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Knowledge roadmap of sustainable development in the textile and apparel industry: a scientometric analysis

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Abstract

Practices in the textile and apparel industry (TAI) have led to numerous environmental and social problems, which have prompted extensive research on the sustainable development of the textile and apparel industry (SDTAI). This paper presents a comprehensive and quantitative analysis of the status quo in the SDTAI domain using scientometrics. From 1987 to 2019, the Web of Science core collection databases (SCI and SSCI) included 863 journal articles related to SDTAI, and our analysis results were as follows: (1) 60 critical research keywords occur in the knowledge base; (2) four research hotspots were identified; (3) five themes constituted the main knowledge area; and (4) based on the knowledge base, research hotspot, and knowledge domain, the knowledge structure consisted of nine subjects and five systems. This paper proposes a knowledge roadmap that can be helpful for practitioners and academicians to better understand the current sustainable development status and trends in the TAI.

Keywords: Textile and apparel, Scientometric, Literature review, Knowledge roadmap, Sustainable development

Introduction

Practices in the textile and apparel industry (TAI) have led to numerous environmental and social problems, such as high emissions, high water consumption, high energy consumption, and heavy pollution. In the European Union (EU), 2–10% of current environmental impacts are a result of TAI consumption (Liu et al., 2020; Manda et al., 2015). In China, the textile industry accounted for 2.6% of the total industrial energy consumption in 2019 (NBSb, 2021); further, 1.96 million tons of wastewater, accounting for 10.5% of the total industrial wastewater consumption, were discharged into sewage treatment plants (Liu et al., 2020). As the second largest industrial polluter after the oil industry, the apparel industry is a 10% contributor to global carbon emissions (Muthukumarana et al., 2018). Additionally, the ineffective disposal of textiles has become an increasingly serious concern in sustainable development (Xu et al., 2019). The significant quantities of textile waste entering landfills each year have resulted in severe pollution and chemical hazards. Annual estimates of the amount of textiles landfilled in 2016 in the USA,

China, and the EU were 29.3, 14.5, and 9.6 kg per capita, respectively (Bukhari et al., 2018). Therefore, to alleviate the adverse impact on the environment and society, the TAI must incorporate sustainable principles.

In recent decades, the sustainable development of the textile and apparel industry (SDTAI) has widely focused on theoretical and industrial modes. Scholars from different disciplines have conducted many studies on SDTAI, involving numerous research fields, such as sustainable consumption behavior (Hong & Kang, 2019; Rausch & Kopplin, 2021), sustainable production (Alkaya & Demirer, 2014; Ozturk et al., 2015), ethical apparel (Carey & Cervellon, 2014; Choi et al., 2012), sustainable design (Fletcher, 2014; Niinimaki & Hassi, 2011), and sustainable business models (Becker-Leifhold & Iran, 2018; Hirscher et al., 2018). With thousands of studies in this field, understanding the research focus and status quo is difficult; furthermore, we can easily overlook the research-associated risks and practice improvements in key issues and major areas.

A literature review is an expedient approach to gain insight into a specific field of study (He et al., 2017). Several studies have reviewed relevant literature on SDTAI. Such as, Luo et al. (2021) reviewed the environmental sustainability assessment methods and discussed about their limitations in the TAI; Mukendi et al. (2020) reviewed research on management perspectives for sustainable fashion and identified social impacts and chances for further research; Islam et al. (2021) conducted a review of environmentally sustainable practices in a variety of manufacturing processes in the TAI and developed a conceptual framework to provide guidance on sustainable practice; Thorisdottir and Johannsdottir (2020) reviewed the document published from 2003 to 2019, focusing on the impact of corporate social responsibility on sustainability of fashion industry; Additionally, Jia et al. (2020) analyzed the drivers, obstacles, practices and metrics of circular economy in the TAI and proposed a conceptual model; Köksal et al. (2017) provided a review of the social issues in the TAI on sustainable supply chain management; and Tey et al. (2018) reviewed the key drivers that influence consumers' willingness on paying more when purchasing sustainable clothing products. Although these studies have made significant contributions to SDTAI, they focus particularly on specific aspects, but do not provide a systematic and extensive view. Furthermore, the manual review method is mainly employed in existing reviews, which is prone to bias in terms of limitations in subjective interpretations, the number of articles reviewed, and a lack of producibility (Hammersley, 2001; Markoulli et al., 2017).

To address the above deficiencies, this study employed scientometrics analysis, a quantitative method aimed at reducing bias caused by manual review, to provide a comprehensive and objective summary of the existing literature. A comprehensive and quantitative review of relevant research will help researchers and industry stakeholders learn about the research status quo and a consideration of future directions. Thus, this study performed a holistic review of relevant studies in the field of SDTAI with scientometric methods. It aims to respectively identify knowledge base (e.g. unstructured key research topics), knowledge hotspots (e.g. unstructured key research topics), and knowledge domains (e.g. structured key research topics) through keyword co-occurrence networks, document co-citation networks, and clustering analysis techniques. We also propose knowledge structures with different saliencies and knowledge roadmaps based on an in-depth analysis of the research results.

Methods

This study applied scientometric methods to conduct a comprehensive review of research associated with SDTAI. Scientometrics is referred to the visualization or drawing of knowledge domains (Pollack & Adler, 2015), a technique that provides quantitative research for literature reviews. The evolution process and structural relationship can be revealed by scientometric analysis in a specific field in terms of a large-scale academic dataset (Chen et al., 2009). In addition, a broader and more diverse set of relevant topics can be studied than with traditional methods (Li et al., 2017). It can also improve objectivity and reliability of study results (Zhai et al., 2020). Researchers in numerous fields have used scientometric methods to draw and examine the intellectual landscape and research topics (Hood & Wilson, 2001; Zhao, 2017). The research method included three stages: tool selection, data collection, and data analysis.

Tool selection

Mainstream software tools for scientometrics analysis mainly include VOSViewer, Ucinet, BibExcel, SCIMAT, and CiteSpace, among others (Cobo et al., 2011). Among these tools, CiteSpace, developed by Chen Chaomei of Drexel University, is characterized by a more comprehensive integration of analysis methods, mainly involving co-occurrence analysis, evolutionary trend detection, cluster detection, and visual analysis functions. CiteSpace is used extensively in various fields, including management, medicine, environmental science, computer science, information science, and social science (Yang & Meng, 2019). Therefore, CiteSpace (5.6.R1) was used in the present research.

Data collection

For this study, the Web of Science Core Collection Database Social Sciences Citation Index (SSCI) and Science Citation Index Expanded (SCIE), by Clarivate Analytics, were selected to obtain bibliographic data, as they consist of the core and influential journal articles in many fields (Pouris & Pouris, 2011). Each bibliographic record contains an author list, title, abstract, keywords, and references. Each reference includes the origin type, volume number, first author's name, publication year, and DOI reference. Using the advanced search function of the Web of Science, bibliographic data was retrieved using two keywords, which were ("textile" or "apparel" or "fashion" or "garment" or "clothing") and ("sustainability" or "sustainable development"). Additionally, journal articles written in English were selected as the literature type. Journal articles published from 1987 to 2019 were selected. Based on the above retrieval criteria, the search obtained 863 records of original research articles.

Data analysis

Specifically, this study mainly adopted keyword co-occurrence analysis, document co-citation analysis, and cluster analysis using the CiteSpace software tool for scientometric analysis. First, the keywords that appeared in the fewest two diverse documents during the same period were obtained by keyword co-occurrence analysis

(Luo et al., 2019). The critical research focus or directions at a specific time were identified using high-frequency keywords. The keyword extraction method used in this paper is the original keywords of the literature. These high-frequency keywords were considered the knowledge base in a certain research domain. Second, highly cited documents in a certain area were acquired using document co-citation analysis (Small, 1973). Documents cited jointly repeatedly in a particular field have potentially greater influence and report much more similar or related concepts when compared with those that are less cited (Chen et al., 2010). Knowledge hotspots were obtained through document co-citation analysis. Third, cluster analysis detected clusters using CiteSpace. The literature topics in the same cluster were more similar than those in other clusters. Thus, the knowledge domains were obtained via the clustering analysis, which likely detected significant details concealed in a mass of information and pursued research fronts, as compared to other scientometric approaches (Li et al., 2017).

Results

Keyword co-occurrence analysis (knowledge base)

Keywords denote the core content of an article. Thus, keyword analysis can be used to identify critical research topics related to a scientific domain (Zhu & Hua, 2017). The keyword co-occurrence network was constituted by 170 nodes and 962 links sourced from the database, as shown in Fig. 1. Each node represents one keyword, whose

Fig. 1 Keyword co-occurrence network for the sustainable development of the textile and apparel industry (SDTAI)

magnitude is proportional to the co-occurrence frequencies. Since keywords are closely related to the core of the literature, analyzing similar keywords can be helpful in identifying the core of SDTAI research. The terms are being grouped below, such as sustainability, sustainable development, green, and sustainable fashion can be grouped into one category. As listed in Table 1, the top 60 terms had 2,081 co-occurrence frequencies, representing up to 92% of all the keyword frequencies.

As shown by the co-occurrence frequencies in Table 1, the following keywords are the most commonly used: sustainability/sustainable development/green/sustainable fashion (414 times), consumption/behavior/consumer/attitude/perception/knowledge/

Table 1 Top keywords with their frequencies for the sustainable development of the textile and apparel industry (SDTAI)

Rank	Frequency	Keyword	Rank	Frequency	Keyword
1	414	Sustainability/sustainable development/green/sustainable fashion	31	9	Recycling
2	245	Consumption/behavior/consumer/ attitude/ perception/knowledge/intention/decision making/willingness to pay/consumer behavior/planned behavior/motivation	32	9	Composite
3	188	Textile/fashion/apparel/textile industry/ apparel/fashion industry/apparel industry	33	9	Policy
4	154	Management/supply chain/supply chain management	34	9	Chain
5	130	Impact/environmental management/environmental sustainability/climate change/environment/Energy	35	9	Technology
6	92	Corporate social responsibility/social responsibility/csr/ responsibility	36	8	Mechanical property
7	87	Performance/financial performance	37	8	Market
8	61	Model	38	8	Value
9	52	System	39	7	Quality
10	45	Life cycle assessment (LCA)	40	7	Business
11	38	Industry	41	7	Textile waste
12	37	Product	42	7	Chain management
13	37	Cotton/fiber/wool/polyester	43	7	Conceptual framework
14	35	Design	44	6	Network
15	34	Framework	45	6	Economy
16	24	Governance	46	6	Implementation
17	24	Perspective	47	6	Efficiency
18	24	Strategy	48	6	Barrier
19	23	Innovation	49	5	Developing country
20	19	Future	50	5	India
21	17	China	51	5	Science
22	16	Circular economy	52	5	Evolution
23	14	Firm	53	5	Risk
24	14	Organization	54	5	Conservation
25	13	Degradation	55	5	Ethics
26	13	Optimization	56	4	Nanoparticle
27	12	Fast fashion	57	4	Reuse
28	11	Challenge	58	4	Ecology
29	10	Driver	59	4	Dye
30	9	Corporate sustainability	60	4	Dynamics

intention/decision making/willingness to pay/consumer behavior/planned behavior/motivation (245 times), textile/fashion/apparel/textile industry/clothing/fashion industry/apparel industry (188 times), management/supply chain/supply chain management (154 times), impact/environmental management/environmental sustainability/climate change/environment/energy (130 times), and corporate social responsibility/social responsibility/csr/responsibility (92 times). Therefore, we can conclude that sustainable supply chain management, sustainable consumer behavior, and corporate social responsibility are the basic components of SDTAI. The remaining 54 primary keywords in Table 1 mainly involved the following four groups.

Performance and model were also important research areas, with occurrence frequencies of 87 and 61, respectively. To allow businesses to concurrently satisfy both sustainability and economic performance, the sustainable business model concept has been utilized in the TAI (Thorisdottir & Johannsdottir, 2019). The business model is the structure of an enterprise's mechanism for creating, delivering and capturing value. (Teece, 2010). Incorporating sustainability into textile and apparel (TA) business models is essential for recognizing barriers and disturbances to the realization of economic, environmental, or social sustainable development goals (Manninen et al., 2018). Some studies focus on diverse methods of introducing sustainability into the business model of the TAI, such as the acquisition of competitive edge, innovation, and model structure. (Sorescu et al., 2011; Westerlund, 2013). Several studies have concentrated on how to evaluate and report on the sustainability of the TA business model (Park & Kim, 2016).

Life cycle assessment (LCA) is a critical topic, with a co-occurrence frequency of 45. LCA is an environmental management and decision support tool for the full life cycle of TA products, including raw material production and acquisition, design, manufacture, transportation, distribution, utilization, and disposal (Yasin et al., 2016). LCA provides industry stakeholders with a scientific basis for the assessment and management of environmental sustainability and identifies improvement strategies. Therefore, LCA has been extensively adopted by researchers in TAI (Kazan et al., 2020; van der Velden et al., 2014; Yacout et al., 2016). Most previous related studies have focused on environmental sustainability assessments of textiles and apparel products [e.g., medical textiles (Ponder, 2009), bed sheets (De Saxce et al., 2012), cotton T-shirts (Kazan et al., 2020; Zhang et al., 2015), recovered cotton (Esteve-Turrillas & de la Guardia, 2017), antibacterial T-shirts (Manda et al., 2015), carpets (Sim & Prabhu, 2018), and cloth diapers (Hoffmann et al., 2020), among others] and various types of natural and chemical fibers (Astudillo et al., 2014; Kalliala & Nousiainen, 1999; Liu et al., 2021; Muthu et al., 2012; Qian et al., 2021; van der Velden et al., 2014; Yacout et al., 2016; Yang et al., 2020).

Textile products and raw materials are also an important research area, with occurrence frequencies of 37 and 37, respectively. Given the significant environmental and resource challenges associated with textile production, such as waste gas and wastewater emissions, energy consumption, toxic chemicals, and solid waste, most studies address environmental sustainability at various levels, such as the raw material production, fiber production, product manufacturing, and product disposal stages of the textile product life cycle (Kazan et al., 2020; Roos et al., 2018; Yasin et al., 2018; Zhang et al., 2018). A number of studies have focused on the environmental impacts of raw material production, such as cotton, organic cotton, acrylic, wool, hemp, nylon, viscose, silk, and

polyester (Astudillo et al., 2014; Kalliala & Nousiainen, 1999; Muthu et al., 2012; Yacout et al., 2016; Yang et al., 2020).

Design (sustainable design) is another critical topic in TAI, with an occurrence frequency of 35. Numerous adverse environmental and social impacts of TA products are a result of production, consumption, and disposal. Design activities have an important impact on the production, consumption, and disposal of TA products across many aspects, such as material selection, energy/water use, processes, and manufacturing, as well as the purchase, use, and disposal of apparel by consumers (Kozlowski et al., 2018). To realize SDTAI, designers play an irreplaceable role (Kozlowski et al., 2019; Niinimaki & Hassi, 2011). In this context, scholars and enterprises increasingly consider the integration of the sustainability concept into TA design process. At present, some studies have developed several sustainable apparel design tools for designers, e.g., considerate design (Black et al., 2012), considered take-and-return (Aakko & Koskennurmi-Sivonen, 2013), and Cradle to Cradle Apparel Design (Gam et al., 2009). Additionally, to achieve sustainability, some strategies have been proposed for designers, such as slow fashion (Štefko & Steffek, 2018), longevity design (Connor-Crabb et al., 2016; Niinimaki & Hassi, 2011), cradle-to-cradle design (Michel & Lee, 2017), and upgrade recycling and remanufacturing design (Sara L. C. Han et al., 2017).

Document co-citation analysis (knowledge hotspots)

Figure 2 shows a document co-citation network with 193 nodes and 332 links generated from 863 articles, visualized and analyzed by CiteSpace. During the CiteSpace analysis, the timeline from 1987 to 2019 was divided into a set of periods, each of which was two years. In each two-year period, the first 25 most frequently cited studies were selected for co-citation analysis.

In the network, every node represented the citation status of the article while the links represented the co-citation relations. The larger node size represented frequently cited publication, implying that these papers have substantially contributed to the SDTAI field. According to Fig. 2, the top 10 most commonly referenced documents from 1987 to 2019, consisting of one book and nine journal articles, are shown in Table 2.

Based on the top 10 frequently co-cited documents, the most important research topics can be preliminarily verified in the SDTAI domain, including sustainable supply

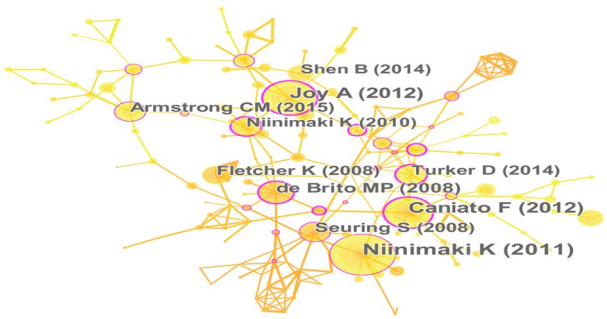

Fig. 2 Document co-citation network for the sustainable development of the textile and apparel industry (SDTAI)

Table 2 Top 10 frequently co-cited documents for the sustainable development of the textile and apparel industry (SDTAI)

Co-citation frequency	Author	Year	Title	Source
39	Niinimäki and Hassi	2011	Emerging design strategies in sustainable production and consumption of textiles and clothing (Niinimäki & Hassi, 2011)	Journal of Cleaner Production
32	Joy et al	2012	Fast Fashion, Sustainability, and the Ethical Appeal of Luxury Brands (Joy et al., 2012)	Fashion Theory
31	Caniato et al	2012	Environmental sustainability in fashion supply chains: An exploratory case based research (Caniato et al., 2012)	International Journal of Production Economics
22	de Brito et al	2008	Towards a sustainable fashion retail supply chain in Europe: Organisation and performance (de Brito et al., 2008)	International Journal of Production Economics
20	Seuring and Mueller	2008	From a literature review to a conceptual framework for sustainable supply chain management (Seuring & Mueller, 2008)	Journal of Cleaner Production
20	Turker and Altuntas	2014	Sustainable supply chain management in the fast fashion industry: An analysis of corporate reports (Turker & Altuntas, 2014)	European Management Journal
19	Armstrong et al	2015	Sustainable product-service systems for clothing: exploring consumer perceptions of consumption alternatives in Finland (Armstrong et al., 2015)	Journal of Cleaner Production
19	Fletcher	2008	Sustainable fashion and textiles: design journeys (Fletcher, 2008)	Book
18	Niinimäki	2010	Eco-Clothing, Consumer Identity and Ideology (Niinimäki, 2010)	Sustainable Development
17	Shen	2014	Sustainable Fashion Supply Chain: Lessons from H&M (Shen, 2014)	Sustainability

chain management, sustainable consumer behavior, sustainable design, and sustainable business model.

As presented in Fig. 2 and Table 2, sustainable supply chain management is an important research topic. Using the exploratory case study method, Caniato et al. (2012) analyzed the motivation, practice, and performance metrics of green supply chain management in companies of different sizes in the TAI. Their research results showed that large firms are more concerned with product and process improvements, as well as related gradual alterations, as compared to small firms. From the perspective of inbound and outbound firms, small firms can fully redesign their supply chain owing to their small size, whereas large firms focus only on certain aspects. Based on the perspectives of stakeholders, de Brito et al. (2008) discussed the impact that the sustainability movement has on the organization and performance of the apparel retail supply chain, expounded the challenges and conflicts from different dimensions of sustainable development, and investigated how to use internal and external organizations in the European supply chain. Seuring and Mueller (2008) proposed a conceptual framework for sustainable supply chain management by summarizing existing knowledge systems. At the same

time, related research in this field mainly focuses on environmental aspects. However, relatively few studies focus on society and the integration of the three dimensions of sustainability. Based on the theoretical framework of Seuring and Mueller (2008), Turker and Altuntas (2014) proposed the status quo of sustainable supply chain management from a conceptual perspective in the TAI. The results of their study showed that raising the overall performance of supply chain sustainability requires these companies not only attach great importance to abiding by the supplier code of conduct, but also to further supervise audit actions, and formulate supplier sustainability standards. These actions can reduce production problems in developing countries.

Based on Fig. 2, sustainable consumer behavior in the TAI is also a key research topic. Joy et al. (2012) analyzed the internal disharmony of fast-fashion consumers, who often pay attention to environmental issues, even if they are concerned with consumption patterns that run counter to ecological best practices. Niinimäki (2010) discussed eco-fashion consumption and consumer purchasing decisions. Their research results showed that moral commitment and values are powerful driving forces for the purchase of eco-clothes. The existing attitude-behavior gap in the eco-fashion field results from designers, manufacturers, and retailers that do not understand the needs and expectations of consumers. Using a literature review and case study approach, Shen (2014) identified and analyzed sustainable fashion supply chain structures, primarily from a consumer perspective, and presented sustainable operations and lessons at H&M.

As presented in Fig. 2 and Table 2, sustainable design in the TAI has become increasingly essential. Niinimäki and Hassi (2011) analyzed consumer interest in design strategies, such as longevity assurance, product satisfaction, product attachment, and emotional satisfaction with the design and service. They proposed a set of design and manufacturing strategies based on these design methods to reduce the impact on the environment during manufacturing and consumption processes. Two versions of sustainable fashion and textiles design proposed by Fletcher (2008) summarized how design concepts and strategies can be used to shape more sustainable products and promote social change throughout the entire lifecycle of a product. Additionally, these studies have explored design approaches to change the scale and nature of consumption, such as service design, localization, speed, and user engagement.

According to Fig. 2 and Table 2, the sustainable business model is the main focus area of current research. The TAI requires innovative sustainable business models to reduce its impact on the environment; a number of opportunities are available through the product service system. Armstrong et al. (2015) explored the positive and negative views of consumers on the characteristics of textiles and apparel product service system to identify obstacles and feasible methods for implementing the product service system model. Their study found that environmental benefits and emotions were the main drivers of positive perceptions. A lapse in service provider confidence and perceived obstacles to accessibility were the main drivers of negative perceptions.

Cluster analysis (knowledge domains)

Document co-citation networks can provide further insight into the SDTAI while cluster analysis allows for the investigation and detection of important subjects, content, and interrelationships (Si et al., 2019). CiteSpace can identify clusters of co-cited

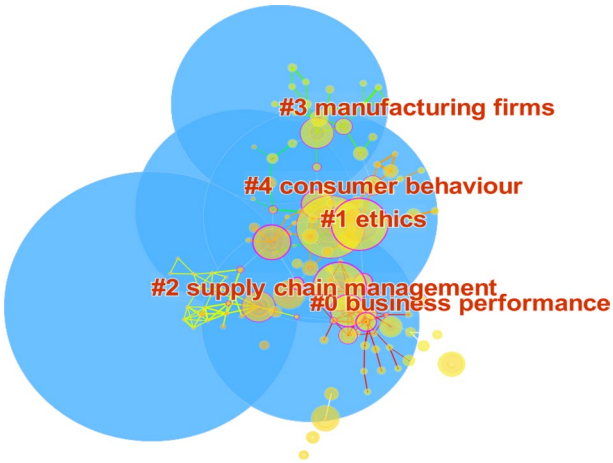

Fig. 3 Clusters in the knowledge domain for the sustainable development of the textile and apparel industry (SDTAI)

Table 3 Top-ranked clusters and the terms within the clusters (LLR)

Cluster ID	Size	Silhouette	Mean year	Cluster Label (LLR)
0	29	0.758	2012	Business performance
1	26	0.902	2011	Ethics
2	23	0.944	2007	Supply chain management
3	19	0.93	2014	Manufacturing firms
4	15	0.928	2009	Consumer behavior

LLR log-likelihood ratio

references, where each cluster corresponds to an underlying theme, a topic, or a line of research. CiteSpace uses three statistical methods for cluster analysis: the log-likelihood ratio (LLR) test, term frequency-inverse document frequency (TF∗IDF), and mutual information (MI) test (Zhao, 2017). Therefore, cluster analysis by CiteSpace was used to analyze the documents to obtain the main clusters. The cluster labels are automatically selected from the top-ranked noun phrases for each cluster, and noun phrases are extracted from titles, keywords, and abstracts of the publications.

Based on Fig. 3 and Table 3, the top five clusters were obtained, with their silhouette score > 0.758, showing the homogeneity of a cluster. The number of documents in each cluster determined the cluster size. The largest cluster, with 29 documents, was cluster #0. The smallest cluster, with 15 documents, was cluster #4.

Cluster #0, i.e., "business performance," including 29 articles, represented a sustainable business model. The sustainable business model concept has been utilized in the TAI (Nosratabadi et al., 2019; Pal & Gander, 2018; Todeschini et al., 2017; Weissbrod & Bocken, 2017). A sustainable business model is a structure used to explore the creation and acquisition of value by a company, aiming to achieve sustainability objectives by adopting active multi-stakeholder management, innovation, and perennial perspectives (Bocken et al., 2014; Boons & Lüdeke-Freund, 2013). The sustainable business model effectively reduces the harmful environmental and social impacts of business activities by providing solutions that help companies achieve both economic and sustainability

goals. Therefore, in response to adverse social and environmental impacts, researchers have attempted to propose instruments and approaches for designing sustainable business models. For example, based on the development of a novel design instrument, known as reDesign canvas, Kozlowski et al. (2018) proposed a business model canvas containing twelve bricks to ensure that entrepreneurs develop a sustainable TA brand. Hirscher et al. (2018) proposed transforming users into worth originators to create sustainable business models in TA design and manufacturing by applying do-it-yourself and do-it-together design strategies. Additionally, some studies have discussed various textile and clothing business models, ranging from collaborative consumption models of textile and clothing products (e.g., leasing, sharing, and exchange) (Armstrong et al., 2015, 2016; Becker-Leifhold & Iran, 2018; Iran & Schrader, 2017; Pal, 2017; Strähle & Erhard, 2017; Todeschini et al., 2017) to used retail (Becker-Leifhold & Iran, 2018; Haug & Busch, 2016; Strähle & Höhn, 2017; Strähle & Klatt, 2017) and upcycled goods (Pal, 2017).

Cluster #1, i.e., "ethics," including 26 articles, represented ethics fashion. Ethical fashion refers to a method of designing, buying, and manufacturing apparel that not only maximizes the benefits for people and communities, but also minimizes the impact on the environment via the Ethical Fashion Forum (Haug & Busch, 2016). This mode is already a means for apparel corporations to satisfy consumers' desire for sustainability. Apparel companies usually focus on the following aspects of ethical fashion: the environmental sustainability of products and fair trade compliance in terms of procurement and production methods (Barnes & Joergens, 2006). Ethical manufacturing and consumer interest in ethical fashion are highly important for many scholars (Niinimäki, 2010). Carey and Cervellon (2014) discussed the attitudes of self-selected fashion-oriented consumers toward ethical fashion by surveying and comparing consumers in Canada, France, and the United Kingdom. Based on comparisons of ethical fashion choices in different countries, Barnes and Joergens (2006) and Joy et al. (2012) found that ethical standards can be used in purchasing decisions, which are usually not applied in fashion choices. Choi et al. (2012) explored consumer concerns, beliefs, and knowledge of ethical fashion. Their results showed that consumer faith in ethical fashion will affect approval for companies that practice sustainable principles.

Cluster #2, i.e., "supply chain management," included 23 articles. TA consumers widely address environmental and social issues; thus, the translation of sustainability principles into operational practices in the supply chain has become increasingly important (Macchion et al., 2018). An effective sustainable supply chain can enhance the brand image of a company and reach a wider range of ethical consumers (Faisal, 2010). Therefore, companies should attempt to achieve strong competitiveness in the market (Yang et al., 2010). Existing studies related to sustainable supply chain management mainly focus on specific areas, such as new product development, ecological materials production, sustainable production, green distribution, and green retail, among others (Macchion et al., 2018; Morana & Seuring, 2011; Shen, 2014). Some scholars have discussed the driving factors and obstacles in sustainable supply chain management. Diabat et al. (2014) suggest that certain factors, such as employee participation, stability, and the community economy, are important in implementing sustainable supply chain management. Li et al. (2014) showed that strengthening the internal governance of enterprises and effective

cooperation with stakeholders can aid in the realization of the sustainability of fast fashion supply chain management. Furthermore, fashion brands are currently in the process of identifying best practices based on economic, social, and environmental considerations by integrating environmentally friendly materials, ethical labor practices, renewable energy, and green manufacturing in terms of sustainable strategies within the fashion supply chain (Nayak et al., 2019). However, thus far, sustainability issues have been mainly addressed from the social or environmental standpoint; further full and comprehensive studies should be encouraged (Marshall et al., 2015).

Cluster #3, i.e., "manufacturing firms," including 19 articles, was related to sustainable production. The TAI faces several issues, such as climate change, environmental pollution, resource depletion, ecological damage, strict regulatory systems, demand for sustainable textiles, and increased textile consumption. Therefore, improving sustainable production levels is an urgent issue that requires a solution (Desore & Narula, 2018; Jeswani et al., 2008). To cope with the above-mentioned problems in TA production, many TA factories around the world have successfully developed and implemented sustainable production methods (Alkaya & Demirer, 2014). Some researchers have focused on redesigning contamination and waste control systems. For example, environmental techniques (anaerobic biotechnology, membrane-based techniques, and nanofiltration, among others) can be combined to decrease wastewater discharge and increase renewable energy use (Dasgupta et al., 2015; dos Santos et al., 2007; Ozturk et al., 2015; Wenzel & Knudsen, 2005; Zabaniotou & Andreou, 2010). Moreover, Wenzel and Knudsen (2005) suggest that water and water-based energy and chemicals can be collected and reused via process integration. Additionally, various studies have focused on redesigning the manufacturing process from an environmental sustainability perspective. For example, some technologies (i.e., retrofitting water softening systems, using drip irrigation flushing, and diverse valves and accessories related to water distribution) have been applied to enterprises (Chico et al., 2013; Dasgupta et al., 2015; Khandegar & Saroha, 2013; Narayanaswamy & Scott, 2001; Nieminen et al., 2007). Furthermore, some studies have focused on the use of natural fibers, natural dyes, recycled materials, ecological materials, and renewable energy in production (Doty et al., 2016; Na & Na, 2015; Niinimäki & Hassi, 2011; Şen, 2008; Sezen, 2013; Zabaniotou & Andreou, 2010).

Cluster #4, i.e., "consumer behavior," including 15 articles, was relevant to sustainable consumer behavior. The TAI is consumer-driven. Demand for products is widely influenced by consumer knowledge, values, and perceptions (Butler, 1997; Dickson, 2000). Thus, there is extensive research examining the barriers and incentives for sustainable consumption in the TAI (Freudenreich & Schaltegger, 2020). For instance, raising consumer awareness of apparel sustainability issues can subsequently alter their behavior (Harris et al., 2016). Almeida (2015) and Ma et al. (2017) examined the effects of eco-labeling and sustainability labeling on the consumer behavior with respect to textiles and apparel. Nam et al. (2017) addressed the factors that affect consumer purchases of green sportswear. Saricam and Okur (2019) adopted the Fritzsche model to examine the effect of personal values on the ethical fashion consumption behavior of consumers. Hong and Kang (2019) investigated how moral philosophy and moral intensity affect consumer willingness to buy sustainable TA products. Some studies have found that fit and style factors also dominate apparel-related

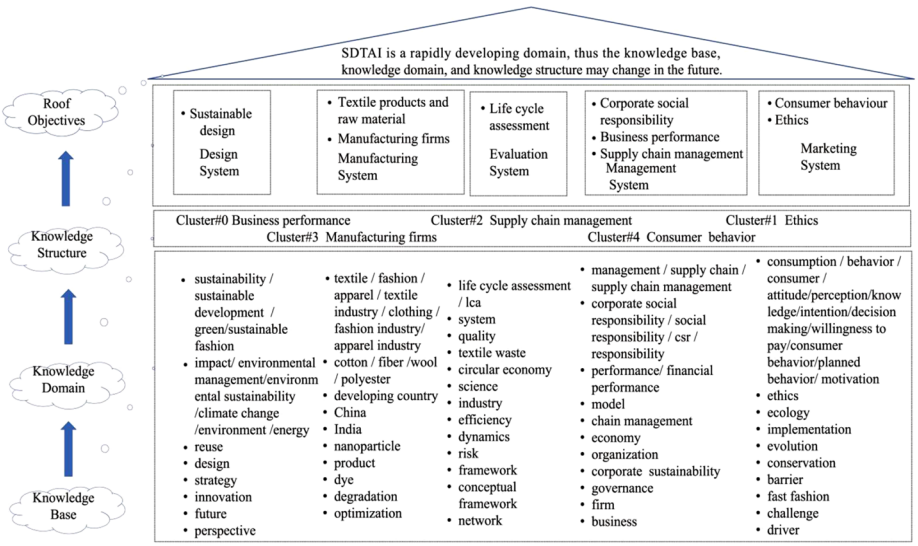

Fig. 4 Knowledge roadmap for the sustainable development of the textile and apparel industry (SDTAI)

decisions (Bly et al., 2015). Only a minority of "ethically hardline" consumers regard sustainability criteria as a primary factor in their apparel purchasing decisions (Niinimäki, 2010). Additionally, by understanding the attitude-behavior gap, some studies have investigated the obstacles that restrict consumers from buying green apparel (Maloney et al., 2014; Phau et al., 2015; Wiederhold & Martinez, 2018).

Discussion

By adopting the scientometrics approach, this study analyzed the knowledge base, hotspots, and domains of SDTAI, followed by integrating them into a knowledge roadmap, as shown in Fig. 4. The knowledge base, domain, and structure formed a knowledge roadmap for the SDTAI. The knowledge base consisted of 60 main keywords obtained from the keyword co-occurrence analysis. The knowledge domains included business performance, ethics, supply chain management, manufacturing firms, and consumer behavior, as identified through cluster analysis. According to the knowledge base, hotspots, and domains, the knowledge structure was developed, involving corporate social responsibility, sustainable business model, LCA, textile products and raw materials, sustainable design, ethics, supply chain management, manufacturing firms, and consumer behavior. These research topics were further grouped into five systems: design, manufacturing, evaluation, management, and marketing. Sustainable design systems for TA involve the use of sustainable design methods and strategies in the product design phase to improve the sustainability performance of TA products throughout their life cycle. TA design aspects have a wide range of environmental and social impacts on the selection, production, purchase, and use of raw materials for products, and have received widespread attention from academia and the practical community. Currently, some scholars have explored the factors influencing the implementation of sustainable design practices for TA. In addition, several scholars have also conducted relevant research on sustainable design methods and strategies for TA.

Sustainable manufacturing systems for TA, on the one hand, focus on improving the environmental sustainability of raw material production and processing processes in the TAI, such as animal feeding, plant cultivation, chemical fiber production and natural fiber production processes. On the other hand, it focuses on improving the environmental sustainability of TA production processes, such as spinning, weaving, dyeing and finishing, sewing, and wastewater waste treatment processes. Currently, some scholars have explored the environmental impacts of various fibers and products such as yarns, textiles and garments, while others focus on sustainable production methods and technologies for the TAI.

The TA sustainability assessment system mainly involves the life cycle environmental impact assessment method, which is an international standardized environmental management and decision support tool that can quantitatively evaluate and manage the environmental impact of TA products throughout their life cycle process, and is widely recognized and applied in the TAI. At present, scholars have mainly carried out the quantification and evaluation of environmental impacts in the fields of various fibers and yarns, textiles and garments, and recycling of textiles and garments.

Sustainable management systems for TA are mainly concerned with various aspects of interaction and management between different stakeholders in the life cycle of TA products. While improving corporate profitability, it can also effectively reduce the negative environmental and social impacts of business activities. For example, by building a sustainable business model, enterprises can achieve the integration of economic and sustainable development; companies also integrate sustainability with supply chain management to build a sustainable supply chain, strengthen internal corporate governance and effective cooperation with stakeholders; in addition, they focus on corporate social responsibility by managing social impact aspects such as human rights and work environment.

Sustainable marketing systems for TA are mainly concerned with influencing consumer behavior during the purchase, use, and disposal of goods and raising consumer awareness of sustainability. Presently, a number of scholars focus on the barriers and stimuli to sustainable consumption, consumers' perceived value, attitudes, intentions and behaviors toward sustainable products. In addition, some scholars focus on an approach to designing, purchasing, and manufacturing apparel-ethical fashion, exploring attitudes, interests, environmental sustainability, and fair trade compliance in sourcing and production methods for ethical fashion products.

Based on the analysis of the knowledge base, knowledge domain, and knowledge structure, the research status quo for the SDTAI can be understood via the knowledge roadmap presented in Fig. 4. As research on the SDTAI is an expanding and multidisciplinary domain, the knowledge roadmap could change in the future. Nevertheless, this study presents a mapping methodology and knowledge roadmap that can serve as a guide for future changes.

The results from the scientometric analysis can be helpful in providing a comprehensive knowledge framework in the SDTAI domain, thus preventing experts from ignoring broader related topics. Additionally, the SDTAI can be continuously performed to obtain updated knowledge.

Conclusions

Raw material acquisition, processing and manufacturing, distribution and transportation, and consumer use and disposal have generated significant environmental and social impacts. Therefore, many practitioners and scholars have focused on sustainability problems in the TAI. However, efforts to fully review these studies are rare. The objective of this study was to provide a comprehensive and quantitative review in the field of SDTAI using the scientometrics approach. Based on the bibliometric review, we propose a knowledge roadmap for SDTAI, which can review its current research and practice and provide valuable references for academia and industry. Additionally, as the research theories and practices in the field of SDTAI continue to develop and improve, relevant research data should be updated regularly, and the knowledge roadmap of TAI can be further improved in future research.

Specifically, the results of this study showed the following. (1) A total of 60 main keywords for the sustainable development knowledge base in the TAI were identified (Table 1). (2) Four research hotspots (sustainable supply chain management, sustainable consumer behavior, sustainable design, and sustainable business model) were identified in the SDTAI domain. (3) The SDTAI knowledge domain was identified, including business performance, ethics, supply chain management, manufacturing firms, and consumer behavior. (4) the knowledge structure consisted of nine subjects (corporate social responsibility, business performance, LCA, textile products and raw materials, sustainable design, ethics, supply chain management, manufacturing firms, and consumer behavior), The nine subjects are further divided into five major systems (design, manufacturing, assessment, management, and marketing).

Based on a review of SDTAI over the past thirty-two years, some possible directions for further investigation are identified. First, existing research has focused on how to guide sustainable consumption behavior of TA consumers, however, there is a lack of focus on whether consumers have the ability to implement sustainable consumption of TA, but the strength of sustainable consumption ability is closely related to achieving sustainable consumption behavior. Therefore, there is a need for future research related to the sustainable consumption ability of TA. Second, although research on influencing factors, methods and strategies, and tools for sustainable design of TA has been carried out, research methods in this area are mostly based on interviews or case studies, and there is a lack of quantitative and empirical research. In addition, there is a lack of quantitative sustainable design tools. Therefore, to promote sustainable design methods to be widely used in practice, the above related aspects should be explored in the future. Thirdly, existing studies have used single or multiple indicators to account for and assess the environmental impacts of TA products based on life cycle theory, and have obtained a large amount of quantitative data on environmental impacts. However, at present, the environmental information of TA supply chains or products is not transparent and traceable, and the quality and reliability of the data are questioned by consumers and society, which poses a challenge to the implementation of sustainable development. With the development of science and technology, modern information technologies such as blockchain, Internet of Things, big data analysis and visualization can be used in the future to achieve transparency, authenticity and traceability of environmental information in the TAI.

Author contributions
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Declarations

Competing interests
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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