure 2, which depicts a publication peak of 66 documents in 2020, compared to 40 in 2019. Green and sustainable development is the focus of the scientific world (Secinaro et al., 2021). In the last ten years, this could explain the increase in the number of publications.

2 We examined journal contribution and influence and discovered that the *Journal of Cleaner Production* is the leading contributor in this field with 25 articles, followed by the *Journal of Manufacturing Technology Management* with ten articles. The impact factor of the *Journal of Cleaner Production* is 7.246, and the impact factor of the *Journal of Manufacturing Technology Management* is 3.385 (as provided on the journal home page). The impact factor is used to rank journals in their fields and assess the frequency with which the 'average article' in a journal gets cited. The *Journal of Cleaner Production* is widely considered the most productive and important leading publication in the field of GM (Pei et al., 2021).

3 According to an author-by-author analysis, Ramayah and Sarkis are the most influential authors in this field, each contributing the most papers (6). Zhu and Zelbst are the authors with the highest number of citations.

4 A total of 290 institutions have published articles on this subject. The International Space University, France, is the leading contributor to the university, with 37 articles, followed by Universiti Sains Malaysia and Universiti Teknikal Malaysia Melaka, with 13 articles each.

   According to the country, India has published the most publications in this field (183) compared to all other countries. The papers have mostly collaborated with the UK and Denmark. With collaboration pathways in mind, we can see that the USA and China have a tremendous amount of joint research.

5 Keyword analysis allows us to see the main research trends in a journal, as keywords can reflect where the authors focus their work (Liu et al., 2012). There are five main clusters in the word clouds. It is found that 'sustainable development' has 68 occurrences, followed by 'gm' (65), 'supply chain management' (54), and 'environmental management' (46). Most of the keywords have few links because they are published in fewer publications that deal with diverse themes of the analysed issue, however, the terms 'GM' and 'sustainable manufacturing' have the greatest linkage network. GM contributes to higher manufacturing efficiency and better product results. It is also noted that GM has close ties to sustainable development. Sustainable development is a most important focus, and may benefit from the use of GM.

6 The theme of this research is 'GM', 'environmental performance', 'green supply chain management', and 'sustainability.' There are long-established research studies in this area. The thematic analysis reveals the need to focus on 'green', 'performance', and 'sustainability' in research design.

6 Conclusions

The study of GM practises is gaining popularity over time. The study provides a detailed bibliometric analysis based on Scopus database publications on GM Practices. In this study, we used network analysis, content analysis, and keyword analysis to investigate the key questions. Because no such rigorous analysis has been conducted in this sector, our study adds significantly to the body of knowledge about GM practises. Setyaningsih et al. (2018) analysed Google Scholar citations. The study has two major drawbacks: the technique relies on a tiny sample of keywords, and the analysis was based on a short sample of articles (76). This paper offers a novel approach to this field of study. This research is unique since it combines bibliometric and thematic analysis to examine GM practises. We examined the flow of discoveries in this field to identify the main themes. The study has some limitations. In the future, a larger number of academic journals will be required to analyse the GM across all discipline journals, including the results of this study, in order to establish more specific rankings of journals, academics, academic institutions, and countries.

This research will lay the groundwork for understanding GM research, its current state, and the direction it is heading from an application standpoint. We propose the following research topics for the future.

1 This analysis revealed a dearth of industry-specific studies and cross-industry comparisons. Thus, researchers need to conduct industry-specific studies. Additionally, GM practices that work in one industrial context may not work in another and require modification. Cross-sector comparison studies can assist in determining whether adjustments are required.

2 Relatively few empirical studies have been conducted on GM practices; however, appropriate theoretical frameworks for future research are needed to guide future studies.

3 In the industry of GM, there are complex considerations that must be considered regarding the development of emerging technologies.

4 The development of new technology in the Industry 4.0 age will affect applied research and GM principles, methods, and system design. There needs to be more attention given to this issue.

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