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Review

Sustainable manufacturing. Bibliometrics and content analysis

Yogesh Bhatt [a], Karminder Ghuman [a], Amandeep Dhir [b, c, d, *]

[a] LM Thapar School of Management, Thapar Institute of Engineering and Technology, (Deemed to be University), Dera Bassi, District Mohali, Punjab, 140507, India
[b] School of Business and Management, Lappeenranta University of Technology, Lappeenranta, Finland
[c] Turku School of Economics, University of Turku, Finland
[d] Optentia Research Focus Area, North-West University, South Africa

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A B S T R A C T

Businesses have practiced and examined lean and green manufacturing principles for the last 25 years, but the sustainability challenges that we face today are still significantly potent. This context creates a need to critically examine the research and practice in this domain to determine the gaps and propose solutions. To achieve that, we applied a two-tier analysis constituting bibliometric and content analyses for developing the intellectual structure of sustainable manufacturing (SM) literature. The study also produced a comprehensive framework to provide a granular understanding of SM literature. The framework demonstrates different paradigms of SM literature as well as the conceptual and methodological advancement of the research frontiers in the domain. The outcomes of the research comprise implications for researchers, managers, and policymakers. The study concludes that most empirical work focuses on the relationship of lean and green practices with organizational and environmental performance, but the role and criticality of sustainability are significantly underrepresented in SM literature. Based on our findings, we call for the integration of sustainability principles, that is, sustainable development goals (SDGs), circular economy, life cycle engineering, and corporate sustainability assessment with SM research.

Contents

* Corresponding author. School of Business and Management, LUT university, Lappeenranta, Finland.
E-mail addresses: ybhatt_phd18@thapar.edu (Y. Bhatt), karminder@thapar.edu (K. Ghuman), amandeep.dhir@lut.fi (A. Dhir).

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1. Introduction

The research on sustainable manufacturing (SM) is gaining increasing attention with environment-friendly companies discovering higher potential to not only lower costs but also to boost overall performance through improved products (Nidumolu et al., 2009). A relatively recent study with 30,000 participants in 60 economies suggests that millennials are willing to spend extra for the products and services offered by firms committed to sustainability issues (The Nielsen Company, 2015). SM refers to the process of developing products and services by incorporating sustainable economic and environmental practices (Akbar and Irohara, 2018). SM deals with conservation of energy and natural resources (Akbar and Irohara, 2018) and ensures the safety and well-being of all stakeholders while producing products and services of desired quality (Jawahir et al., 2013). SM is different from traditional manufacturing in that it is considered more holistic and comprehensive in its approach, while the latter is primarily concerned with either the economic or value-creation perspective (Stark et al., 2017).

The existing literature has used lean and green manufacturing as synonyms to SM. However, these terms have certain similarities and contrasts. Lean and green manufacturing both focus on stakeholder engagement within the organization and supply chain, reducing or optimizing waste and process lead time, key performance indicators and similar techniques and methods for implementation (Dües et al., 2013). However, lean and green manufacturing also differ from each other; for instance, they consider waste in different ways (Dües et al., 2013). Therefore, lean manufacturing can be considered as a subset of SM because SM focuses not only on environment-friendly manufacturing but also includes social responsibility in its broader horizon (Joung et al., 2012). Furthermore, SM insists on simultaneous attention to all three dimensions of sustainability (people, planet, and profit) (Ren et al., 2015).

With reference to literature on the nexus between sustainability and manufacturing, extant literature reviews have examined various perspectives. This includes SM (Eslami et al., 2019; Gbededo and Liyanage, 2018; Gbededo et al., 2018; Lee et al., 2019; Zarte et al., 2019), green manufacturing (Pang and Zhang, 2019; Paul et al., 2014; Shrivastava and Shrivastava, 2017), environmental sustainability assessment methods (Brundage et al., 2018), technological application perspectives for SM (Garetti and Taisch, 2012), and design for SM (Ahmad et al., 2018; Kishawy et al., 2018). These review studies mostly adopted qualitative approaches for analyzing existing literature, and, thus, fell short in depicting a holistic paradigm of the research domain (Pang and Zhang, 2019). Scholars have made attempts to analyze the knowledge structures pertaining to the nexus between sustainability and manufacturing by employing qualitative as well as bibliometric analysis methods (Pang and Zhang, 2019). However, recent literature has also emphasized that there is a dearth of holistic approaches for examining SM literature (Gbededo et al., 2018). To the best of our understanding, not many studies combine the qualitative as well as quantitative methods for linking the seminal works in the field of SM. This is necessary in order to demonstrate the evolution of SM literature. Consequently, there is an urgent need to critically examine the research and practice conducted so far in the SM domain to determine their limitations and thereby propose the way forward.

To fill this gap, we employed a two-tier analysis consisting of bibliometric and content analyses. The current study outlined the intellectual structure of SM literature comprising different paradigms, and the dominant logic, emphasis and limitations for each paradigm. Furthermore, we developed a comprehensive framework based on the insights of the present study. The two important research questions (RQs) which came up for exploration in the study are as follows:

RQ1: What is the intellectual structure of SM literature?
RQ2: In which direction should SM literature as a domain evolve in order to contribute toward meeting the different sustainability challenges?

The three main value additions of the current study are: (a) It is one of the early endeavors that deploys quantitative tools for developing the intellectual structure of SM literature. The cocitation analysis, similarity indexing, exploratory factor analysis (EFA) and subsequent content analysis resulted in the identification of six paradigms that illustrate the intellectual structure of the domain of research. The six different paradigms identified through this study are capability development for environmental performance, lean principles and environmental management, environmental management and firm performance, lean and green integration, green supply chain management (GrSCM), and sustainability. (b) The study links these six paradigms to six different predominant logics that shaped and influenced the research and practice in each of these paradigms. Furthermore, it describes in detail the approach, emphasis and limitations associated with each of these paradigms of SM literature. (c) The present study also identifies the gaps and limitations in the existing literature and makes pertinent recommendations for future research in the domain of SM. (d) This study develops a comprehensive framework on SM, which organizes the disparate literature into an intellectual structure of the field.

The remaining article is structured in six sections. Section 2 briefly describes the existing review studies on SM. Section 3 describes in detail the research methods employed for the study. Section 4 comprises three subsections, with Section 4.1 discussing the six identified paradigms in detail, followed by a discussion on gaps and limitations in Section 4.2 and direction for future research in Section 4.3. Section 5 proposes a comprehensive framework for SM literature, followed by Section 6, where the conclusion, theoretical, and practical implications and limitations are discussed.

2. Review studies on sustainable manufacturing

The review of the prior literature on SM suggests that scholars have conducted several review studies on SM, green and clean manufacturing, and lean and green practices. Some of these literature review studies are discussed here.

2.1. Sustainable manufacturing

In the SM context, our survey analyzed the eight existing review studies. To begin with, Gbededo et al. (2018) presented a review of SM studies published between 2006 and 2015 and proposed a simulation-based analytical framework on life cycle sustainability analysis. Gbededo and Liyanage (2018) reviewed prior literature and attempted to integrate the community dimension in sustainability analysis by applying the concepts of socio-economic reciprocation, along with motivation and social exchange theories.

Eslami et al. (2019) discussed the various dimensions of sustainability and further explored the environmental dimensions in combination with manufacturing for understanding the domain of SM. Similarly, Lee et al. (2019) analyzed the extant SM literature to understand the growth trajectory of the field and proposed that in the age of the digital revolution, the nature of SM is expected to change. Zarte et al. (2019) reviewed the SM literature with reference to decision support systems (DSS) on all three dimensions of sustainability. The study also observed that existing DSS are concentrated toward synchronization of the three dimensions of sustainability. Further, the study also observed that at the operational level, decisions are broadly guided by either environmental or economic dimensions.

In addition to the five review studies in the context of mainstream SM, three additional reviews studied the technological application and design for SM. Garetti and Taisch (2012) reviewed the trends and challenges of SM and classified the research into four clusters. Kishawy et al. (2018) studied SM with reference to conceptualization, execution sequence and evaluation techniques. Their study further suggested five stages for achieving an effective sustainable system, namely the development of standard operating procedures, optimized processes, replacement with sustainable raw material, adoption of clean technology and development of environment-friendly product design. Similarly, Ahmad et al. (2018) analyzed the literature on design tools for product development. Their study categorized the tools based on the dimensions of sustainability incorporated into them. It suggested that most of these tools are rooted in a life cycle perspective. The study further observed tools incorporating all three dimensions of sustainability were less mature as compared to tools with one or two dimensions incorporated.

2.2. Green and clean manufacturing

We examined a total of four review studies in this context. Paul et al. (2014) performed a literature review to explore the meaning, significance and approach toward green manufacturing. The study also analyzed concepts such as SM, environment management techniques, and GrSCM. Vieira and Amaral (2016) identified the strengths and weaknesses of methodologies, tools, and regulations related to clean manufacturing and the barriers and strategies to overcome them. Hole and Hole (2018) analyzed the functions of production, consumption, and recycling in the textile sector and observed a low level of recycling and consumer awareness, which impacted sustainability in the sector. The most recent of all, Pang and Zhang (2019) employed bibliometric methods to analyze SM literature from the perspective of green manufacturing. This study provided a general cartography of green manufacturing literature and stratified the extant literature under the three headings of application, organization, and system. It also analyzed the evolution of literature in this domain of research.

2.3. Lean and green integration

In this category we considered a total of seven review studies. Initially, Garza-Reyes (2015) developed a conceptual outline of the lean and green research and highlighted its various dimensions. Hartini and Ciptomulyono (2015) analyzed the interrelation, linkage, and effect of lean and green SM on firm performance. Hallam and Contreras (2016) identified 13 parameters and used these parameters to develop a management model to integrate the lean and green practices with firm performance. Caldera et al. (2017) identified the synergies emerging from the application of lean and green interventions, while Cherrafi et al. (2017) identified drivers of management concepts (such as lean, six sigma, and sustainability), pinpointed their impact on these management concepts and highlighted the integration barriers. Ciccullo et al. (2018) identified lean, agile, and sustainable practices and integrated them with a sustainable supply chain paradigm. Finally, Brundage et al. (2018) focused on the assessment methods. Their study analyzed various environmental sustainability assessment methods to provide a better understanding of design at an early stage of product development using learnings from specific phases of the product life cycle.

3. Methodology

We undertook a two-tier analysis comprising bibliometric and content analyses to develop the intellectual structure of SM literature. Bibliometric analysis is a popular research method that enables scholars to examine the past and future growth of scientific work (Di Stefano et al., 2010; Olk and Griffith, 2004; Schildt et al., 2006). Content analysis is a qualitative method that researchers utilize for extracting the insights of a study and its objectives (Williamson et al., 2013).

The present study included content analysis to investigate the dominant logic, approach, emphasis, and limitations of the six dimensions that emerged from quantitative analysis of the existing research studies on SM. The associated bibliometric analysis used a well-defined protocol (see Fig. 1), which begins by defining a topic of intellectual interest and then follows four sequential steps to provide directions for advancing research on the topic in future.

3.1. Selection of studies

The current study utilized the Web of Science (WOS) database for data collection and screening of the peer-reviewed journal articles. Researchers use the WOS database extensively for

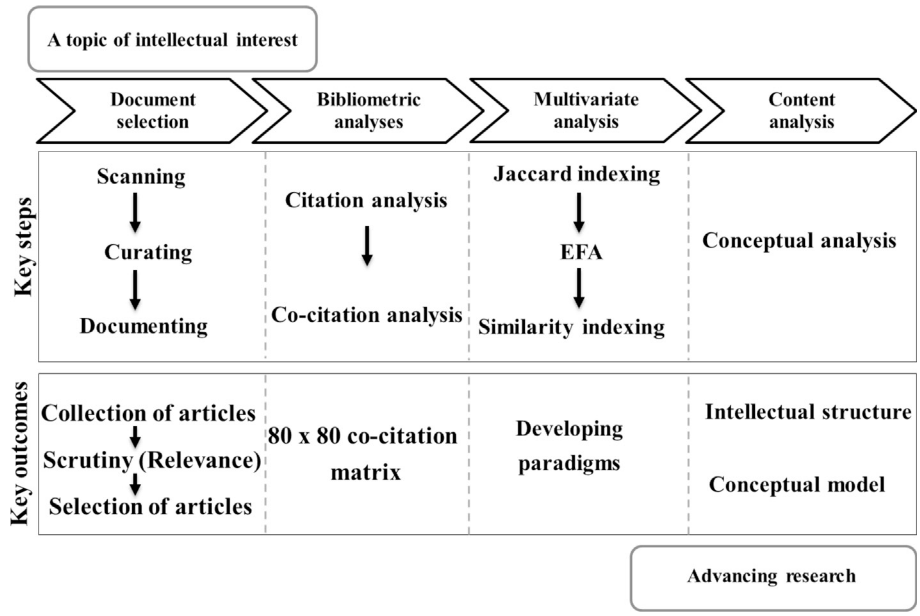

Fig. 1. Protocol for a bibliometric study.

bibliometric analysis as it offers various benefits for undertaking such studies (Ferreira et al., 2014). The study collected peer-reviewed journal articles indexed in the Social Sciences Citation Index (SSCI) of the WOS database. Scholars have utilized a similar approach in other bibliometric-based studies (e.g., Hota et al., 2019; Almahendra and Ambos, 2015; Vogel and Güttel, 2013; White and Griffith, 1981). The selection of relevant studies included three sequential steps, namely scanning, curating, and analysis.

3.1.1. Scanning

The study employed the combination of different strings of keywords ("Lean" OR "Agile" OR "lean manufacturing" OR "lean philosophy" OR "lean thinking" OR "lean production") AND ("Sustainab*" OR "Green" OR "triple bottom line" OR "TBL" OR "Eco-efficiency" OR "eco-sustainability" OR "sustainable manufacturing"). We utilized these keyword combinations for searching the relevant studies in the WOS. The search, conducted in May 2019, resulted in 343 research articles. The prior studies in this research domain influenced the keyword selections, for example, SM (Lee et al., 2019; Pang and Zhang, 2019), sustainability (Cicculló et al., 2018; Henao et al., 2019; Zarte et al., 2019), triple-bottom-line (Ahmad et al., 2018; Henao et al., 2019), lean manufacturing (Henao et al., 2019), lean (Cicculló et al., 2018), lean thinking (Martínez León and Calvo-Amodio, 2017), lean and green (Caldera et al., 2017), eco-efficiency (Garza-Reyes, 2015), and eco-sustainability (Garza-Reyes, 2015).

The extant literature has also studied the concept of SM from the broader perspective of triple-bottom-line (TBL), eco-efficiency, and socio-efficiency. TBL refers to integrating profit, people, and planet in corporate strategies and practices (Kleindorfer et al., 2005). Eco-efficiency is often equated with sustainable business practices at the business level (Dyllick and Hockerts, 2002).

3.1.2. Curating

The study utilized only peer-reviewed journal articles in the English language since these works are a body of certified knowledge and mostly suggest reliable results (García-Lillo et al., 2017). We further manually scanned these documents for their respective applicability to the study. After detailed scrutiny, we excluded the review studies and the articles that were not directly linked to the field of study. We performed bibliometric analysis of the remaining 162 empirical papers with BibExcel, a widely used software package (Zhao et al., 2018).

3.1.3. Analyzing

The most productive journals that have published the top co-cited articles derived from our bibliometric analysis are as follows: 19% of the articles included in the study were published in the *Journal of Cleaner Production*, followed by the *International Journal of Operations & Production Management* (13%), the *International Journal of Production Economics* (9%), *Production and Operations Management* (7%), and the *Journal of Operations Management* (6%) (see Fig. 2.1). Among those, the top 15 cited articles are stated in Fig. 2.2.

3.2. Bibliometric analysis

Bibliometric analysis is rooted in the methodology which involves the statistical analysis of scholarly documents (Garfield, 1955). The analysis of data sets over long periods with emphasis on capturing the emergence of the intellectual structure may be challenging using a qualitative review (Casillas and Acedo, 2007). However, bibliometric analysis augments the analysis and helps unravel the intellectual structure of a domain with sufficient objectivity (Garfield, 1979). For these reasons, bibliometric analysis as a method has gained the attention of scholars from various disciplines of management research such as sustainable development (Hassan et al., 2014; Quental and Lourenço, 2012; Zhu and Hua, 2017), sustainable consumption (Liu et al., 2017), lean concept and logistics management (Wichaisri and Sopadang, 2018), circular economy (D'Amato et al., 2017), green and sustainable innovation (Franceschini et al., 2016), green manufacturing (Pang and Zhang, 2019), manufacturing (Caviggioli and Ughetto, 2019), sustainability (Fahimnia et al., 2015), finance (Xu et al., 2018), and tourism (Benckendorff and Zehrer, 2013), among others.

There are different software packages that are available for executing bibliometric analysis, namely BibExcel (Fahimnia et al., 2015), CiteSpace (Shin and Perdue, 2019), Gephi (Xu et al., 2018) and VOSviewer (Koseoglu et al., 2019), among others. The present study utilized BibExcel for citation analysis, co-citation analysis,

Fig. 2.1. Top productive journals.

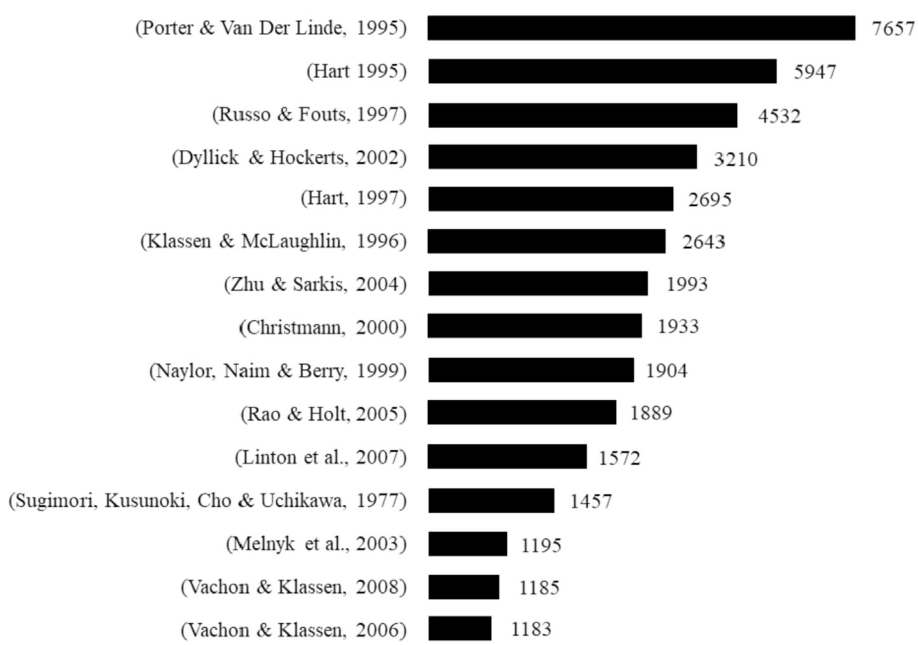

Fig. 2.2. Top cited articles.

and similarity indexing. BibExcel is a widely used software package for co-citation analysis (Zhao et al., 2018). Furthermore, we utilized SPSS 25.0 for EFA and VOSviewer for graphical visualization. Scholars argue that VOSviewer is an appropriate software to investigate large data sets and offers a range of sophisticated options that help to better visualize results (van Eck and Waltman, 2014; Fahimnia et al., 2015).

3.3. *Co-citation analysis*

Bibliometric-based studies employ co-citation analysis extensively (Acedo et al., 2006). It helps in determining an article's intellectual affiliations and mapping the intellectual structure in a field of study (Calabretta et al., 2011), grounded on the argument that any two articles can be considered pertaining to the same field of research if they are frequently cited together (Culnan, 1986). As citations grow over time, co-citation analysis contributes to outlining the intellectual structure of a domain through the identification of the most influential research work in that area. The older documents have a longer period to accumulate citations (Vogel and Güttel, 2013). Using the results of co-citation analysis, we selected the top 80 co-cited articles out of 162 articles to create a co-citation matrix, which we further processed for a more detailed analysis. Fig. 3 illustrates the co-citation bar graph, derived from the co-citation analysis and depicting the top co-cited pairs.

3.4. *Multivariate analysis (MVA)*

MVA analyzes multiple variables in one relationship or set of relationships, strengthening analytical aspects of research for decision-making and problem-solving (Hair et al., 2014). This study applied EFA as an MVA technique and further analyzed the results of EFA using similarity indexing. Before performing the EFA, however, we treated the data with Jaccard indexing to normalize the 80 × 80-cell symmetrical matrix as discussed below.

3.4.1. Jaccard indexing

BibExcel software provides the descriptive statistics on the co-cited articles by creating a symmetrical matrix. The cells depict co-citation counts of the respective studies in the matrix. The current study utilized an 80 × 80 symmetrical matrix. Past research suggests that in the absence of any methodological guide for determining the threshold level for the number of articles to be examined (Eom, 2009), the researcher can determine the size of the co-citation matrix in accordance with its suitability for statistical treatment (García-Lillo et al., 2017). In the process, the diagonal of the matrix formed has zero as its primary value, as a study cannot be cited twice in the same document. Past studies have suggested various methods to treat the diagonal. In this study, the principal diagonal of the correlation matrix was treated as per the suggestion of White and Griffith (1981). Prior bibliometric studies adopted similar methodology (Casillas and Acedo, 2007; Uysal, 2010). We further treated this matrix using Jaccard indexing to normalize (Small and Greenlee, 1980) the 80 × 80-cell symmetrical matrix. The normalization of the data helped to overcome dissymmetry of scale between oft-cited and less-cited documents (Gmür, 2003). Later, we loaded the Jaccard index-treated matrix into SPSS 25.0 for conducting the EFA.

3.4.2. Exploratory factor analysis

EFA is one of the most commonly employed procedures in bibliometrics-based studies (McCain, 1990). The current study utilized EFA for enhancing the robustness of the results and utilized the Jaccard index-treated 80 × 80 symmetrical matrix to conduct EFA. We conducted the factor extraction by employing principal component analysis (PCA) and Varimax rotation. We used the Kaiser normalization to optimize the variables to conceptually important latent variables. We only considered the articles with significant loadings (absolute value, 0.4 or more) while those below the threshold limit of 0.40 were ignored. The researchers used the eigenvalue (>1) test, scree plot, Horn's test, and cumulative variance explained as criteria for determining the number of factors to be considered for the study. For maintaining the principle of parsimony, interpretability of the factors, and considering the criteria for cumulative variance explained (Hair et al., 2014), the study considered six factors, and they explained over 65% cumulative variance. The EFA helped in identifying six paradigms of SM research. Appendix Table 1 illustrates the loading of various studies into various factors or paradigms.

3.4.3. Similarity indexing

Once we grouped the articles into a factor with significant loadings (absolute value: ≥0.4), we tested each article in the group for the strength of its similarity with other articles in the group. Prior studies suggest employing measures of relative document similarity has an advantage over frequency counts (McCain, 1990). This similarity index helped in the classification of the group based on the similarity strength of the articles within the group. We only considered a maximum number of 12 articles with significant similarity strength (absolute value, 0.2 or more) to be aligned to a paradigm. The following formula calculated the similarity index (S):

$$\text{Similarity index }(S)=\frac{\text{Sum of co}-\text{citation of document A and B}}{[(\text{Sum of co}-\text{citation of document A})+(\text{Sum of co}-\text{citation of document B})-(\text{Sum of co}-\text{citation of document A and B})]}$$

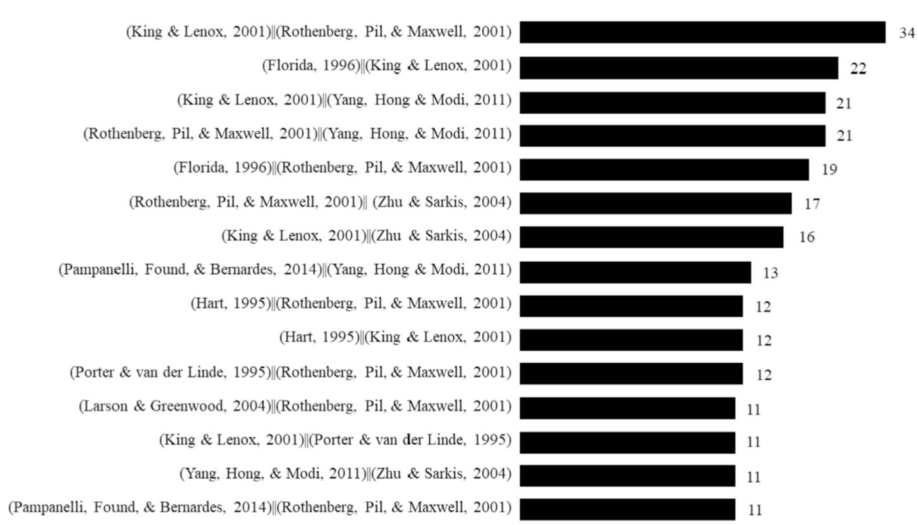

Fig. 3. Top Co-cited articles.

Table 1
Loading of factors after exploratory factor analysis (EFA).

Study	P1	P2	P3	P4	P5	P6
Rao (2002)	0.78					
Klassen & Whybark (1999a)	0.69					
Bowen et al. (2001)	0.68					
Vachon & Klassen (2006)	0.65					
Hart (1995)	0.63					
Geffen & Rothenberg (2000)	0.61					
Hall (2000)	0.61					
Pullman et al. (2009)	0.58					
Melnyk et al. (2003)	0.55					
Klassen (2001)	0.54					
Zhu & Sarkis (2004)	0.51					
Russo & Fouts (1997)	0.49					
Klassen (2000)	0.46					
Porter & van der Linde (1995a)	0.42					
Florida (1996)		0.64				
Rothenberg et al. (2001)		0.64				
King & Lenox (2001)		0.63				
(Porter and Van der Linde, 1995b)		0.57				
Pil & Rotherberg (2003)		0.56				
Sroufe (2003)		0.54				
Corbett & Klassen (2006)		0.50				
Montabon et al. (2007)			0.76			
Yang et al. (2010)			0.76			
Christmann (2000)			0.72			
Klassen & McLaughlin (1996)			0.62			
Vachon & Klassen (2008)			0.48			
Pagell & Gobeli (2009)			0.40			
Rothenberg (2003)			0.42			
Piercy & Rich (2015)				0.82		
Pampanelli et al. (2014)				0.81		
Ng et al. (2015)				0.81		
Verrier et al. (2016)				0.78		
Chiarini (2014)				0.77		
Verrier et al. (2014)				0.76		
Galeazzo et al. (2014)				0.71		
Aguado et al. (2013)				0.67		
Jabbour et al. (2013)				0.66		
Vinodh et al. (2011)				0.64		
Faulkner & Badurdeen (2014)				0.64		
Yang et al. (2011)				0.64		
Thanki et al. (2016)				0.63		
Garetti & Taisch (2012)				0.57		
Miller et al. (2010)				0.58		
Kurdve et al. (2014)				0.55		
Achanga et al. (2006)				0.47		
Vachon (2007)				−0.41		
Klassen & Whybark (1999b)				−0.42		
Kitazawa & Sarkis (2000)				−0.42		
Zhu et al. (2008)					0.86	
Zhu et al. (2005)					0.71	
Carvalho et al. (2011)					0.68	
Govindan et al. (2014)					0.68	
Green et al. (2012)					0.67	
Azevedo et al. (2012)					0.63	
Rao & Holt (2005)					0.56	
Panizzolo (1998)					0.52	
Cherrafi et al. (2017)					0.49	
Cabral et al. (2012)					0.45	
Govindan et al. (2015)					0.42	
Gimenez et al. (2012)						0.67
Sarkis et al. (2010)						0.66
Hutchins & Sutherland (2008)						0.62
Dyllick & Hockerts (2002)						0.58
Linton et al. (2007)						0.58
Lewis (2000)						0.49
Sarkis (2001)						0.44

Note: P1: Capability development for environmental performance; P2: Lean principles and environmental management; P3: Environmental management and firm performance; P4: Lean and Green Integration; P5: Green SCM; P6: Sustainability.

At the end of the EFA, the researchers deployed VOSviewer to illustrate the intellectual structure of the SM literature comprising the top 80 co-cited research articles. The distinct clusters of these studies are demarcated by the dotted lines on the map generated through VOSviewer software (Fig. 4).

4. Discussion

4.1. Paradigms of sustainable manufacturing

A total of six factors emerged as a result of the EFA, which we regard as the six important paradigms of SM literature. In this section, we discuss the dominant logic, emphasis, and limitation of each of these six paradigms.

4.1.1. Capability Development for Environmental Management

This paradigm comprises 14 research articles within the identified pool of 80 studies used for the EFA. The similarity index (see Fig. 5) presents the similarity strength between selected research articles in this paradigm.

The dominant logic: The predominant focus is on the capability development of firms for environmental management (EM). However, it also puts a strong emphasis on achieving a competitive advantage by developing synergy between a business and its natural environment under resource constraints.

Emphasis: The studies examine the aspects related to capability development for EM. The notion of environmental management practices (EMPs) for competitiveness gained significant traction when Hart (1995) provided the idea of the “natural resource-based view” (NRBV) regarding a firm. NRBV deals with achieving a competitive advantage based on an organization’s dynamics with its natural environment under the resource constraints. In this regard, Klassen (2000) suggests that continuous improvement initiatives positively impact environmental performance (EP) and further points toward pollution prevention as a more appropriate strategy for improved EP as compared to pollution control.

Klassen and Whybark (1999a) developed an empirical model to explore the influence of EM orientation of the operations manager on the investment in environmental technology. The focus is on the manufacturing process and an organization’s EP. Hall (2000) discussed the conditions that enabled the emergence of environmental supply chain dynamics (ESCD) and suggested that influential command over the suppliers by channel leaders on the basis of their technical capabilities and significant EP enables the emergence of ESCD.

Geffen and Rothenberg (2000) evaluated the impact of the supplier–OEM (original equipment manufacturer) relationship on the EP of the production units. They suggest a well-built relationship with suppliers, reinforced by a suitable incentive mechanism that can help in the effective adaptation of innovative environmental technologies.

Bowen et al. (2001) empirically tested the impact of SCM capability for enabling the environment-friendly supply chain. They highlighted that strategic purchasing, supply processes, and a proactive EM approach enable SCM capabilities. Rao (2002) analyzed the ISO 14000-certified organizations in the South East Asian economies. They observed that leading ISO 14000-certified organizations not only worked for their performance improvement but also strove toward the greening of their respective suppliers to achieve competitiveness and improved economic performance. Vachon and Klassen (2006) suggested positive effects of technology on integrating tier-one suppliers and major customers in the form of effective monitoring and collaboration regarding EP and environmental practices.

Limitation: The paradigm suggested that the symbiotic

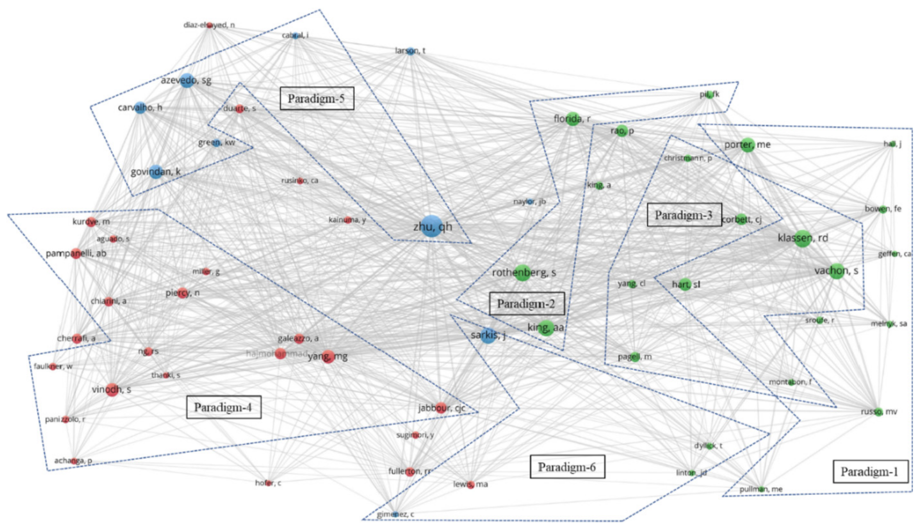

Fig. 4. Intellectual structure of the SM research.

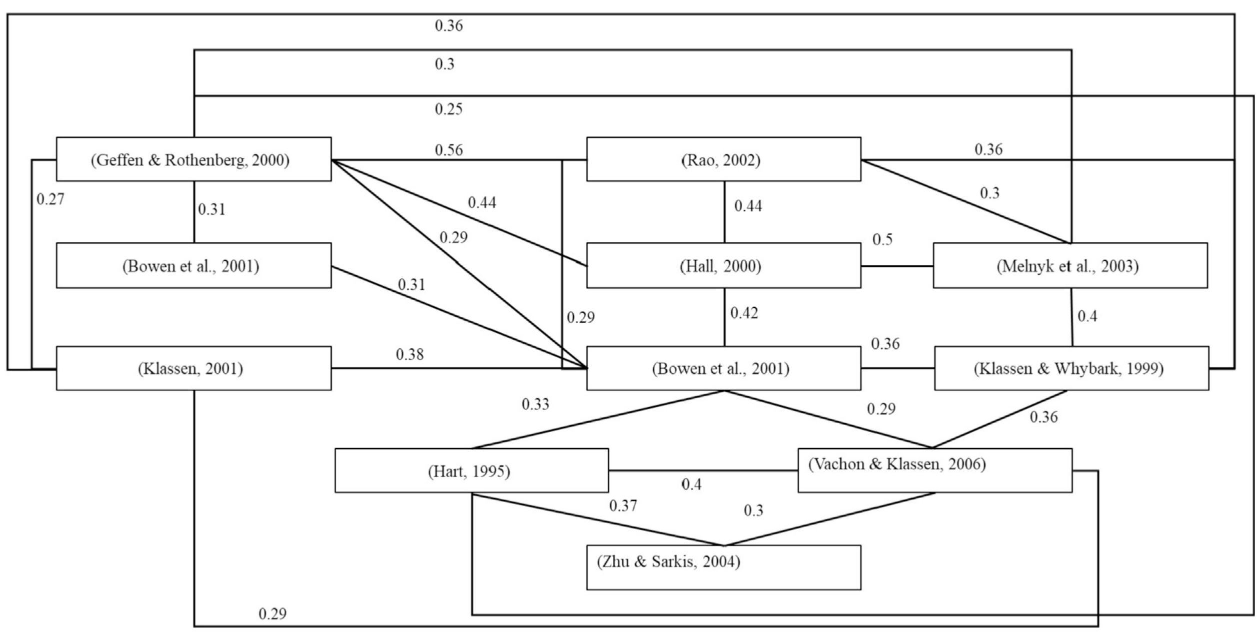

Fig. 5. Similarity index for capability development for environmental performance paradigm.

association between EM and an organization's competitive advantage provides a new strategic orientation. It has made a strong case for organizations to channel their resources toward the capability development of the firms in this regard. However, the necessary tools, techniques, and practices needed for their effective implementation require more attention from researchers and practicing managers.

4.1.2. Lean practices and environmental management

A total of seven articles were part of the paradigm on learning practices and EM. The similarity index in Fig. 6 presents the similarity strength.

The dominant logic: The predominant belief that guided the research and practice in this paradigm is rooted in the dynamics of lean practices and environmental management.

Emphasis: The focus of research in this paradigm is on examining the impact of lean tools and principles on EM. With reference to this, King and Lenox (2001) empirically tested the interrelationship of lean manufacturing with EP and observed that firms incorporating quality management systems have a higher probability of incorporating environmental management systems (EMS). While examining the correlation between advanced manufacturing practices and innovative initiatives toward environment-friendly manufacturing, Florida (1996) observed that firms transforming their manufacturing process with innovative approaches are more likely to address environmental issues. Analyzing the effect of EP on operations, Pil and Rotherberg (2003) suggested that enhanced EP contributes toward improved operational performance of quality parameters and, hence, leads to competitive advantages for firms. Similarly, Sroufe (2003) observed a positive correlation of EMS with the operational performance of organizations.

Limitations: Rothenberg et al. (2001) cautioned against overreliance on lean manufacturing as the most effective tool to grapple with SM challenges. Rothenberg et al. (2001)

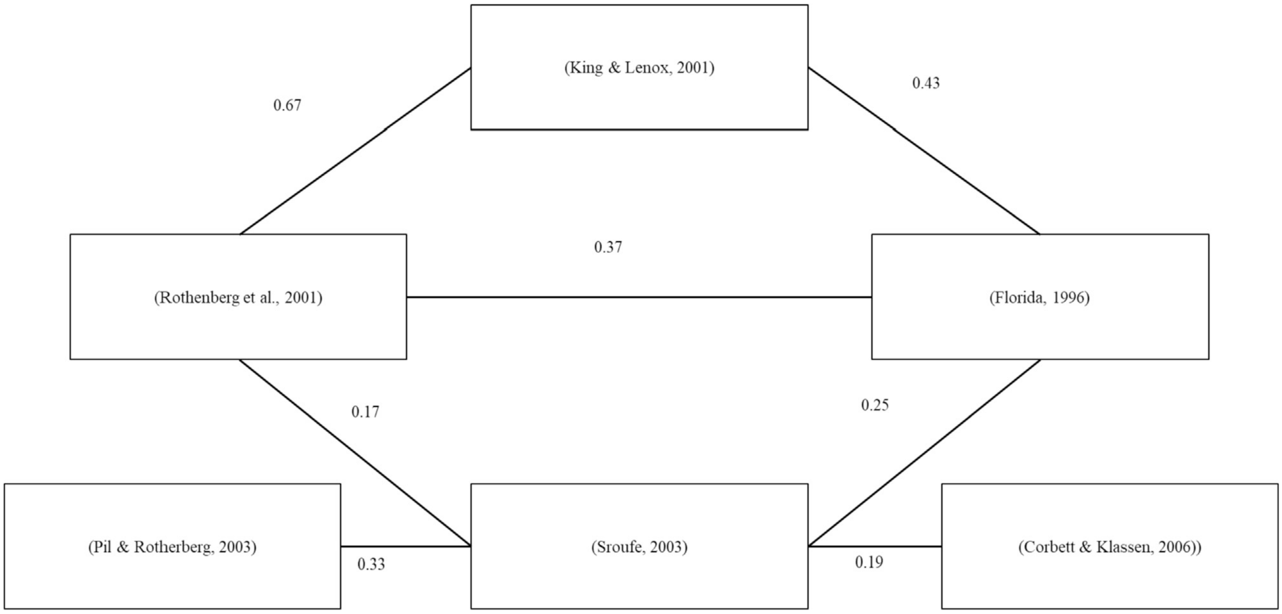

Fig. 6. Similarity index for lean principles and environmental management paradigm.

recommended that effective lean manufacturing may significantly impact EP but will not be able to mitigate all the environmental problems. The discussed paradigm documents the impact of lean practices on EM, but it fails to take into consideration the overall impact of EM on organizational performance.

4.1.3. Environmental management and firm performance

We discuss ideas and practices with reference to SM in this paradigm examining the relation of environmental goals with business objectives for an organization. Previous research studies treated this relationship as a trade-off between the two (Porter and van der Linde, 1995a). The prevailing wisdom cast environmental aspects of business processes as an impediment to the financial performance of organizations (Florida, 1996). The literature also suggests the notion of being environmentally sustainable at the cost of operational and economic performance still exists (Hajmohammad et al., 2013; Porter and van der Linde, 1995a). The EFA identified a total of seven articles in this paradigm, and the similarity index presents the similarity strength between selected research articles in this paradigm (see Fig. 7).

The dominant logic: In this paradigm, the predominant belief that guided the research and practice is that EM is an extended perspective of operations management. Corbett and Klassen (2006) supported the argument by employing two profound fields of lean operations, namely total quality management (TQM) and SCM.

Emphasis: The studies in this paradigm discuss the effect of different EMPs on key performance indicators (KPIs) related to firm performance. Using content analysis and canonical correlation, Montabon et al. (2007) studied the interaction between EMPs and performance measures and identified the six most statistically significant EMPs. Klassen and McLaughlin (1996) employed a conceptual framework to link the EP of an organization with the stock market performance and found a stronger positive performance on the stock market with strong EP and vice versa. Christmann (2000) utilized the resource-based view as a theoretical underpinning and empirically tested the interrelationship between environmental best practices and cost-competitive advantage for a firm. The study found that the complementary assets (resources or capabilities of a firm) are a significant factor in moderating the performance of the firm. Yang et al. (2010) extended the horizon of this discussion and suggested that EMPs are the extended perspective of best practices in manufacturing, supply chain management and related continuous improvement initiatives. They explored the interaction between supplier management, continuous improvement, EMPs, and manufacturing competitiveness. Similarly, Vachon and Klassen (2008) utilized a natural resource-based view and studied the effect of “environmental collaboration” on operational performance within the supply chain. They proposed that environmental best practices in SCM enable relatively better enhancement of manufacturing capabilities when environmental collaboration is done with suppliers as compared to collaboration with customers.

Limitations: Extant research suggests that minimizing or eliminating the negative environmental and social effects on account of operations of a firm cannot just be a collection of some good-to-have activities. Instead it must be a vital component of business strategy, enabling the organization to create a competitive advantage (Garza-Reyes, 2015). This paradigm documents the effect of EMPs on KPIs, it examines these practices in isolation from other organizational interventions. Furthermore, it does not take into account the different nuances associated with the integration of lean and green practices implemented by an organization.

4.1.4. Integrating lean and green practices

We grouped 20 research papers representing the integration of lean and green practices in this paradigm. Fig. 8 presents the similarity strength between selected research articles in this paradigm.

The dominant logic: Lean manufacturing arguably meets the objectives of operational efficiency and productivity, and, recently, even those of consumer satisfaction, organizational agility, and resilience (Garza-Reyes, 2015). Environmental challenges, however, have motivated organizations to broaden the horizon of these objectives and realign the process across their value chain (Garza-Reyes, 2015). Complementing these views, the current paradigm guides research and practice toward integration and synchronization of lean and green practices as one system for attaining SM.

Emphasis: The studies in this paradigm discussed the various facets of lean and green practices integration. Kurdve et al. (2014)

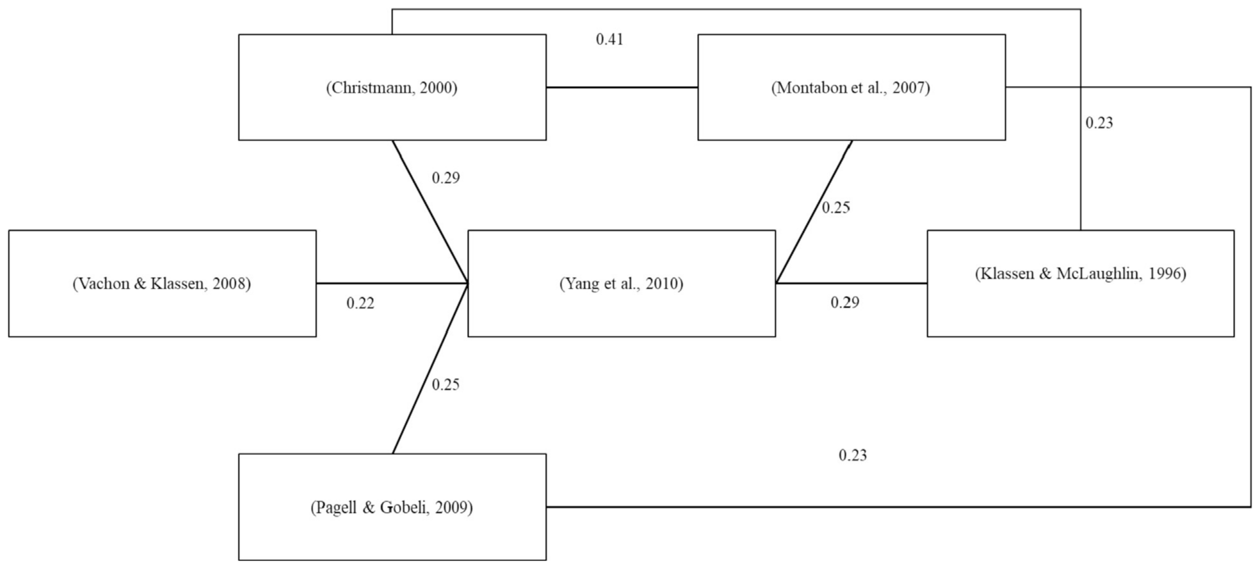

Fig. 7. Similarity index for environmental management and firm performance paradigm.

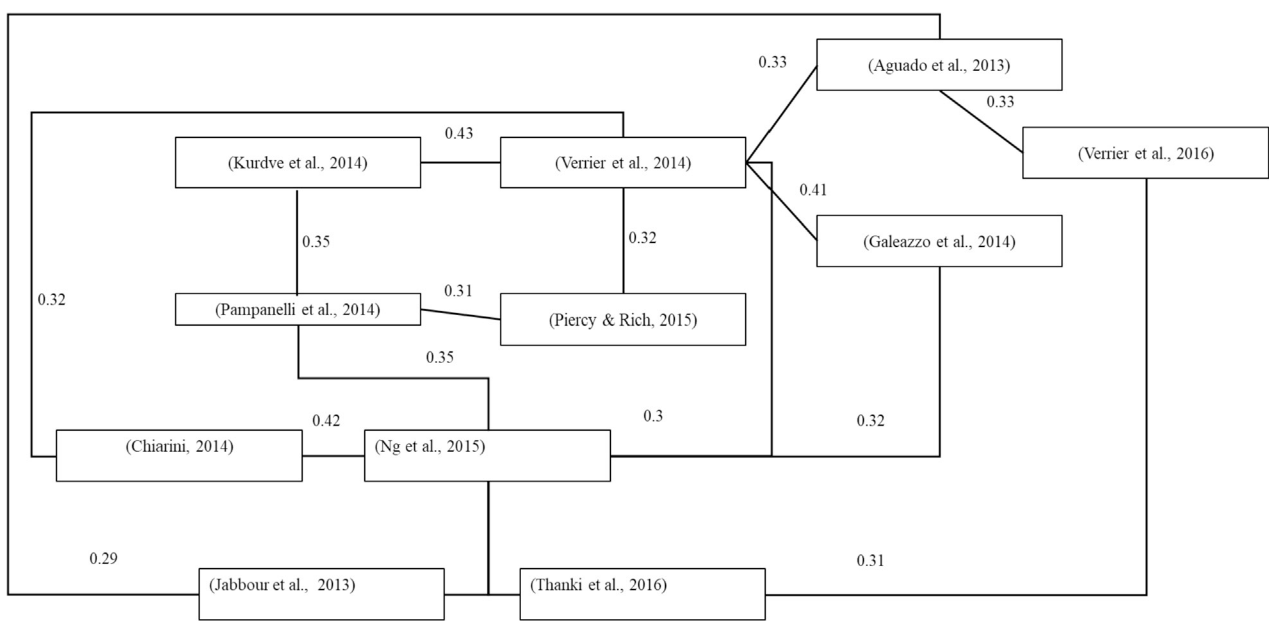

Fig. 8. Similarity index for lean and green integration paradigm.

studied the integration of the established management and the improvement systems which evolved in an organization. They observed that the major challenges of integration of EM with operations were the dearth of integration strategy, sustainability measures, and ownership of EM. Ng et al. (2015) developed a mechanism to streamline the integration of green manufacturing practices for their effective implementation and proposed lean and green metrics named Carbon-Value Efficiency (CVE). The study offered metrics that may work as a beacon for evaluating lean and green performance. Pampanelli et al., (2014) developed an integrated model for augmenting the performance of cellular manufacturing in a plant using lean and green manufacturing practices. They utilized the Kaizen methodology for enhancing the mass and energy flows of a production facility with adequately developed lean practices. Verrier et al., (2016) used indicators on lean and green performance and measures of green intentions to construct a framework for lean and green management. They developed a framework that gauges the lean and green practices and compares performance of the firm with that of competitors. Aguado et al., (2013) proposed a framework regarding the deployment of SM using the process of environmental innovation and the application of lean principles. They utilized pull methodology and Environmental Value Stream Mapping (EVSM) as a key component. Chiarini (2014) recommended “value stream mapping” as an effective lean tool to identify the environmental footprints of the manufacturing process. Piercy and Rich (2015) developed a framework on the lean–sustainability linkage and explored other benefits of the linkage beyond the environmental ones. Thanki et al. (2016) used the analytical hierarchy process approach for analyzing the interrelationship between green manufacturing, associated practices, and a firm’s performance, and they developed an integrated lean and green model for sustainable growth.

Limitation: The guiding philosophy, emphasis of the research, and practices in this paradigm are to integrate lean and green as one system, but the focus is largely confined within the boundaries of the organization or the manufacturing unit. Furthermore, it does not place due emphasis on the environmental impacts arising out of end-to-end value and supply chains.

4.1.5. Green SCM

Eleven research articles represent the paradigm on GrSCM. The similarity index of the articles in this group is illustrated in Fig. 9.

The dominant logic: In this paradigm, the predominant belief that guided the research and practice is to go beyond the boundaries of the firm and analyze the application of lean and green practices on supply chain constituents.

Emphasis: Various aspects of GrSCM are discussed in this paradigm. Using data from Chinese production units, Zhu et al. (2005) identified the drivers, practices, and outcomes of the environment-amicable practices in SCM. Zhu et al. (2008) empirically examined five underlying implementation factors for GrSCM practices in different manufacturing organizations. Similarly, Green et al. (2012) found that GrSCM practices improve the capability of an organization to protect the environment as well as strengthen its financial feasibility. Azevedo et al. (2012) developed a framework for analyzing the effects of upstream lean and green practices on sustainable business growth. The outcome of the study points toward the significant contribution of lean and green upstream intervention leading to improvement in resource efficiency in terms of recycling, reuse, and remanufacturing. Furthermore, the study suggested that this also results in a reduction in process lead time, inventory, waste, and energy use. Rao and Holt (2005) established the relationship among various latent constructs of GrSCM, economic performance, and competitiveness. Their study observed that GrSCM is a result of greening initiatives at various components of the supply chain and that greening of inbound supply chains and manufacturing also leads to the greening of outbound supply chains. Therefore, it results in competitiveness and enhanced economic performance. Carvalho et al. (2011) developed a model comprising Lean, Agile, Resilient, and Green (LARG) practices and supply chain characteristics to explore the symbiosis and divergence within LARG practices. Furthermore, it also investigated their impact on practices within SCM. In another study, Cabral et al. (2012) employed an analytical network process approach to determine the most suitable practices and KPIs within the LARG paradigm, which may enable organizations to improve their SCM performance. Similarly, Govindan et al. (2015) employed a similar approach to determine the most suitable practices within the LARG paradigm, which may enable organizations to improve their supply chain performance. Govindan et al. (2014) also examined the impact of lean, resilient, and green practices on SCM and observed that waste reduction or elimination and greener production have a positive effect on SCM sustainability.

Limitation: The research in this paradigm goes beyond the boundaries of the organization and examines the application of lean and green practices across the supply chain. However, it does not fully consider the social impact across the value chain and the social aspects in competitive context, as identified by Porter and Kramer (2006).

4.1.6. Sustainability

This paradigm includes a total of seven research articles. Fig. 10 illustrates the similarity index of the articles in this group.

The dominant logic: In this paradigm, the predominant belief that guided the research and practice was to shun the myopic view (e.g., practices, performance) and to adopt the overarching framework of sustainability.

Emphasis: The studies in this paradigm discuss the application of lean and green from the perspective of sustainability. In one of the most influential studies in this domain, Dyllick and Hockerts (2002) evaluated the application of sustainability at the business level and proposed six measures for leaders endeavoring to pursue the path of corporate sustainability. Hutchins and Sutherland (2008) examined the classification, measures, and indicators of social responsibilities of organizations and the social dimension of sustainability. Their study evaluated the relationship between the financial activities of organizations and the social dimension of sustainability, and then suggested decisions on sustainability issues at the corporate level, which can affect national measures of sustainability. Gimenez et al. (2012) observed that environmental improvement initiatives within the organization positively impact all three aspects of sustainability, whereas social improvement

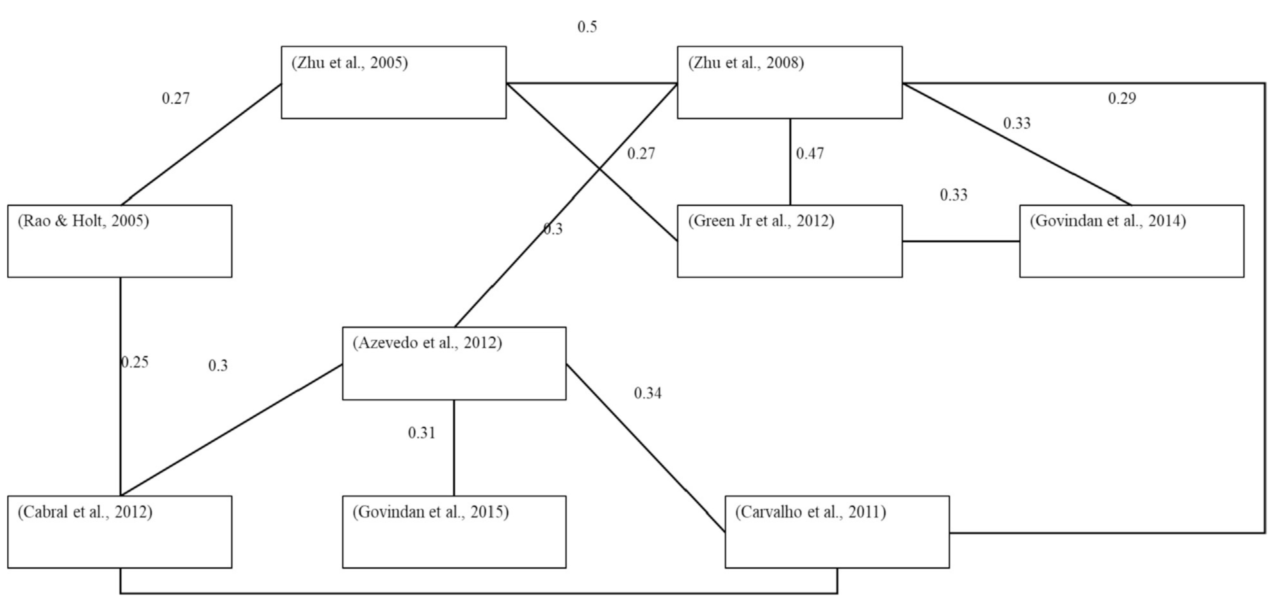

Fig. 9. Similarity index for green SCM paradigm.

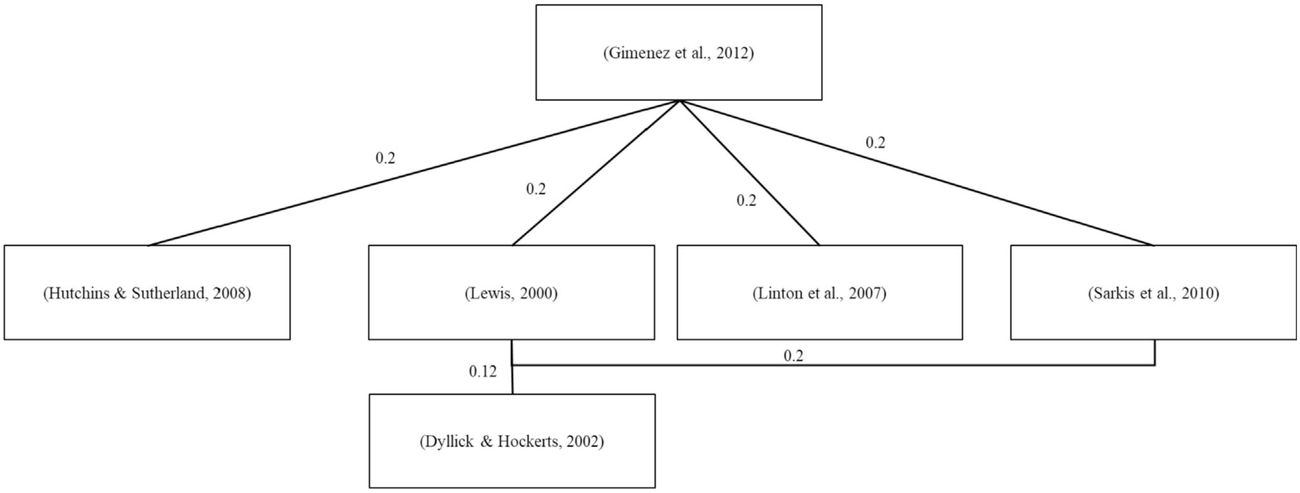

Fig. 10. Similarity index for sustainability paradigm.

initiatives within organizations only affect the environmental and societal dimensions. Linton et al. (2007) discussed the convergence of sustainability and SCM practices. They provided a perspective where best practices related to operations and EM are moving from the local optimum to the global optimum, encompassing the entire supply chain.

Limitation: The literature presents discussions on the need for and criticality of sustainability; however, its representation in the SM literature is very minimal. The possible reason could be the amount of difficulty associated with estimating the outcome and impact related to various sustainability initiatives.

4.2. Gaps and limitations

The present study identified four broad gaps and limitations based on the insights gained from the papers discussed in this study. These are as follows:

a) **Lean practices for environmental performance:** Prior literature suggests that scholars should focus on urgent issues related to the lean practices for EP. This includes studying the effect of lean manufacturing on the EP (Chiarini, 2014), integrating lean and green practices (Galeazzo et al., 2014) and establishing the interface of lean manufacturing and management human capital for EP (Jabbour et al., 2013).
b) **Sustainable supply chain:** Scholars have identified different gaps with respect to sustainability across the supply chain. This includes the impact of lean, agile, and GrSCM practices on supply chain sustainability (Govindan et al., 2014) and the impact of lean manufacturing and SCM in EP (Hajmohammad et al., 2013).
c) **Connection between stakeholders and environmental sustainability:** The literature identifies that connections between stakeholders and environment sustainability are not well examined. This includes the social dimension of sustainability (Govindan et al., 2014), the role of customers in SCM regarding EP (Hajmohammad et al., 2013), and the interrelationship of stakeholder management with the adoption of EMPs (Sarkis et al., 2010).
d) **Generalizability problems:** Prior literature suffers from limitations pertaining to the generalizability of the study results. The most poignant reason could be that prior literature had an industry-specific focus (Chiarini, 2014; Govindan et al., 2014); for instance, only highly environmentally regulated industries were considered (Galeazzo et al., 2014). In addition to this, other possible reasons could be geographical limitations (Sarkis et al., 2010), limited sample size of the companies (Chiarini, 2014; Hajmohammad et al., 2013; Sobral et al., 2013), convenience sampling (Zhu et al., 2008) and the inherent limitations of the studies' employment of cross-sectional methodology (Yang et al., 2011).

4.3. Future research direction

Based on the insights derived from the bibliometric and content analyses, this study came up with four broad recommendations for future research in the domain of SM. These recommendations can contribute to guiding organizations, practitioners, and scholars in achieving the objectives of sustainable development.

a) **Alignment of organizations with SDGs:** Future studies can investigate the alignment of the manufacturing and environmental practices of an organization with different Sustainable Development Goals (SDGs). This is important since the SM approach is not being practiced by most industries (Alkaya and Demirer, 2015). In one of the recent studies, de Oliveira Neto et al. (2019) argued that there is a dearth in the number of manufacturing-related studies that are directly aligned to SDGs. Other possible future directions could be (a) exploring the synergies that can be developed between multiple SDG targets through the practices of circular economy; similarly, the country-specific contexts to understand these synergies should be examined (Schroeder et al., 2019); (b) the trade-off across SDGs and their linkages to the life cycle assessment should be examined (Laurent et al., 2019); (c) the relationship between the criteria of SM and a sustainable world should be examined (Moldavska and Welo, 2019), for example, by developing corporate sustainability assessment tools that can guide manufacturing organizations to meet the SDGs; (d) sustainable consumption and production (SCP) practices should be aligned to the SDG framework; for example, scholars can examine how SCP can play a significant role in successful execution of the SDGs framework.
b) **Practices for environmental performance:** Prior literature has recommended the need for more granular studies on

lean and green integration but in more complex, uncertain, and munificent business environments (Galeazzo et al., 2014). Scholars recommended the need for examining the role of lean-based SCM in the EP of a firm by taking into consideration the role of the end customer (Hajmohammad et al., 2013). Future studies should also focus on developing the KPI of multidimensional EP, which can predict monetary outcomes for a firm (Yang et al., 2011).

c) **Integration of social dimensions into SM:** The field needs research to better understand the integration of human resources and EMPs (Jabbour et al., 2013). There exists an acute need for examining the effect of operational managers' attitudes on environmental issues (Pagell and Gobeli, 2009). Scholars can analyze the social elements beyond the employees and address social issues ranging from the local to the international. Furthermore, they should aim to conduct more detailed investigation into distinct social elements (Pullman et al., 2009).

d) **Role of newer technologies for SM:** Future research can explore the extent to which the integration of new technological innovations such as artificial intelligence, blockchain, machine learning, and big data analytics can effectively answer the challenges faced by SM. Recent studies have also recommended the need for integration of newer technological innovations since these strengthen the research outputs (de Oliveira Neto et al., 2019; Schroeder et al., 2019).

5. Comprehensive framework for SM

The study proposes a comprehensive framework based on the insights gained from the bibliometric and content analyses of prior SM literature (see Fig. 11). The insights include the intellectual structure of SM outlined using the six paradigms, different gaps, and limitations in extant literature in the domain and recommendations for future research. The proposed framework has three main components: (a) sustainable manufacturing which comprises the six existing paradigms as well as the upcoming paradigms of future research (referred to as miscellaneous); (b) conceptual and methodological advancements which comprise research frontiers in the domain of SM; and (c) outcomes which comprise implications for researchers, managers, and policymakers.

5.1. Sustainable manufacturing

This component of the framework represents the six existing SM paradigms along with a future paradigm, referred to as miscellaneous.

a) **Capability development for environmental management:** It focuses on the capability development for EM with emphasis on achieving competitive advantage by developing a symbiotic relationship between the organization's dynamics and its natural environment under resource constraints.

b) **Lean principles and environmental management:** The focus is on lean principles along with its tools and techniques in order to address the SM challenges.

c) **Environmental management and firm performance:** It deals with the research and practice on environment management as an extended perspective of operations management.

d) **Integration of lean and green practices:** It deals with the synchronization of lean and green practices as one system for attaining SM.

e) **GrSCM:** It examines the application of lean and green interventions covering the entire supply chain and going beyond the boundaries of the organization.

f) **Sustainability:** It aims at developing an overarching framework of sustainability that shuns the myopic view (e.g., practices, performance).

g) **Miscellaneous:** The current framework also speculates on the paradigms which may emerge in future research. The miscellaneous paradigm includes performance assessment methods for gauging the impact of SM and the policy-

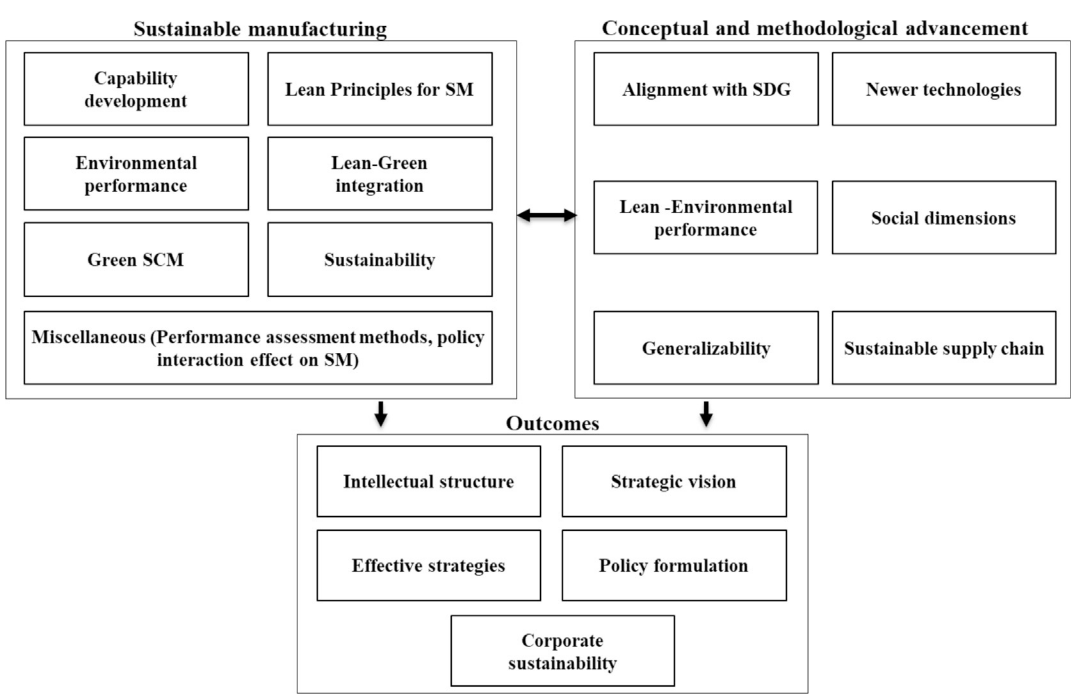

Fig. 11. Comprehensive framework of the SM literature.

pervasiveness and interaction effect for SM. The performance assessment methods may discuss the techniques and methods from a methodologist perspective, primarily dealing with the analytical techniques that SM studies employ. The policy-pervasiveness and interaction effect may analyze the relationship of SM policies with technology innovation for achieving SM. Finally, the interaction effect deals with the impact of market and behavioral failures on investment decisions concerning SM from a policy analyst perspective.

5.2. Conceptual and methodological advancements

This component of the framework represents the conceptual and methodological advancements with reference to the research frontiers in the domain of SM. The key elements of the conceptual and methodological advancements are delineated below.

a) **Alignment with SDG:** It guides firms in better aligning themselves with different SDGs. It includes sustainable consumption, social dimensions, digital technologies, circular economy, and life-cycle engineering with reference to alignment with SDGs.
b) **Sustainable supply chain:** It deals with selection of different environmental technologies and the role of the end customer in the firm's EP and sustainable supply chain.
c) **Lean environmental performance:** It governs the integration of lean and green practices in more complex and uncertain business environments and developing the KPI of multidimensional EPs that can predict the financial performance of the firm.
d) **Social dimensions:** This aspect guides firms and researchers on understanding the integration of human resources and EMPs as well as the impact of operational managers' attitudes on environmental issues. Furthermore, it also deals with examining the relationship between stakeholder management and the adoption of various EMPs and analyzing programs which address local to international social issues to facilitate more detailed investigation into distinct social elements.
e) **Newer technologies:** It aims to explore the integration of new technological innovations for effectively addressing the challenges faced by SM.
f) **Generalizability:** It deals with the different causes that have led to the challenge of generalizability of the study results in the domain of SM.

5.3. Outcomes

The outcome component represents the practical implications of the SM research for researchers, managers, and policymakers. It has three main elements as discussed below.

a) **Intellectual structure:** It deals with the evolutionary journey and intellectual structure of the SM literature capturing the interplay between the dominant logic, emphasis, and limitation of each of the six paradigms.
b) **Effective strategies, corporate sustainability and strategic vision:** The identification of the six paradigms is necessary for the development of effective strategies, corporate sustainability and strategic vision of organizations.
c) **Policy formulation:** A better understanding of the paradigms of SM is necessary for policy formulation. The developed policies may deliver efficient decision-support systems, infrastructure development, and technological advancement in the alignment of manufacturing and EMPs of organizations with SDGs.

6. Conclusion

The present study performs a bibliometric review and content analysis and classifies the SM literature into six different paradigms for developing the intellectual structure as well as a comprehensive framework of the field. The theoretical and practical contributions of the study are as follows.

6.1. Theoretical implications

Two main theoretical implications are: first, we have documented the evolutionary journey and intellectual structure of SM literature by suggesting six important paradigms. The first paradigm, Capability Development for Environmental Management, predominantly focuses on the capability development of firms for environmental management (EM). We have observed a strong emphasis on achieving a competitive advantage by developing synergy between a business and its natural environment under resource constraints. The second paradigm, Lean Practices and Environmental Management, suggests that the research and practice in this paradigm are rooted in the dynamics of lean practices and environmental management. The third identified paradigm, Environmental Management and Firm Performance, suggests that EM is an extended perspective of operations management. The fourth paradigm namely, Integrating Lean and Green Practices, guides research and practice toward integration and synchronization of lean and green practices as one system for attaining SM. The core concept of Green SCM, the fifth paradigm identified in the study, is to go beyond the boundaries of the firm and analyze the application of lean and green practices on supply chain constituents. Sustainability is the sixth paradigm. In this paradigm, the predominant belief that guided the research and practice was to shun the myopic view (e.g., practices, performance) and to adopt the overarching framework of sustainability.

Second, we have proposed a comprehensive framework that captures (a) the interplay among the dominant logic, emphasis, and limitations of each of the six paradigms and (b) conceptual and methodological advancements which comprise research frontiers in the domain of SM. This framework will further guide the research and practice in the domain of SM.

6.2. Practical implications

The three main practical implications are as follows. First, the intellectual structure and the comprehensive framework of the SM literature developed in the present study offers valuable insights to practitioners for better understanding the influence of SM practices in increasing corporate environmental sustainability. Furthermore, it helps them to understand the importance of SM for achieving sustainable competitive advantage.

Second, we have presented a granular understanding of the various aspects of SM, which can enable practitioners to develop a strategic vision and formulate more effective strategies for deployment of various aspects of SM. Furthermore, it will provide a way to develop new paradigms and pathways to achieve the integration of people, planet, and profit aspects in business strategies and practices.

Third, policymakers may obtain inputs from the current study's findings for policy formulation. For example, the policies developed may deliver efficient decision-support systems, infrastructure development, and technological advancement in the alignment of manufacturing and EMPs of organizations with SDGs.

6.3. Study limitations

A few considerations limit the current study findings. First, like other studies based on bibliometric analysis, the present study also suffers from the phenomenon of the Matthew effect (García-Lillo et al., 2017). According to the Matthew effect, authors may cite from a journal due to the stature of the author or of the particular journal in the field of research even though the article may have limited proximity to the field of study. Due to this, the true affinity among the articles may not be accurately assessed from the results of co-citation analysis. Second, the study may have limitations due to the underrepresentation of the recently published works, since such works have lower citation count compared to articles published earlier. Third, the review focused solely on articles appearing in peer-reviewed journals, and other forms of publication conference reviews, proceedings, monographs, and book chapters were excluded. Despite these limitations, the present study makes a significant contribution toward literature in the field of SM. Thus, it offers crucial insights on SM both for scholars and practitioners, enabling them to carry forward the research agenda in the domain of SM.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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