



# A critical analysis on the triple bottom line of sustainable manufacturing: key findings and implications

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## Abstract

Because of the environmental consequences of manufacturing activities, the general public, industry, and academia are becoming more aware of sustainable manufacturing (SM), which incorporates environmentally friendly manufacturing processes while emphasizing overall triple bottom line (TBL) performance in manufacturing. This article employs various text mining techniques and bibliometric analysis including cluster analysis, Pearson coefficient and research landscape to conduct an extensive investigation on SM with a focus on the TBL, in which the research content of SM with the TBL is reviewed and discussed systematically from a wide angle and with reduced bias. In this study, three new indicators about the ratios of the number of scientific papers between social, environmental, and economic dimensions of SM are devised to show the weight and level of importance of dimensions in SM, covering scientific papers from 30 years. The findings from this study indicate that the influential power of SM varies across the three dimensions, with a particular emphasis on the social dimension of SM from various countries, implying a current state of imbalance status in TBL for SM, at the same time, the economic and environmental dimensions share similar research topics and academic emphasis in SM. Based on these findings, recommendations based on sustainable development goals (SDGs) of the United Nations (UN) are made to increase the social influence of SM. This article firstly reveals the individual status of the social dimension and the situation of unbalanced TBL in SM, providing sustainable suggestions for enhancing the effectiveness of SM and achieving balanced TBL regarding the SDGs.

**Keywords** Sustainable manufacturing · Triple bottom line · Text mining · Sustainable Development goal · Literature review

## Introduction

Sustainability is one of the crucial issues as the continuously growing demand worldwide (Stock and Seliger 2016) and has attracted the attention of multiple industries and research fields like supply chain management (Koberg and Longoni 2019; Zhou et al. 2020) and civil engineering (Zavadskas et al. 2018). Due to the demands for a good quality of life and population growth and meeting with customer demands,

manufacturing industries consume a significant amount of resources and result in the generation of pollution (Cassettari et al. 2017). As mentioned by Sun et al. (2020), the manufacturing industry has become one significant contributor to carbon emission and resource consumption currently. To mitigate environmental damage, government legislation has placed restrictions on manufacturing activities, such as the number of harmful emissions (Malek and Desai 2019). As customer awareness grows, products manufactured using green technologies gain a competitive edge in the market. Under these circumstances, the manufacturer must strike a balance between financial gain and the viability of their operations (Chan et al. 2017). Furthermore, sustainable manufacturing (SM) has been identified as one promotional initiative aimed at minimizing negative environmental impacts while meeting customer demand. According to Rosen and Kishawy (2012), sustainable manufacturing (SM) was defined as the process of creating goods and services using processes and systems that minimize negative environmental impacts, conserve natural resources, protect the

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safety of customers and workers, and make manufacturing processes economically viable. However, there are numerous obstacles to achieving SM for businesses, researchers, and governments (Zhou et al. 2022). For example, as pointed out by Nordin et al. (2014), the main barriers of SM include the lack of awareness and understanding in companies, lack of demand from customers, and lack of government regulation. Furthermore, the complicated influences among the machining factors can also hinder the optimization setting of manufacturing processes, resulting in energy and material waste (Yip et al. 2020).

The concept of “triple bottom line (TBL)” was proposed to balance the social, environmental, and economic concerns in operations (Kleindorfer et al. 2005), in which it provides a framework to integrate multiple indicators of sustainability. A growing number of studies have investigated the significance and underlying the relationship between the TBL concept and the sustainability levels of manufacturing processes. Through the correlation between performance indicators of manufacturing and TBL dimensions of manufacturing facilities, Govindan et al. (2016) underlined the significance of the balance between economic, environmental, and social dimensions using the sustainable indicators for manufacturing facilities. Goyal et al. (2013) created performance indicators based on the important success criteria derived from the relationship between organizational strategy and sustainability. Helleno et al. (2017) created a sustainability evaluation model for manufacturing processes by integrating value stream mapping and the TBL dimensions in manufacturing. These studies demonstrate the significance of incorporating TBL characteristics into manufacturing processes in order to enhance manufacturing performances, assessment procedures, and manufacturing strategy formulation. Actually, the three dimensions of TBL perform as the pillars to remain the development in balance (Ahmed and Sarkar 2019). TBL requires multiple industries to consider all three dimensions of sustainability in a comprehensive way (Ahmad and Wong 2019). It includes various sub-factors under each dimension, which can perform as indicators of sustainable measurements (Agrawal and Singh 2019). For instance, a sustainability assessment model of transportation in China has been developed according to TBL (Stefaniec et al. 2020). Besides, Janjua et al. (2020) have developed the TBL indicators for the evaluation of sustainable buildings. What’s more, a sustainable evaluation model for manufacturing systems based on the TBL was proposed to improve organizational sustainability (Junior et al. 2018).

The significance of TBL in sustainable manufacturing is evident. One of the representative studies of sustainable manufacturing with the TBL concept from Ahmad et al. (2022) that article reviews and evaluates the new sustainability assessment techniques for manufacturing and makes recommendations based on the TBL

concept of sustainability. This study provides another viewpoint for investigating the importance level of TBL on SM, in which text mining and bibliometric analysis are used to extract the important information of TBL in the SM with general content but not limited to assessment approaches, emphasizing the research content and the resource flow between the dimensions in SM. On the other hand, this study is necessary to investigate the influential capability of three dimensions in order to better design manufacturing strategies for the dimensions that require improvement, which necessitates research on the particular dimension and the interaction between dimensions. Also, in the current works, the TBL concept has not been used to classify the indicators of SM in a way that is consistent with the internal standard. As a result, it is necessary to assess the state of development of research on SM within the framework of TBL in order to identify research gaps and emerging trends concerning international standards. Additionally, with the advancement of technology in the modern era, it was discovered that distinct voices were received within the three dimensions of TBL (Ajmal et al. 2018). For example, it continues to lack research on the impact of manufacturing processes on worker health (Schneider et al. 2019), indicating a focus on operational efficiency but a lack of attention on safety concerns. Thus, in this situation, it is necessary to assess and investigate the interaction between the three dimensions using the current state of the TBL concept in SM. Overall, there are two research gaps in the field of SM:

1. The interaction of the three pillars of TBL has not been investigated in order to promote the manufacturing sector’s sustainable development.
2. Even when an imperfect situation involving SM based on TBL is discovered, rare recommendations are made, particularly those that conflict with the international standard.

To address the aforementioned limitation, this work used bibliometric and text mining techniques to examine the state of SM with the TBL concept focusing on three dimensions. The abstracts of collected papers relevant to the three dimensions of TBL were selected from the Scopus database for statistical and textual analyses using VOSviewer and Nvivo. The bibliometric analysis approach was used to assess the differences between the three dimensions in terms of the research landscape. On that basis, recommendations aligned with the United Nations’ sustainable development goals were made to academia and industry in order to increase the social dimension of SM’s influence, which the research gaps mentioned previously can be addressed by this study.

## Methodology

### Bibliometric analysis

Bibliometric analysis is a type of information science analysis that employs quantitative approaches to examine bibliographic materials (Broadus 1987). It could illustrate the trends in a particular research area by displaying the number of publications related to various topics by year. Additionally, bibliometric analysis can be used to visualize the network relationships between authors, organizations in the citation network, and networks of co-authors. Thus, the bibliometric analysis may provide a holistic view of the entire research field.

It has attracted the attention of researchers in a variety of fields due to its ability to identify patterns in the literature. For instance, it was used to examine the trends in Smart-City research over the last two decades (Mora et al. 2017). Even for the updated research topic nowadays such as Covid-19, the COVID-19 research activities have been evaluated using bibliometric analysis too (Chahrour et al. 2020). Also, a literature review based on bibliometric analysis was conducted in the research area of supply chain management to ascertain the research gaps in the study of disruption risks (Xu et al. 2020).

### Text mining — thematic analysis

Thematic analysis is a qualitative technique for identifying hidden themes within a collection of textual documents (Delgosha et al. 2021). It can be used to investigate the detailed keyword within the various themes of the dataset, which has stimulated the interest of researchers from a variety of fields. For example, Tate et al. (2010) conducted a thematic analysis of supply chain social responsibility research. This work may assist supply chain managers in identifying major emerging trends through the use of hidden theme keywords. Additionally, it has been used to ascertain the primary focus of blockchain technology applications in finance research (Gan et al. 2021). It demonstrates the primary uses of blockchain technology in the finance industry, which include cryptocurrency, process innovation, and digitalization. Numerous studies in the field of manufacturing have also been conducted using the thematic analysis method. For instance, Shukla et al. (2019) examined the effects of manufacturing flexibility on the performance of manufacturing systems. Also, Zhou et al. (2022) used thematic analysis to determine the challenges and opportunities associated with ultra-precision machining. However, it still lacks the application of thematic analysis to the evaluation of the sustainable performance of manufacturing. The wide application of the text mining technique provides strong evidence that the applicability in this study.

### Data collection

The scholarly scientific paper database, Scopus, was searched to collect the papers of SM for bibliometric analysis in order to ascertain the characteristics of SM with the TBL concept. To categorize the papers clearly according to the three dimensions of TBL for SM, the three pairs of words “sustainable manufacturing/society”, “sustainable manufacturing/economics”, and “sustainable manufacturing/environment” were entered into the Scopus search engine. On the other hand, in order to determine the proportion of research on SM that utilizes the TBL concept, the ratio “number of studies on SM/number of studies on SM that incorporate the TBL concept” was calculated. The filter functions have been enabled, ensuring that only sources meeting the criteria of “author”, “title”, “source”, and “abstract” are included. The preliminary search for the number of papers relating to SM and SM with TBL concept revealed that the number before and around 1991 appeared to be close to zero; consequently, we selected papers published after 1991 to ensure a large proportion of papers relevant to this study are included. In addition, the bibliometric analysis in the discussion sections demonstrated that the origin of paper traces back to around 1991; thus, the sources for this study cover the years 1991 to 2020. Then, this study would utilize a systematic literature review to organize the text material subsequently. A systematic literature review is a method for evaluating scientific articles to ensure the validity of the results. As a result, 9604 papers satisfy the above criteria for the word pairings “sustainable manufacturing/society”, “sustainable manufacturing/economics”, and “sustainable manufacturing/environment”, while 16,720 papers satisfy the above criteria for the word pairing “sustainable manufacturing”. The number of SM and SM with TBL concept papers, as well as the ratio between the number of papers of SM and each dimension of TBL, are selected for the parameters of bibliometric analysis, whereas the frequency of keywords in the textual source and the similarity index of the contents of each dimension of TBL are selected as text mining parameters in the subsequent sections of this study. VOSviewer software is used to create a map of the SM research landscapes using the TBL concept. Software NVivo was used to conduct statistical and textual analyses on the Scopus sources.

## Results and discussion

### Publication and citation numbers of SM regarding triple bottom line

The number of scientific papers published reflects the academic and industrial interest in the publication's contents (Kessler 1963); thus, it is one of the indicators used to determine the weight and level of importance of a research topic in related fields. The number of papers published on SM and SM with the TBL concept: environment, society,

and economy over a 30-year period, was determined in this study. To begin, two distinct categories of papers are collected: those on “sustainable manufacturing” and those on “sustainable manufacturing with TBL”. The number of papers on “sustainable manufacturing” is denoted by  $P_{SM}$ , while “sustainable manufacturing with the TBL concept”,  $P_{TBL}$ , is determined by

$$P_{TBL} = P_{Society} + P_{Economy} + P_{Environment} \quad (1)$$

where  $P_{Society}$ ,  $P_{Economy}$ , and  $P_{Environment}$  are the numbers of papers with the contents of SM with the social dimension, SM with the economic dimension, SM with the environment dimension, respectively. The three pairs of words “sustainable manufacturing/society”, “sustainable manufacturing/economic”, and “sustainable manufacturing/environment” were input to the search engine of Scopus to obtain  $P_{Society}$ ,  $P_{Economy}$ , and  $P_{Environment}$  respectively, while  $P_{SM}$  is obtained by directly inputting “sustainable manufacturing” to the search engine of Scopus. Consequently, the number of papers for  $P_{SM}$  and  $P_{TBL}$  is determined and shown in Fig. 1. Referring to Fig. 1, at the beginning state of SM from the years 1991–2000, the variation of the number of paper between “sustainable manufacturing” and “sustainable manufacturing with the TBL concept” is small, it implied that the direction of SM was well equipped with the TBL concept at the beginning state of SM. The difference in the number of papers begins to become significant

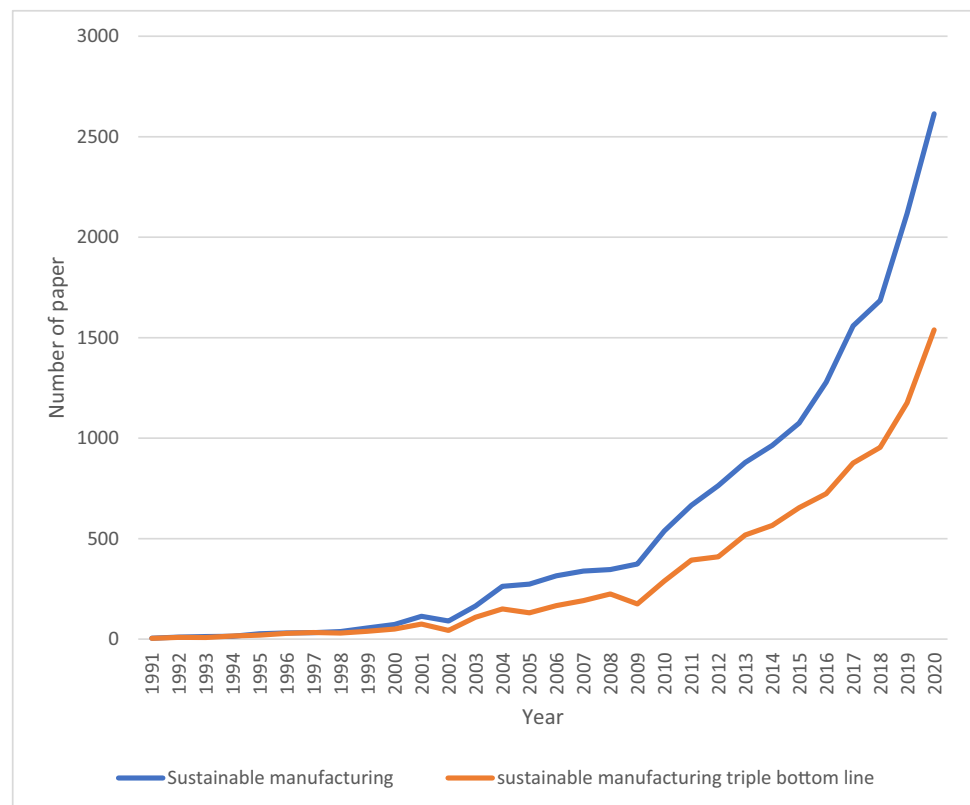
after 2000, and the difference continues to grow over time from 2000 to 2020. The above observation demonstrated that in the last two decades, academia, and industry have used alternative approaches to achieve SM, such as reducing energy consumption (Raileanu et al. 2017), designing machining parameters to produce the optimal machining condition (Xiong et al. 2016) and lengthening of tool life (Guo et al. 2021; Yip and To 2017). The proportion of SM that employs the TBL concept is illustrated in greater detail in Fig. 2, where the ratio of papers relating to SM and SM that employ the TBL concept,  $r_{TBL/SM}$  is defined as:

$$r_{TBL/SM} = P_{TBL} / P_{SM} \quad (2)$$

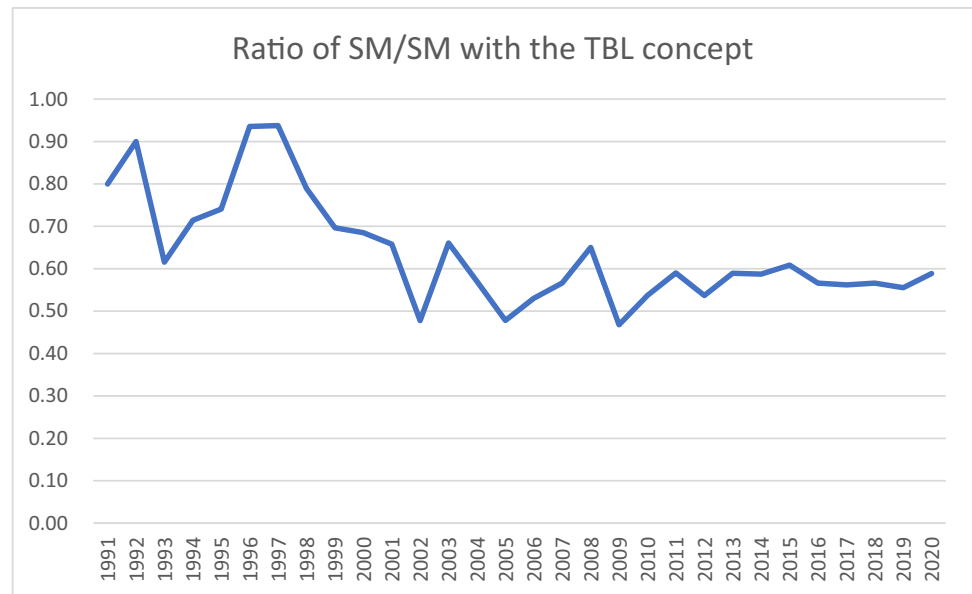
Similar conclusions can be drawn from the values of  $r_{TBL/SM}$ . Between 1990 and 2000, the values of  $r_{TBL/SM}$  are close to 0.6–0.94, indicating that a significant proportion of SM research employs the TBL concept. And, after 2000, the values of  $r_{TBL/SM}$  fall to around 0.6. And, up to 2020, the values of  $r_{TBL/SM}$  decrease to 0.58, indicating that nearly 40% of researchers achieve SM through non-TBL approaches rather than by adhering to the TBL concept.

The papers relating to SM that contain information on each of the three dimensions (economy, society, and environment) are collected and counted separately, as illustrated in Fig. 3. According to Fig. 3, the economic and environmental dimensions of the TBL concept on SM receive a greater number of papers

**Fig. 1** The number of papers of SM and SM with the TBL concept. At the beginning of SM (1991–2000), the number of papers between “sustainable manufacturing” and “sustainable manufacturing with the TBL concept” was small, indicating that SM was well equipped with the TBL concept. The difference in papers becomes significant after 2000 and grows from 2000 to 2020



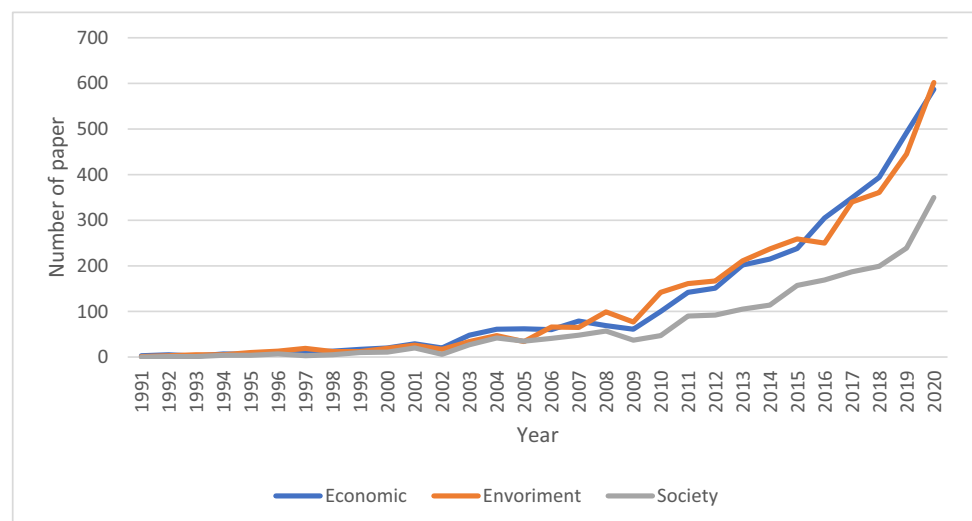
**Fig. 2** The ratio of the number of papers relating to SM and SM with the TBL concept.  $r_{TBL/SM}$  values are close to 0.6–0.94 between 1990 and 2000, indicating a large proportion of SM research uses TBL.  $r_{TBL/SM}$  drops to 0.6 after 2000.  $r_{TBL/SM}$  values decrease to 0.58 by 2020, indicating that nearly 40% of researchers achieve SM through non-TBL approaches



than the social dimension. After 2005, the difference becomes noticeable. Between 2005 and 2020, the total number of papers published in the economic and environmental dimensions is 3506 and 3516, respectively, with 1967 being solely for the social dimension. The number of papers on the economic and environmental dimensions of the TBL concept is approximately 78% greater than the number of papers on the social dimensions. The significant difference in the number of papers published in the economic/environmental and social dimensions indicated the unbalanced nature of the TBL concept in terms of SM execution, particularly in the research and industrial sectors. The TBL concept shifts the focus of SM to economic and environmental dimensions and places neglect on the social dimension, which is consistent with literature findings that TBL places a greater emphasis on the economic (Schönsleben et al. 2016).

Apart from the number of papers published by SM and SM that use the TBL concept, the citation of scientific papers is referred to as scholarly communications (Redner 1998) and is a proxy for the relationship between research and the sciences (Eom and Fortunato 2011). Additionally, it is used as an indicator for demonstrating scientific quality and accurately captures the overview of the scientific paper's influences (Zahedi and Haustein 2018). This session will determine the number of citations for papers on SM with the TBL concept and will reflect the influence of SM with the TBL concept on other fields, including but not limited to manufacturing. To avoid misunderstandings caused by the relatively large number of papers on economic and environmental dimensions, the citations of the papers are firstly normalized as per document. Due to

**Fig. 3** The number of papers of SM using the economic, social, and environmental dimensions of the TBL concept. Economic and environmental dimensions of TBL on SM receive more papers than social. The difference is noticeable after 2005



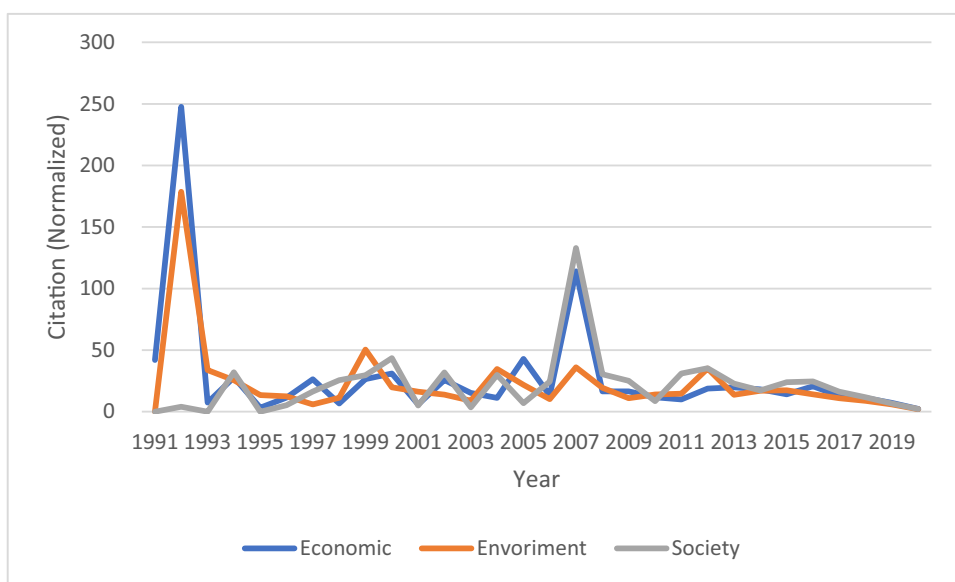
the availability of sufficient bibliographic data, it is possible to collect a sufficient number of papers for analysis and review of the dynamics of scientific productivity in terms of influences. As shown in Fig. 4, the normalized citation counts for papers on SM with TBL in each of the three dimensions are expressed individually. According to Fig. 4, the normalized citation counts for each of the three TBL dimensions are comparable from 1991 to 2020. Even so, the social dimension’s normalized citation count significantly exceeds that of the environmental dimension in 2007. By comparing the normalized citation counts of SM across three dimensions, we can surmise the effects of individual TBL dimensions on other domains. These findings indicate that the influences of three distinct dimensions on other areas are comparable, indicating that they are all significant in academia and industry, regardless of whether they fall within or outside manufacturing. Table 1 summarizes the findings of the normalized citation count and the number of papers for SM and SM with TBL.

### Research landscape

The visual maps of the research landscape for SM and its TBL concept are generated individually; therefore, three maps are output and shown in Fig. 5. The data sets cover the last 5 years, from 2015 to 2019. The size of the nodes and words in the maps indicates the density of document occurrences; thus, a larger size of the nodes and words in the Figure indicates a greater number of documents produced by the respective countries in each of the three dimensions of TBL. By comparing the visual maps of SM of the individual three dimensions of TBL, it is possible to compare the contents of SM with three dimensions in terms of countries and clusters of countries.

According to Fig. 5, the USA has the largest sizes in terms of both word and nodes across the three maps, with research on SM encompassing all three dimensions — economy, environment, and society. The preceding information established that the USA initiated research on SM

**Fig. 4** The normalized citation number of papers with three individual dimensions of TBL. The influences of three distinct dimensions on other areas are comparable, indicating that they are all significant in academia and industry, whether within or outside manufacturing



**Table 1** The summary of the number of papers and normalized citation papers

| Indicators                                  | Findings  | Implication   |
|---|---|---|
| $r_{TBL/SM}$                                | The ratio of SM with TBL/SM is near 1 from the year 1991 to 2000 and drops to 0.58 in 2020  | Most of the research on SM employed the TBL concept from 1991–2000, and, SM was achieved by other approaches rather than applying the TBL concept after the year 2001       |
| $P_{Society}, P_{Economy}, P_{Environment}$ | The accumulated numbers of papers for the economic and environmental dimensions from 2005 – 2020 are higher than that of the social dimension about 78% | The focus of SM with the TBL concept shifts to economic and environmental dimensions  |
| Citation number (normalized)                | The normalized citation number for all three individual dimensions of TBL are similar over the years from 1991 to 2020                                  | The influences of the three individual dimensions on other areas are similar, which they are all important in academia and industries within or outside manufacturing areas |

using the TBL concept in the last 5 years. And the same is true for China. The variation becomes significant for the remaining countries that participate in SM research using the TBL concept. In comparison to the other two dimensions, the economic dimension has the most countries conducting SM, with countries of Asia, Europe, and North America. Additionally, some developing countries, such as Colombia, Serbia, Romania, and Oman, have begun conducting SM research on the economic dimension, in which their countries do not appear on the map of the other two TBL dimensions of SM research.

Another noteworthy observation is that the USA, which has the largest node size across all maps, is shown to cluster with various countries for each three-dimensional dimension. The USA's nodes on the map are connected to a variety of countries, each of which has a distinct for three dimensions. For example, in the economic dimension, the USA clustered with Turkey, Portugal, and Columbia, indicating that these countries have recently begun research in the SM area focusing on economic issues; the formation of a cluster on the map indicates that they share citations for research works with the countries in the same cluster, implying that several countries with new experience in SM research specifically refer to the works of others. For the social dimension, the USA formed a cluster with China and Singapore, as these countries conducted research on SM and accounted for a sizable portion of the research output, as indicated by their respective sizes and nodes on the map. As a result, it implied that the primary strategies for conducting SM with a social component are linked by countries with a strong research capability, as measured by the number of papers produced by those countries. For the environmental dimension, the USA clusters solely with Canada; whereas, other countries with relatively large nodes, such as India and China, cluster with a variety of countries. This explains why the dominant countries conducting research on SM with an environmental dimension have a diverse range of strategies at various stages of development. As a result of the foregoing observations, we can conclude that the three dimensions of SM are distinct in terms of the number of countries involved, the cluster of countries involved, and the interactions between the dominant and remaining countries during the research process.

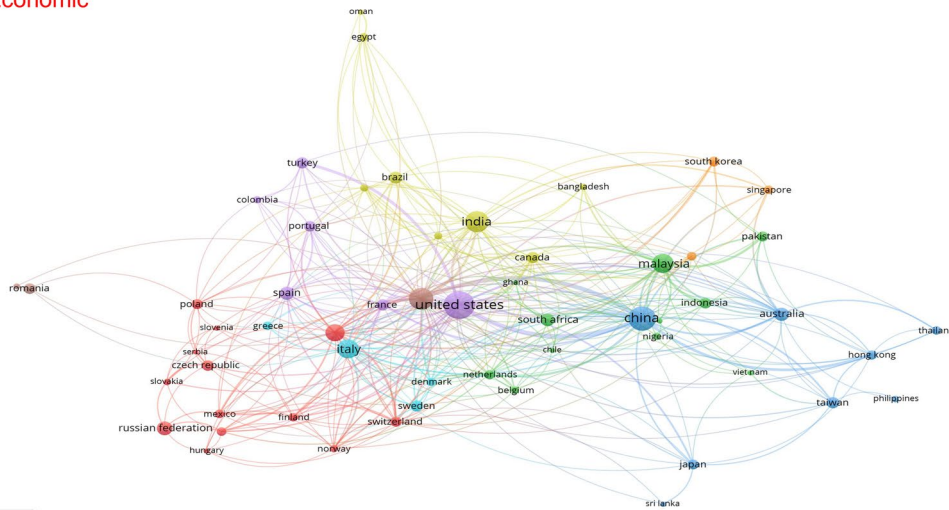
Besides the visualization of the countries involved in SM research, Fig. 6 showed the radar diagram of the countries producing the SM research with the three dimensions, which is used to display data about the countries and the number of papers produced by the corresponding countries in the form of a two-dimensional graphical chart. The relative positions of countries and the angle of the shape within the radar diagram enable the description of cross-country correlations and trade-offs. According to Fig. 6, the shape of SM was distinct from the other two dimensions in the social

dimension. The pattern of the diagram for the social dimension included a thin needle pointing to the USA, indicating that the USA is the dominant state in the SM research on the social concept and demonstrating the USA's high influence over other countries in the SM research on the social dimension; whereas, the radar diagram for the other two countries included patterns with flat areas without a point, it means that the influential power of the countries involved in the research of economic and environment are evenly distributed.

### **Thematic analysis — the current status of SM with the TBL concept**

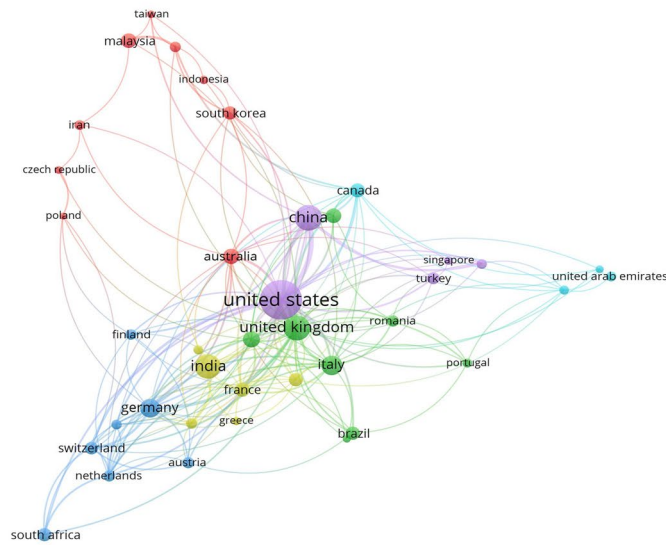
Thematic analysis can be employed to investigate the details of the differences in content between the three individual dimensions of TBL by analyzing the textual contents of papers. The SM papers are classified into three categories based on the three TBL dimensions in this article: SM/society, SM/economy, and SM/environment. The frequency of keywords in the papers is determined and output with a prioritized list based on the frequency. The frequency of keywords in scientific papers has been demonstrated to be an important source for revealing the evolution of research over the specified period (Chen et al. 2019). The corresponding keywords are reorganized in order of their frequency of occurrence in the input files. To conduct an inter-comparison of the specific dimension between the years 2005 and 2019, the input files are divided into three time periods: 2005–2009, 2010–2014, and 2015–2019. Figures 7, 8, and 9 illustrate the results of the keyword ranking for the three dimensions of society, environment, and economy. For the social dimension, the keywords “materials”, “technology”, “management”, “energy”, and “industry” rank highly in all three-time frames, indicating that recent SM research with the social concept has concentrated on these five primary themes. However, these five major themes are primarily concerned with engineering and management issues, such as technology, material science, energy consumption, industry practices, and management skills for achieving sustainable manufacturing. On the contrary, the terms commonly used in literature as keywords for the social dimension, such as “health”, “life”, and “safety” (Gbededo and Liyanage 2018) have not been seen as keywords in the social dimension. This implies that the focus of research on SM with a social concept shifts away from common social concerns and toward technological and industrial perspectives. For the environmental dimension, the top-ranking keywords are “environment”, “technology”, and “management”. This indicates that SM research on the environmental dimension is focused on these three mainframes and that SM research on the environmental dimension makes use of technology and management skills to achieve sustainability. One noteworthy observation

SM - Economic



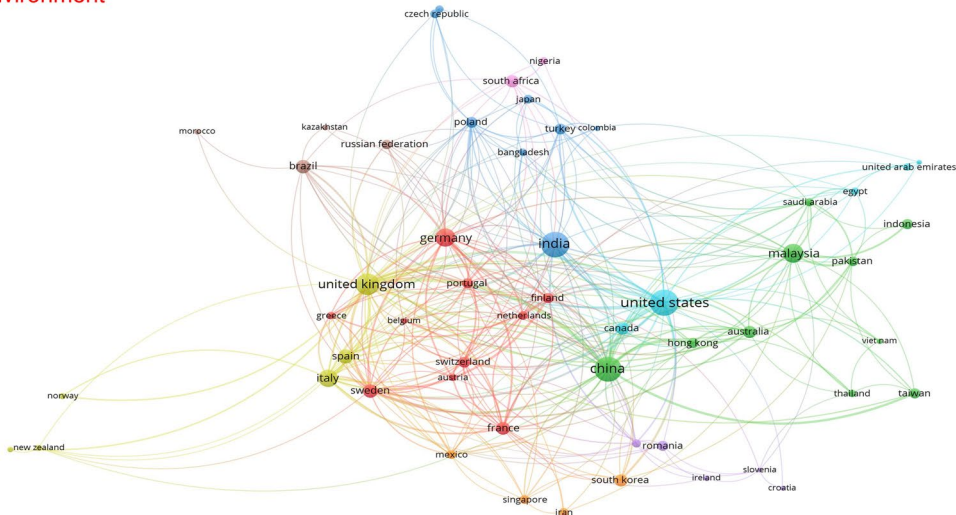
VOSviewer

SM - Society



VOSviewer

SM - Environment



VOSviewer

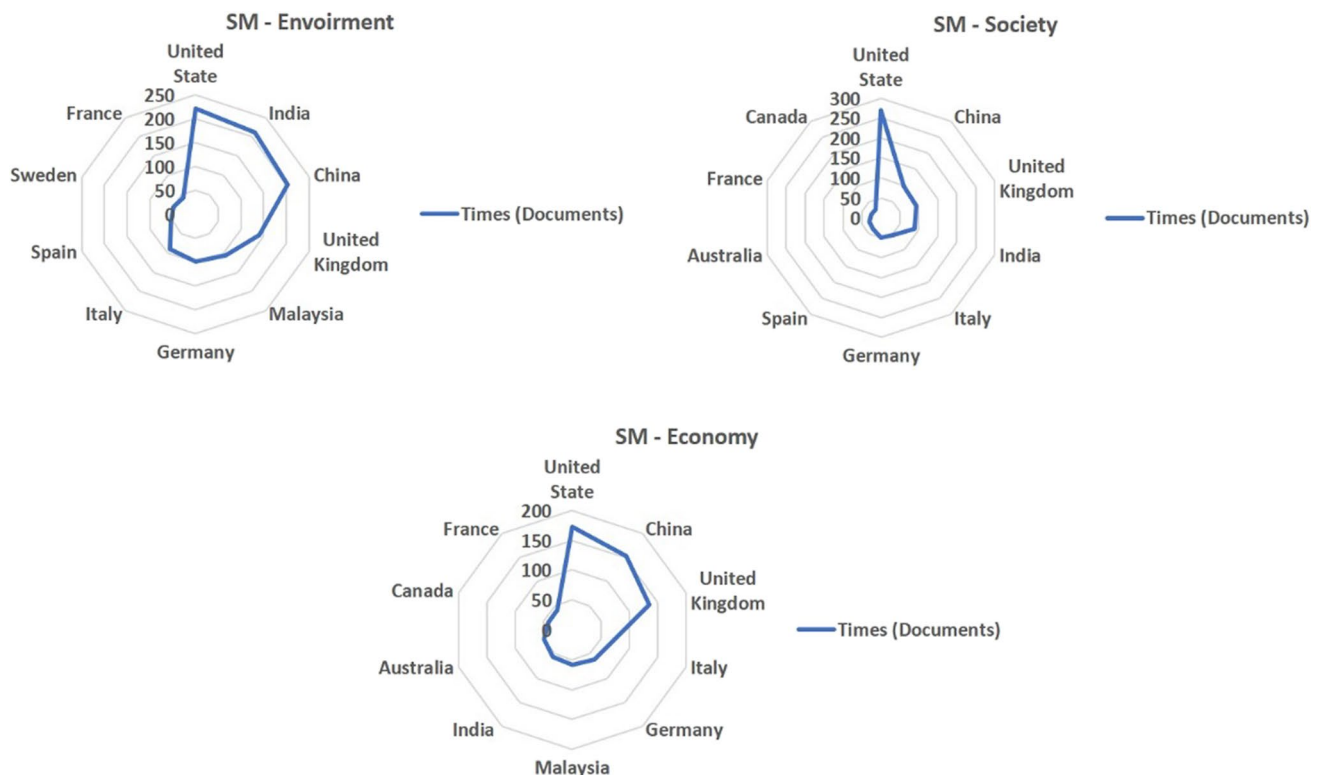


**Fig. 5** The visual maps of the research landscape for SM with three dimensions: economy, environment, and society. The size of the nodes and words in the maps indicates document density; larger nodes and words in the Figure indicate more documents produced by each country in each of the three dimensions of TBL

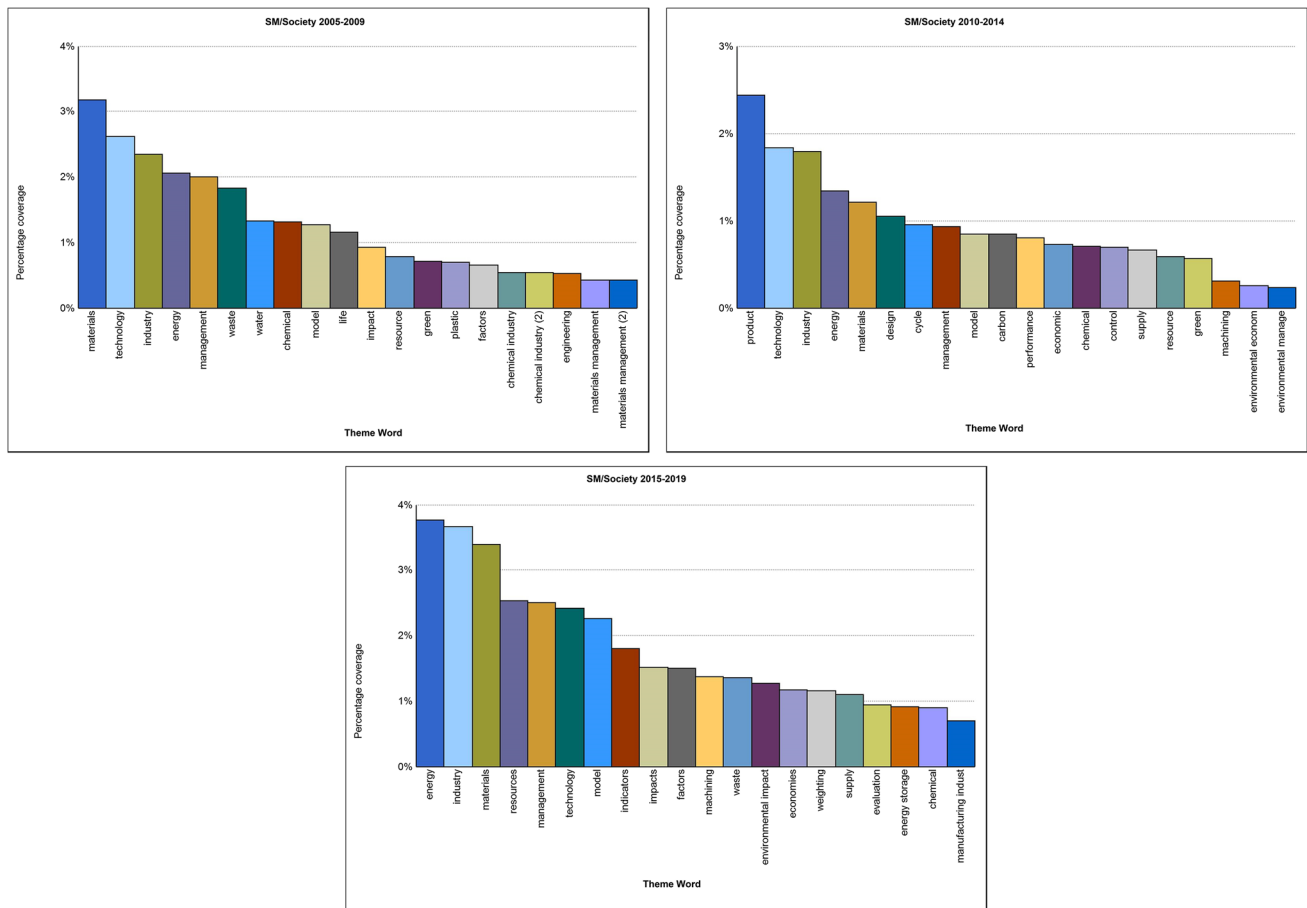
from the result is that, for the keyword “energy”, it was first ranked in the time period 2005–2009 and then gradually decreased over the years until the keyword “energy” was ranked even lower in the time period 2014–2019. This finding indicated that the emphasis on SM with an environmental dimension has shifted away from energy consumption in recent years, even though energy consumption has always been the primary focus of SM research (Zhao et al. 2017). And, up to the most recent time period, 2015–2019, a few new keywords “activities”, “cycle”, “waste”, and “chemical” appear that did not appear in previous time periods. This explains why the SM research on the environmental dimension has recently taken a new direction which is markedly different from the previous stage, and why the environmental dimension of SM research has begun to make major advances in terms of the research frame. For the economic dimension, the keywords “economic”, “cost”, “technology”, and “management” all rank highly, implying that the keywords’ apparent meaning revolves around resources

and their cost value. As a result of these findings, it is clear that SM research employs an economic perspective with a particular emphasis on cost, which is a key indicator in the economic dimension for quantifying the effectiveness of SM strategies. Additionally, the SM research works with the economic concept employ management and technology to achieve the optimal state of manufacturing sustainability.

Figure 10 illustrates a comparison of keyword rankings across three dimensions from 2015 to 2019. We can see from the results that the keywords for the two dimensions, environment and economy, appear at the top of the search results for their respective dimensions. For instance, in SM research focusing on the environmental dimension, the top-ranking term is “environment”, while the top-ranking term for the economic dimension is “economic”. This phenomenon, however, does not occur in the social realm. The top three rankings do not include the word “society”, but rather the terms “energy”, “material”, and “industry”, which are more closely related to engineering and environmental issues than to social issues. Additionally, the terms “resources” and “waste” appear in the social dimension’s keyword list, implying that the social issue of SM is focused on resource management, which is inextricably linked to the “environment” dimension. The thematic analysis demonstrates the disjunction between the research on SM and the



**Fig. 6** The radar diagrams of the counties producing SM research with three dimensions. The three-dimensional radar diagram of SM research displays data about the countries and the number of papers in a two-dimensional graphical chart



**Fig. 7** Inter-comparison of the social dimension of SM research from 2005 to 2019. Input files are divided into three time periods: 2005–2009, 2010–2014, and 2015–2019 to compare a specific dimension between 2005 and 2019, which it shows the keyword ranking for social dimension

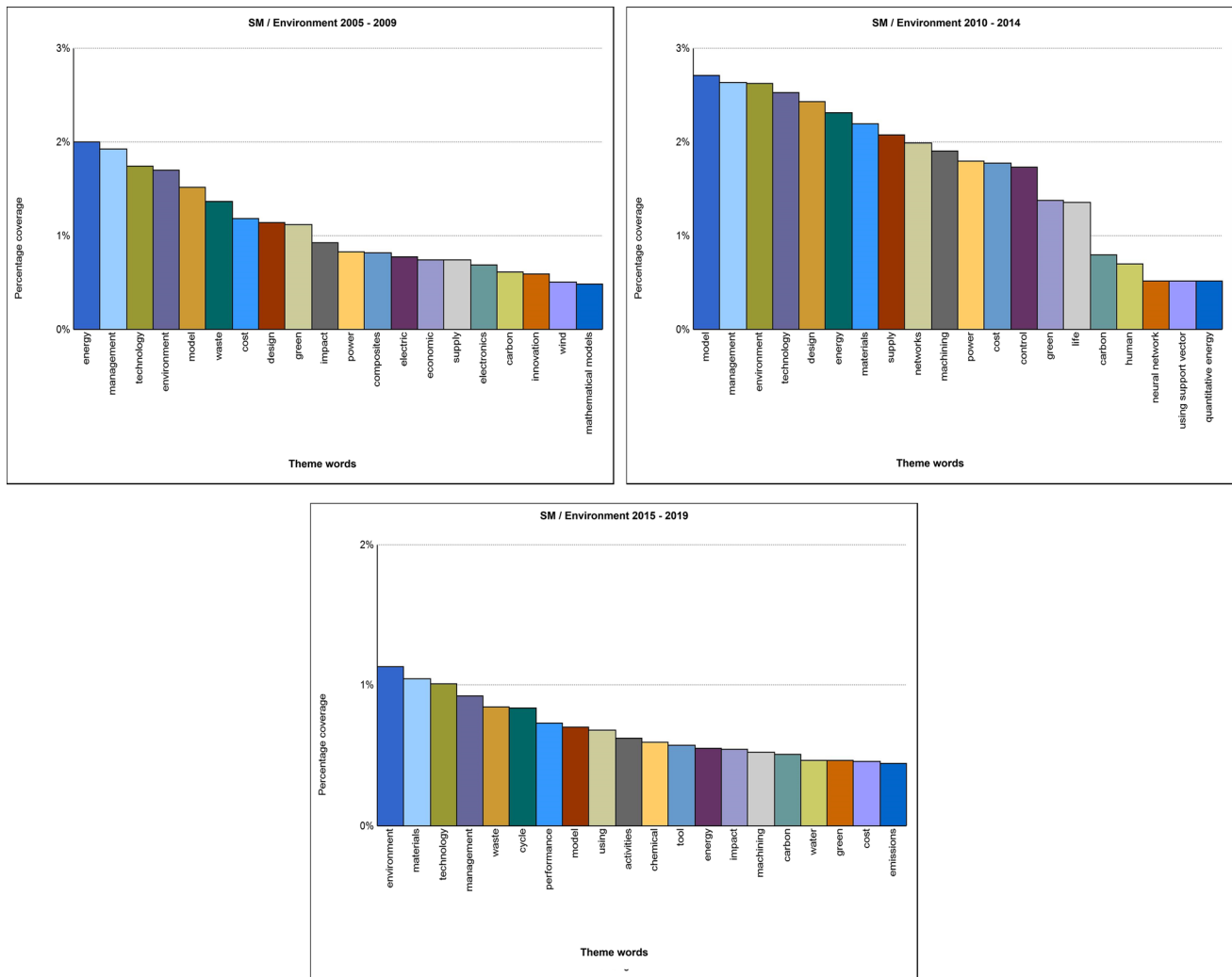
TBL concept. Overall, the implication of the comparisons between inter/cross dimensions is shown in Table 2.

### Cluster analysis and Pearson correlation

Cluster analysis generates a graphical representation of the input that conveys information about the input's similarities and differences by showing the distance between nodes in a graph/map. The greater the distance between two nodes, the less similar the target objects are for the input files. Cluster analysis is carried out using an iterative multidimensional scaling algorithm. The cluster analysis in this study is based on the textual contents of papers on three dimensions of TBL of SM: economy, environment, and society. Figure 11 illustrates a three-dimensional cluster map of SM papers from 2015 to 2020. The nodes “Environment”, “Economy”, and “Society” respectively represent the contents of SM research on the environment, economy, and society. According to Fig. 11, the cluster map shows that the nodes denoting “Environment” and “Economy” are clustered together. This explains why the content of SM research on “Environment” and “Economy” is relatively similar.

On the contrary, the “society” node is the furthest away from the “Environment” and “Economy” nodes. Similar logic is used; the degree of similarity between the contents of SM research on “society” and those on “Environment” and “Economy” is relatively low. The aforementioned demonstrated that the society of TBL dimensions has an independent status in SM research, with its contents distinct from those of “Environment” and “Economy”, while the contents of “Environment” and “Economy” are overlapping and similar to each other. The research ideas and directions on the environmental and economic dimensions of TBL are interdependent and share characteristics. The cluster analysis reveals the similarity and overlapped characteristics of TBL's environment and economy in terms of SM research and the individual state of the social dimension.

Pearson correlation coefficient is used to determine the covariance of two items, which is a statistical tool that is frequently used to determine the degree of similarity between two items by displaying a numerical value. Pearson correlation coefficients close to 1 indicate that the two nodes/input files are the most similar. The textual contents of SM papers incorporating the three dimensions of the TBL concept are



**Fig. 8** Inter-comparison of the environmental dimension of SM research from 2005 to 2019. Input files are divided into three time periods: 2005–2009, 2010–2014, and 2015–2019 to compare a spe-

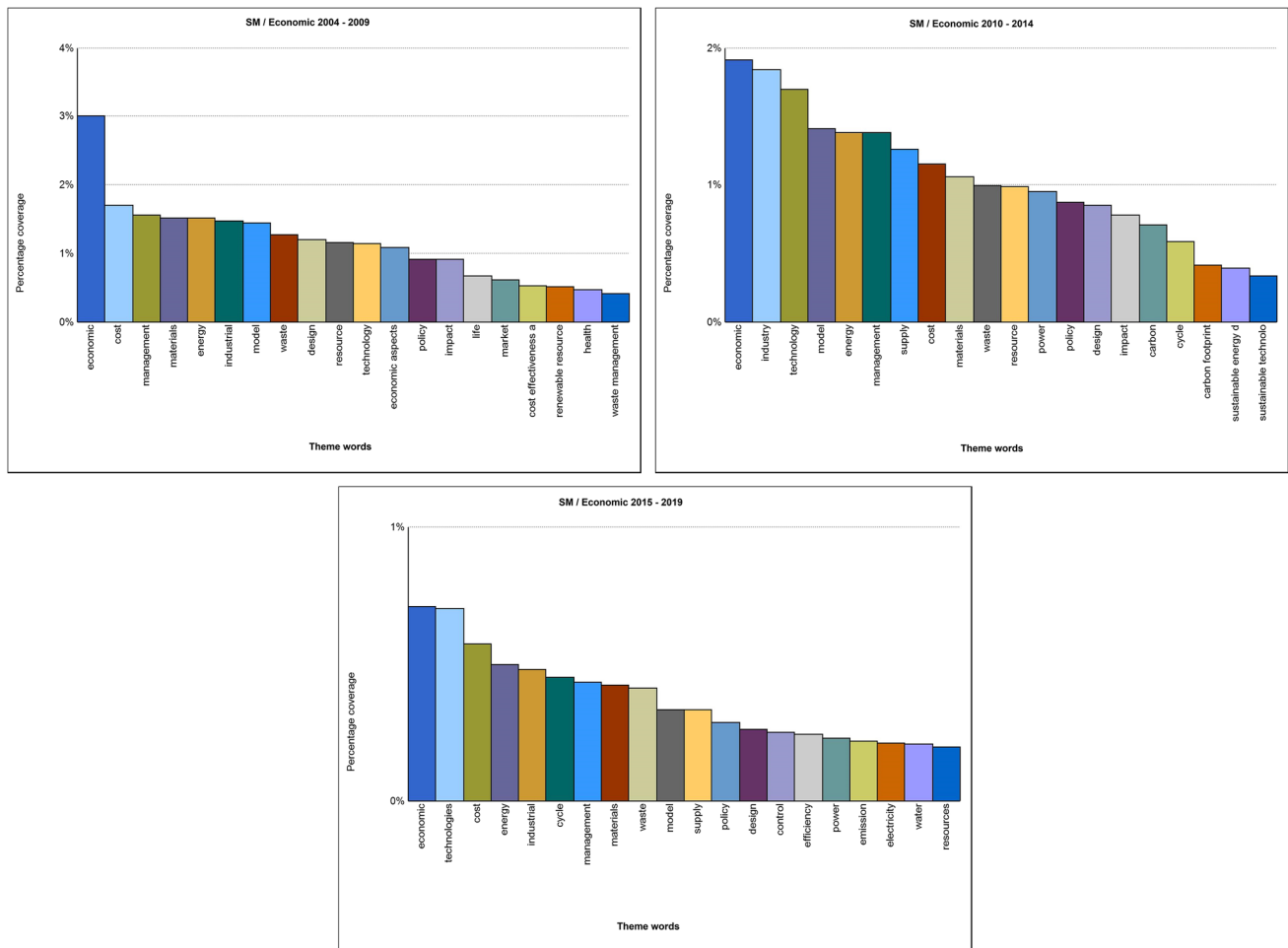
cific dimension between 2005 and 2019, which it shows the keyword ranking for environmental dimension

collected individually and then used as input to calculate the Pearson correlation coefficient between pairs of two nodes, the results of which are shown in Table 2. According to the results of Table 3, the Pearson correlation between “environment” and “economy” is 0.9699, which is the highest value among all TBL dimension pairs. Pearson correlation coefficients for dimension pairs relating to the “society” dimension are relatively low, at 0.937 and 0.9219 for the pairs society/environment and society/economy, respectively. The above results indicate a high degree of similarity between the textual contents of SM research on the environmental and economic dimensions, whereas SM research on the social dimension has a relatively low degree of similarity to both the “environment” and “economic” dimensions. Pearson correlation demonstrates the similarity of textual contents between the pair of three

TBL dimensions, and it demonstrates that the social dimension research has an independent state with a distinct research direction distinct from the other two dimensions, which agrees with the cluster analysis results. Overall, the implications of Pearson correlation coefficient and cluster analysis are shown in Table 4.

### Future directions and suggestions for sustainable manufacturing with triple bottom line concept

The international sustainable development goals by United Nation provide a comprehensive framework for achieving sustainable development in a variety of sectors, including



**Fig. 9** Inter-comparison of the economic dimension of SM research from 2005 to 2019. Input files are divided into three time periods: 2005–2009, 2010–2014, and 2015–2019 to compare a specific dimen-

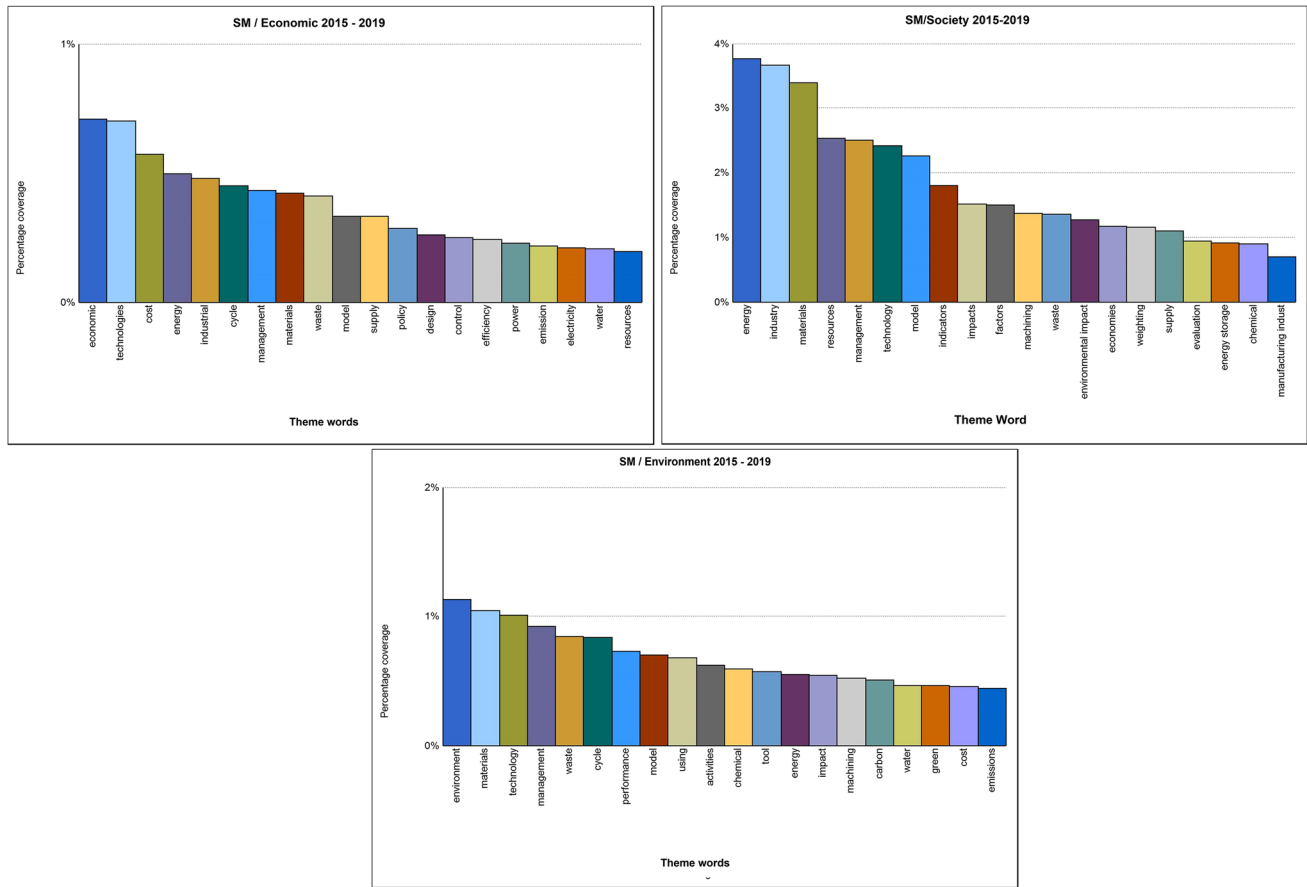
sion between 2005 and 2019, which it shows the keyword rankings for economic dimension

manufacturing, and it strongly recommends and emphasizes the critical role of TBL in achieving sustainability (Moldan et al. 2012; Tsalis et al. 2020). The sustainable development goals serve as a guide to demonstrate the fundamental and underlying principle of sustainability, which states that the TBL concept should be retained, and the three dimensions balanced. The bibliometric and textual analysis of this study reveals an imbalance in TBL for the manufacturing sector, with a disproportionate emphasis on the economic and environmental dimensions, while the social dimension is given a lightweight in comparison. With this observation, the embrace and recommendations made in this article are strongly endorsed by sustainable development goals by United Nation. The United Nations’ 2030 Agenda for sustainable development outlines a strategy focused on people, the planet, and prosperity, all of which are concepts found in all dimensions of TBL. The agenda aims to consolidate universal peace while maintaining a high level of freedom. Agenda 2030 establishes and

develops 17 sustainable development goals and 169 targets. Among these goals and targets, we focus on 9.2 and 9.c of Goal 9 and 12.7, 12.a of Goal 12, as these two goals are appropriate for the production and manufacturing sectors in order to achieve sustainable manufacturing development. And, the specific targets were chosen because they have a high potential for increasing social awareness and weighting the social dimension of SM, as well as achieving a balanced TBL of SM. Table 5 summarizes the selected targets and goals.

**Goal 9 of sustainable development goals and the suggestions**

As this session's objective is to resolve the TBL imbalance and increase the weighting of the social dimension, a few targets are chosen as the foundation for the suggestions made, the indicators for which are detailed in Table 3. For goal 9, it aims to “promote inclusive and



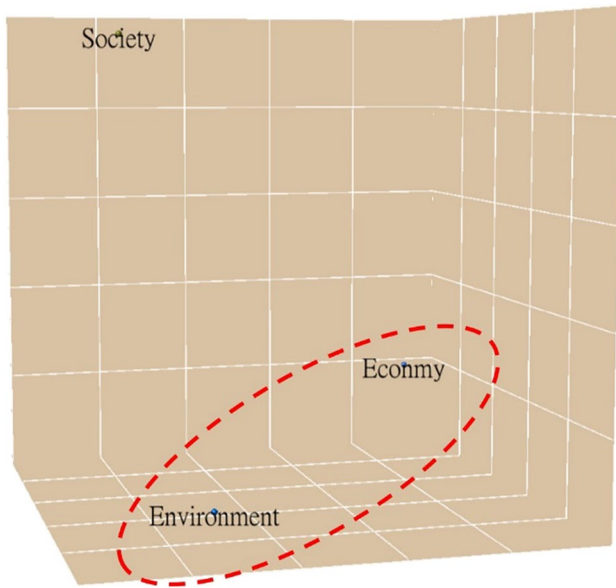
**Fig. 10** 2015–2019 keyword rankings in three dimensions. The comparison of the keyword ranking between three dimensions in the period 2015–2019

**Table 2** The implication of the comparisons between inter/cross dimensions

| Comparison      | Dimension                               | Implications   |
|-----------------|---|--|
| Inter-dimension | Social dimension                        | Shifts away from common social concerns and toward technological and industrial perspectives |
|                 | Environmental dimension                 | Use of technology and management skills to achieve sustainability                            |
|                 | Economic dimension                      | Particular emphasis on cost  |
| Cross dimension | Comparison between all three dimensions | The disjunction between the research on SM and the TBL concept                               |

sustainable industrialization and foster innovation”, which are the objectives of SM. Within Goal 9, the targets 9.2 “Increase employment and gross domestic product (GDP) in the industrial sector” and 9.c “Increase access to information and communications technology and enable least developed countries to have a feasible way to access the web/internet” have been chosen to raise the attention on the social dimension of SM. For target 9.2, it proposed expanding the dimensions of employment and GDP in the industrial sector, with an emphasis on employment issues and the income generated as a social indicator.

Stakeholders in SM should consider whether companies act responsibly toward society in general (Jennifer Ho and Taylor 2007) as social awareness of the corporation’s role in sustainability is growing, and the corporation’s roles and responsibilities are being emphasized concurrently (Adams et al. 1998). According to target 9.2, industries sectors are strongly encouraged to create jobs in order to contribute to corporate social performance, which is one of the most effective ways to increase cooperation’s competitiveness and manufacturing sectors’ sustainability capacity. Therefore, in this study, manufacturing firms



**Fig. 11** The cluster map of SM papers with three dimensions in the year 2015–2020. A three-dimensional cluster map of SM papers published between 2015 and 2020. Environment, economy, and society nodes represent the respective contents of SM research on environment, economy, and society

**Table 3** The Pearson correlation coefficient of three dimensions of TBL in the year 2015–2020

| TBL dimension A | TBL dimension B | Pearson correlation coefficient |
|-----------------|-----------------|---------------------------------|
| Environment     | Economy         | 0.9699                          |
| Society         | Environment     | 0.9370                          |
| Society         | Economy         | 0.9219                          |

are encouraged to follow Swedish practices in conducting employment practices in order to increase the social impact of TBL. Swedish companies typically disclose quantified information about employee issues and ethical reporting, and the company that executes the level of social disclosures using this approach is a determinant of the level of social disclosures (Jennifer Ho and Taylor 2007). However, there are widespread criticisms that

disclosure practices favored industry funders. Craig and Diga (1998) investigated five Asian countries with disclosure practices and discovered that industries exhibited a high degree of benefit orientation toward capital providers, rather than consideration for the entire workforce and community. As a result, industries should be aware of the issues to avoid further shifting the focus of TBL to the economic dimension when conducting the employee measurement.

For target 9.c, it is proposed to increase access to information and communications technology and to develop a feasible method for evaluating the web/internet for least developed countries. Al-Roubaie (2010) examined the role of information and communication technologies in alleviating poverty in Muslim-majority countries. Additionally, the work demonstrated the efficacy of information and communication technology facilities in addressing the social dimension of sustainable development, relying on a united nation. The approach gives benefits to the generation and dissemination of new knowledge, which is one of SM’s ultimate goals. Recent scientific research in information and communication technology has primarily focused on identifying technological gaps, particularly in terms of storage capacity and computing speed (Wu et al. 2018). Thus, the suggestion here for SM is that the research and development of SM using information and communication technology should involve extensive collaborations between various agencies, particularly industry, governments, and commercial organizations, in which the collaborations should be aligned with socially responsible practices in terms of social policies and regulations, and thus the collaborations can meet the obligation with high efficiency. It improves the effectiveness of sustainable development practices, particularly the social dimension of SM.

**Goal 12 of sustainable development goals and the suggestions**

For Goal 12, target 12.7, it states “facilitate sustainable public procurement practices in accordance with national policies and priorities”. For manufacturing sector roles, industries should include upstream supply chain management activities that influence purchasing and selling (Gunasekaran and Spalanzani 2012). Recently, businesses have shifted their focus to global

**Table 4** The implications of Pearson correlation coefficient and cluster analysis

| Analyses                        | Results  | The implications  |
|---------------------------------|--|---|
| Pearson correlation coefficient | A high degree of similarity between the textual contents of SM research on the environmental and economic dimensions                 | The research of SM in social dimension has an independent state |
| Cluster analysis                | The degree of similarity between the contents of SM research on "society" and those on "Environment" and "Economy" is relatively low |   |

**Table 5** The summary of selected targets and goals from the United Nations' sustainable development goals by United Nation

| Goal | Target number | Target   | Indicators  | TBL dimension for SM        |
|------|---------------|--|---|-----------------------------|
| 9    | 9.2           | Increase in the dimensions of employment and gross domestic product (GDP) in the industrial sector   | 1. Proportion of GDP and per capita of manufacturing area; 2. proportion of total manufacturing employment                                      | Economy/society             |
|      | 9.c           | Increase the access level of information and communications technology and enable to provide a feasible way to assess the web/internet for the least developed countries | The proportion of population assess to the mobile network using technology  | Society                     |
| 12   | 12.7          | Facilitate the public procurement practices that are sustainable, referring to national policies and priorities  | Number of countries implementing sustainable public procurement policies and action plans   | Society/economy/environment |
|      | 12.a          | Support developing countries to enhance scientific and technological capacity to have more sustainable patterns of consumption and production                            | Amount of support to developing countries on research and development for sustainable consumption and production and environmental technologies | Society/environment         |

operations through outsourcing and procurement from third parties. This means that the manufactured components offered by third parties should support sustainable development, allowing the manufacturer to exert influence over downstream parties to promote fair trade, particularly in supply management (Hollo et al. 2012). Therefore, the word “sustainable supplier cooperation” by Hollos et al. (2012) could be used to describe the SM strategies in this study. Sustainable supplier collaboration is distinct from traditional supplier collaboration in that it requires specific suppliers to contribute in terms of social performance toward green, with the coordination’s contents including co-planning activities, trustworthy promises, and sustainable feedback, all of which are frequently cited and discussed in literature works. As a result, manufacturers should leverage the benefits of this concept to further increase the weight placed on TBL’s social impact.

For target 12.a, it states about “Support developing countries to enhance scientific and technological capacity to have more sustainable patterns of consumption and production”. This is the implementation target, and it aims to mitigate the negative environmental impacts of economic growth without increasing social impacts, through efficient use of technological innovation and green fabrication processes. Indeed, the focus of sustainable production has shifted recently to attempting to resolve the “consumption-sustainability dilemma” through the use of relative decoupling (O’Rourke and Lollo 2015), which primarily addresses consumption issues through the fabrication of products with a single purchasing advice for customers. As a result, the main practices for this are to encourage customers to take responsibility for green purchasing; however, the manufacturer’s responsibility for sustainable consumption is not mentioned. Manufacturers should make an effort as well and design products with enhanced performance and longer life cycles, attempting to produce fewer units but of higher quality. The approach is believed to enable the support of sustainable production through the use of green technologies, thereby benefiting the social dimension of SM through lower product and manufacturing costs, increased sales volume, and customer loyalty with less resource consumption.

## Conclusion

Triple bottom line, as a foundation and principle underlying SM, has garnered attention from the manufacturing sector. This study uses bibliometric and text mining to illustrate the historical and current situations of TBL of SM, thoroughly comparing and revealing the variations between three dimensions to show the imbalanced focus of TBL at the moment. The information in this paper serves as a reference for academia and industry in order to more effectively implement SM while maintaining the equity of importance of all TBL

dimensions. Finally, recommendations have been made to align with the sustainable development goals of the United Nations in order to increase the influence of SM's social dimension. In general, the following findings are noteworthy:

1. SM research initially used the TBL concept; however, beginning in 2000, SM research began to employ alternative approaches.
2. The citation numbers for the three dimensions of TBL indicate that their influences on other areas apart from the manufacturing sector are comparable.
3. The dominant countries conducting research on SM with an environmental component are taking divergent paths.
4. The ideas and directions of SM research on the environmental and economic dimensions of TBL are interdependent with shared characteristics, demonstrating the social dimension's independent status and the SM's imbalanced TBL situation.
5. Sustainable development goals by United Nation provide direction for developing practices that increase the social impact of SM and contribute to achieving a balanced TBL.

With the above results and conclusions, the target audience, particularly industries and research institutions, can gain a better understanding of the current development of SM and how manufacturing processes integrate with the TBL concept in order to achieve sustainability, with a focus on the expertise, technological approach, and research works conducted in various countries. Importantly, we have provided the suggestions aligned with the sustainable development goals of the United Nations in order to strengthen the impact of the social dimension based on the deficiency of current SM strategies. This study gives academics and industry with a reference for adopting SM more successfully while preserving the value of each TBL dimension.

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**Data availability** Data available on request from the authors.

## Declarations

**Ethical approval** This work does not contain any ethical issues or personal information.

**Consent to participate** No human or animal was involved in this work; thus, no consent was required.

**Consent for publication** All authors have given their permission for publishing this work.

**Conflict of interest** The authors declare no competing interests.

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