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REVIEW

Microfiber pollution: an ongoing major environmental issue related to the sustainable development of textile and clothing industry

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Abstract
Textiles release microfibers to the environment during production, use, and at end-of-life disposal. There is a potentially large and growing risk to the environment associated with microfiber pollution, which requires protection and sustainable development in the textile and fashion industry. To date, early-stage research efforts, perhaps the most important initial actions to explore more feasible and effective solutions, into microfiber pollution from the perspective of environmental sustainability have been fragmented. In this study, we discuss the sustainability of the textile and fashion industry for economic and social development. The potential sources of microfiber pollution are analyzed from the supply chain of the textile and fashion industry. Additionally, actionable solutions, including a shift in consumer behavior, retailer recycling programs, and government behavior in the development of a sustainable economy and environment protection for textile and fashion industry, are proposed. Finally, we conclude that there is no silver bullet solution to microfiber pollution until now, but a collaborative cross-sector group of related industries conducting comprehensive research to inform a multi-industry approach must form part of the answer.

Keywords Microfiber pollution · Sustainability · Textile and fashion industry · Consumer behavior · Recycling program · Government behavior

1 Introduction

We all wear various fibrous materials, such as jackets, trousers, and socks, every day, without considering where they might end up. Fibers that shed from textiles and garments, especially microfibers, are ubiquitous in air, soil, rivers, lakes, and oceans, and are regarded as anthropogenic litter that has become a global concern for the sustainability of textile and fashion industry. There is clear evidence that microfibers as emerging contaminants are widely distributed in the marine environment globally (Barrows et al. 2018; Liu et al. 2019d; Suran 2018; Zabala 2018). Textiles are estimated to be the largest microfiber

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source in the environment (Carney Almroth et al. 2018). Experiments indicated that a single 6 kg domestic wash has the potential to release as many as 700,000 fibers (Napper and Thompson 2016). Over nine trillion fibers could be released per week in the UK, according to the figures cited in a Spin report provided by the National Federation of Women's Institutes (NFWI) (National Federation of Women's Institutes 2018). Synthetic microfibers and nanofibers have been estimated to comprise up to 35% of primary microplastics in the marine environment, which are found in marine habitats worldwide including shorelines (Barrows et al. 2018; Browne et al. 2011), the sea surface (Eriksen et al. 2014; Lebreton et al. 2018), deep-sea sediment (Sanchez-Vidal et al. 2018), and Arctic sea ice (Obbard et al. 2014; Peeken et al. 2018), as well as freshwater habitats (Eerkes-Medrano et al. 2018a; Li et al. 2018), and drinking water (Eerkes-Medrano et al. 2018b; Pivokonsky et al. 2018). Microfibers have been detected in the digestive tracts of a range of aquatic organisms and seafood including commercially important fish and shellfish (Barboza et al. 2018; Dehaut et al. 2016; Halstead et al. 2018; Rochman et al. 2015; Waring et al. 2018). Research has overwhelmingly focused on aquatic systems, although microfiber pollution is also serious in terrestrial ecosystems (de Souza Machado et al. 2018; Unice et al. 2018). Synthetic microfibers, such as polyethylene terephthalate (PET), regenerated cellulose, nylon, and polypropylene, are known to be pervasive marine pollutants (Gago et al. 2018). However, in the freshwater environment (River Trent, UK) and in atmospheric fallout, natural textile fibers, such as cotton and wool, constitute a significantly greater proportion of microfiber pollution than synthetic ones (Stanton et al. 2019). The natural fibers, such as cotton, silk, wool, and flax, and the regenerated cellulosic fibers, such as rayon, Tencel, and lyocell, are biodegradable in the environment. However, the degradability and environmental friendliness of natural fibers are affected due to processing procedures such as dying, coating, and other functional fabric treatment to inhibit fiber loss and for durability and antibacterial ability. Although the environmental distribution of microfibers was influenced by complex factors, such as the type of microfiber and location of the sources, microfiber pollution has been documented in the global environment (Mishra et al. 2019).

A large accumulation of microfibers in the environment will become more severe because of the growth in textile production, and the absence of microfiber degradation and effective recycling technologies. In recent decades, the rapid turnover in fast fashion has been a dominant factor in the growth in both production and waste (Pensupa et al. 2017). With microfibers globally recognized as an emerging environmental contaminant, omitting the comprehensive research on their potential sources and designing collaborative approaches to control microfiber pollution at multiple stages will fail to meet the sustainability needs of the textile and fashion industry.

The main objective of this review is to approach microfiber pollution through the perspective of sustainable development of the textile and clothing industry. We discuss the role of textile and fashion industries in economic and social sustainable development. We identify the potential sources of microfiber in the fashion and textile lifecycle and explore possible approaches to control microfiber shedding and pollution at multiple stages of textile and garment design, production, retailing, use, and end-of-life recycling. Some actionable approaches to control microfiber pollution for the textile and fashion sustainability and environment protection are proposed from the perspectives of producer, consumer, retailer, and government. This review is divided into four sections. Firstly, we describe the study design of this review, and the search strategy and study selection of studies. Secondly, we discuss role of textile and fashion industries in economic and social sustainable development. Thirdly, we discuss the risk of microfiber pollution for the textile and fashion industry sustainability. Then, we review the potential microfiber sources during textile

and garment production, use, and at end-of-life disposal. Control of microfiber pollution at different stages including fiber, yarn, and fashion production, a shift in consumer behavior, retailer recycling programs, and government action in the sustainable development of textile and fashion industry are discussed. Our review concludes that comprehensive research and collaborative control on microfiber pollution are important measures for the conservation of the environment and maintaining the sustainability of the textile and fashion industry.

2 Study design, search strategy and study selection

2.1 Study design

We conduct the literature review with a primary aim to discuss the potential negative impact of microfiber pollution on the sustainable development of the textile and clothing industry, and to propose some actionable approaches to control microfiber pollution. In 2014, microfibers were first studied as a typical microplastic pollutant in intertidal ecosystem surrounding Halifax Harbor, Nova Scotia (Mathalon and Hill 2014). We review the related studies about microfiber pollution published between January 2014 and October 2020, and some studies about textile and fashion industry sustainability published before 2020. In this study, we regard microfibers as a new type of pollutant that has existed since the emergency of textile and clothing industry but has only been paid attention to in recent years. In existing research, microfibers are more regarded as emerging pollutants and a special form of microplastics. However, we consider microfibers pollution as an ongoing major environmental issue related to the sustainable development of the textile and clothing industry in this review.

2.2 Search strategy and study selection

In order to conduct an exhaustive review of the existing studies about potential sources of microfiber and effective control measures on microfiber pollution, the main scientific publication databases are searched. Web of Science (http://apps.webofknowledge.com), ScienceDirect (https://www.sciencedirect.com/), SAGE(http://sage.cnpereading.com), Taylor & Francis Online (https://www.tandfonline.com), and Wiley Online Library (https://onlinelibrary.wiley.com) are searched through with the following search query: microfiber OR microfibre, microfibers OR microfibres, microplastic fiber OR microplastic fibre, textile microfibers, synthetic fibers AND microplastics, microplastic textiles, microplastics fabric OR clothes OR clothing, microplastics washings OR laundering, microfiber pollutants OR pollution. An additional manual snowball search is also done through Microsoft Bing engine(https://cn.bing.com), in which some related reports published by nonprofit organization are also reviewed. Broad studies are also searched through deliberately analyzing the references of the some significantly related research and review articles. When multiple references are present, the latest ones will be given priority. Conference abstracts, news report, and literatures not written in English are excluded. The literature search is carried out by four authors (J.L. L., J.Y. L., Q. B. Y., and B. Z.). Eligibility assessment of the identified literature is independently performed by three authors (J. N. D., X. Y. Z., and G. M. Z.).

3 Textile and fashion industry sustainability

3.1 Role of textile and fashion industry

Textile and fashion industries have contributed significantly in economic and social terms including incomes, employment, especially for women, and foreign currency receipts for some developing countries (Keane and Willem te Velde 2008). In some developing countries, such as China, India, Bangladesh, Vietnam, and some other Southeast Asia countries, the textile and fashion industry provides opportunities for export diversification, which depends more on the strongest comparative advantages of their labor and raw material costs. High-quality fabrics and luxurious fashion brands are still the traditional advantageous industries of some developed countries including Japan, the European Union countries, and the USA. According to the newly released World Trade Statistical Review 2018 by the World Trade Organization (WTO), the current dollar value of world textiles (SITC 65) and apparel (SITC 84) exports totaled $296.1 bn and $454.5 bn, respectively, in 2017, an annual increase of 4.2% and 2.8% (World Trade Organization 2018). The textile and fashion industry is of vital importance to the nation's economy and the people's livelihood worldwide. The production and consumption of textile and fashion have promoted economic integration and cooperation between different countries. Beyond the economic impact, the textile and fashion industry is closely related to employment, gender, and poverty issues. The supply chain offers entry-level jobs for all kinds of labor and one in six people worldwide works in a fashion-related job, and 80% of them are women (UNECE 2018). These data indicate that the sustainable development of the textile and fashion industry has a significant impact on the achievement of the UN Sustainable Development Goals. The role of the textile and fashion industry has never been underestimated and will not be replaced in the future.

3.2 Sustainability of textile and fashion industry

Textile and fashion industry has an often-underestimated impact on the sustainable development of our planet. The industry is the second highest user of water worldwide, producing 20% of global water waste. The United Nations Economic Commission for Europe (UNECE) has noted that the disposal fast fashion industry is the second largest user of water globally, producing 20% of global water waste (UNECE 2018). One cotton shirt requires 2700 L of water for fabrication, the equivalent of what one person drinks in 2.5 years (Fund 2013). The report of the Ellen MacArthur Foundation 2017 has assessed the global impact of the textile industry in "Appendix B.2: Resource use and negative externalities associated with material flows" (Foundation 2017; Leal Filho et al. 2019). The global annual water usage requirement for the textile industry is estimated as 93 billion cubic meters, for cotton production is estimated as 4600 L/kg fiber, for plastic-based fiber production is estimated as 38 L/kg fiber, and for dyeing textile materials is 88 L/kg fiber. The chemicals and dyestuffs are estimated as 42 million tons and 1 million tons, respectively. The total greenhouse gas emissions are approximately 1200 million tons. When compared with cotton production, the greenhouse gas emissions for plastic-based fibers production are estimated as 11.9 kg CO_2 e/kg fiber, more than 1.5 times that of cotton production. For the subsequent processing, including spinning, weaving, and dyeing,

approximately 9.6 kg CO_2 e/kg fiber are estimated. Especially for cotton, fertilizers, and pesticides is extensively used, and they are estimated as 8 million tons and 200,000 tons, respectively.

The rapid increase in population in some developing countries and the emergence of the global middle class will foster an increased demand for clothes and home textiles. If the production and consumption continue at the current rate, the environmental issues will become more serious because of water use and wastewater discharge, chemical, and microfiber pollution. Meanwhile, the fast fashion industry will increasingly produce large volumes of cheap, disposable clothing, which is becoming an environmental and social emergency ("The price of fast fashion" 2018). The majority of discarded clothes are disposed of in landfills or incineration with unscientific technologies. Both natural and synthetic fibrous materials cannot be easily biodegraded within 200 days in natural aquatic aerobic environments (Zambrano et al. 2019). There is no doubt that clothes continue to impact the environment after production. Usage and final disposal may ultimately cause more environmental problems than currently recognized.

Meanwhile, economic globalization has promoted the fashion supply chain to become international, and accelerated the shift in some conventional industries, such as spinning, weaving, and clothing, to low and middle-income countries (LMICs). Fast fashion is mass-produced in LMICs because of cheaper labor, although most brands are founded by companies located in developed countries. These LMICs often lack advanced technologies and stringent laws to control environmental pollution at the primary stage of industrial development. The estimated data indicate that ten rivers that carry more than 90% of the plastic waste that ends up in the oceans are all in LMICs, including the Amur, Hai He, Huang He, Chang Jiang, Zhu Jiang, Mekong, Ganges–Brahmaputra-Meghna, Indus, Nile, and Niger rivers (Schmidt et al. 2017).

Continuing with the emerging trend of critical environment protection, increased labor cost, and world trade friction in recent years, significant industrial restructuring is emergent in some traditional strong textile and fashion countries, such as China, India, European Union (EU28), and the USA, in which low added value textile and fashion industries will be placed in restricted categories (Sheng Lu and Association 2018). Rising labor and production costs have already caused a steady shift in production to lower-cost suppliers in a number of other countries, and this is expected to continue (ILO 2019). The shift of the textile and apparel industry from developed countries and regions to the developing and underdeveloped ones will not end the current environmental problem, but the development model is repeating now in different areas. The shift will improve local economic development and social progress in those areas while the environmental costs, which are the most direct negative impacts, will likely be ignored. Currently, the sustainable textile and fashion industry without environmental microfiber pollution is a pressing concern around the world.

4 Fibrous materials are the main potential sources of microfiber pollution

Fibrous materials are the original sources of microfibers in the environment, which are released during periods of textile production, use, care, and waste disposal (Liu et al. 2019a, b, c, d). Microfibers have lower density (cotton and flax, 1.5 g/cm^3; wool and silk, 1.3 g/cm^3; polyester, 1.4 g/cm^3; nylon and acrylic, 1.15 g/cm^3; polypropylene, 0.9 g/cm^3;

and aramid, 1.47 g/cm^3) than that of soil particles (~2.65 g/cm^3), which makes microfibers are more transportable(Brahney et al. 2020). The diameter of microfiber is less than 10 µm(Jerg and Baumann 1990). Microfibers have higher length to diameter ratios, on the order of 10^3, and greater surface-area-to-volume ratios (cotton, ~9800m^2/g; flax, ~9600 m^2/g; wool, ~7200 m^2/g; silk and synthesis fiber, on the order of 10^4), which increase drag forces and reduce settling velocity(Brahney et al. 2020; Liu, Yang, et al. 2019a). The physical and structural characteristic of microfibers makes them are susceptible to water transport and wind entrainment in longer range and larger scale.

The potential sources and major possible transfer pathways of microfibers are demonstrated in Fig. 1.

Inside modern homes, the release of short fibers from clothes and textiles during usage and care is a potential microfiber source. They have been always detected in indoor environments (Dris et al. 2017). Microfiber shedding from clothes and home textiles with a loose structure, such as knitted sweaters and fleece blankets, is very common during daily use, a

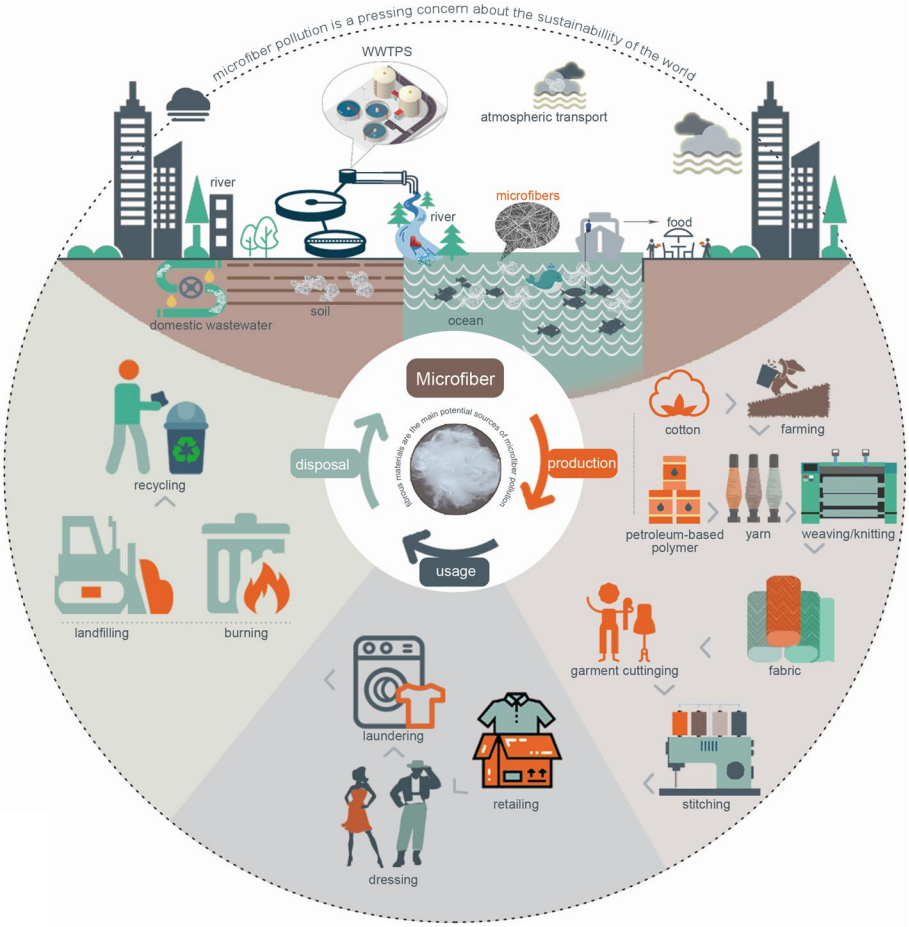

Fig. 1 The potential sources and major possible transfer pathways of microfibers in the textile and fashion supply chain. Note that just the home textile and clothes are considered, not all fibrous materials, such as agricultural, engineered, and industrial textiles are not included. (WWTPS = wastewater treatment plants)

typical example of which is fibrous pilling (Napper and Thompson 2016). Although microfiber shedding through physical actions, such as tumbling, agitation, and friction, during laundering have been considered as the main sources (Carney Almroth et al. 2018; Hartline et al. 2016; Pirc et al. 2016; Salvador Cesa et al. 2017), it has been overestimated when compared with microfibers released from textile factories in solid waste and wastewater, especially those operating the full production chain including yarn spinning, fabric weaving, dyeing, and scrubbing processes (Liu et al. 2019b). Washing clothes in the river or stream is a potential source of microfibers, which is still customary in many less-developed parts of the world, especially in rural areas (Gordon et al. 2009).

By taking microfiber generation quantity as a criterion, the wastewaters discharged by textile industries and domestic laundering are likely to be the primary, direct, and main pathways to transfer microfibers to the aquatic environment. Wastewater treatment plants of modern cities (WWTPs) are a key source of secondary microfibers (Murphy et al. 2016; Ziajahromi et al. 2017). Although low microfiber concentrations are detected in wastewater effluent, WWTPs still have the potential to act as a significant source for the release of microfibers. Despite efficient removal rates of more than 95%, final effluents act as the entrance route of microfibers, given the large volumes constantly discharged into aquatic environments (Prata 2018; Xu et al. 2018). Microfibers have also been detected in sewage sludge produced in all of the primary, secondary, and tertiary WWTP stages, and the sludge disposal methods also affect the dispersive modes of microfibers in the environment (Lares et al. 2018). Sewage sludge applied as agricultural fertilizer is thought to be one of the leading contributors of secondary microfibers following the breakdown of larger plastic items (Kay et al. 2018). In summary, WWTPs are potentially key sources of microfibers in river catchments, especially the centralized WWTPs in textile and clothing industrial parks and towns with the developed textile industry(Zhou et al. 2020). The wide application of advanced technologies in WWTPs could sufficiently reduce the quantities and concentrations of microfibers in rivers and oceans.

Rivers are potentially the major transport pathway for all mismanaged microfibers, delivering the microfibers into inland lakes and the ocean (Besseling et al. 2017). Substantial microfiber quantities originate from land-based sources, including fibrous materials used for thermal or light barriers on farmland, and textile covers used in capital construction projects, which accumulate in soil ecosystems and are exported in rivers via rain and the atmosphere. The microfiber pollutants in freshwater systems continue to flow downstream and are ultimately discharged into the marine environment through rivers, particularly as rivers are the main sources of water for the oceans. Estimates indicate that ten rivers, eight of which are in Asia: the Yangtze, Indus, Yellow, Hai He, Ganges, Pearl, Amur, and Mekong rivers, and the Nile and Niger rivers in Africa, carry more than 90% of the plastic waste delivered oceans (Schmidt et al. 2017). The number of inhabitants connected to sewage installations and the removal efficiency of microfibers by WWTPs are two important factors that obviously affect the total amount of microfibers in rivers (Siegfried et al. 2017). It is indisputable that rivers are the potential major transport pathways for a substantial proportion of microfibers in the marine environment, which are generated from land-based sources.

5 Actionable approaches to control microfiber pollution

The impact of microfiber on environmental pollution is already significant today and is likely to increase in the upcoming decades. The potential negative impacts of microfiber on human health are still largely unknown. That is precisely the main problem. Because

microfiber pollution is ubiquitous, it needs to be addressed before it can become a serious issue(Suran 2019). The current global approach to addressing microfiber pollution, such as devices to mitigate microfiber release from clothing during washing or to capture microfibers released in the wastewater(Napper et al. 2020), is failing. It is hoped that all stakeholders execute their social responsibilities and corporate microfiber pollution mitigation strategies as actions employed in climate change mitigation (Cadez et al. 2019). Microfiber pollution should not cost the earth, and some actionable sustainability approaches to control microfiber from the textile and fashion are proposed as shown in Fig. 2, and details are discussed in the following subsections.

5.1 Control microfiber pollution at the source

While microfiber pollution needs to be addressed through the entire textile chain from fibers to consumers, technology innovation in the textile industry will mitigate the problem at the source. The developments of new types of fiber production, the innovation of design, and production processing of yarn and fabric are important methods to reduce microfiber release because of the shedding of yarn hairiness and fluff on clothes at the source, although very few research data are found on the effect of yarn and fabric properties on the microfiber release(Rathinamoorthy and Raja Balasaraswathi 2020). The development and

Fig. 2 Some actionable approaches to control microfiber pollution for the textile and fashion sustainability and environment protection are proposed from the perspectives of producer, consumer, retailer, and government

use of eco-friendly biofabrics and sustainable bio-textiles as well as the use of natural and regenerated fibrous materials for the new trend fashion and textile industries are the first pathways to close microfiber pollution. The chemical and physical properties of fiber, such as the chemical composition, length, density, surface and cross-sectional shape, fineness, tenacity, strength, elongation at break, elasticity, and ability to resist friction, are the dominant factors determining the shedding resistance. The structure parameters of yarn and fabric such as blend proportion of different fibers, number of hairs per meter, hair length, yarn twist, yarn density, yarn count, weave repeat, and fabric weight per square meter will directly influence the anti-pilling and abrasion resistance performance of the fabric. Specifically, staple yarns and fleece fabrics are likely key sources for microfiber during laundry (Carney Almroth et al. 2018). Increased abrasion resistance and reduced pilling and fuzzing of yarns are effective measures to anti-microfiber-shedding, which can help to reduce microfiber shedding released into laundry water. Reducing pilling and abrasion in general use is also key in prolonging the life cycle and reducing microfiber shedding. Anti-microfiber-shedding innovations, such as new craft through function finishing and coating for fleece and underwear to prevent microfiber release from knitted fabric used as base, will create clothes that are equally as warm without the negative impact on environment. This suggests that the improvements in the properties of fiber, yarn, and fabric at the design and production stage are the most effective methods to limit microfiber emissions. The intervention of fashion brands at the stage of fiber selection, yarn spinning, and fabric design can effectively improve the sustainability from the material source to end-of-life recycling. Multiple stakeholders in the fashion supply chain contribute to solving the problem of microfiber pollution from fiber, yarn, fabric, and garment producers, to retailers to fashion brands. The resources and waste strategy should incorporate eco-design principles and offer incentives for recycling, disassembly, and durability designs in some developing countries that are the main production and export sources of textiles and clothes. It should also establish a new investment fund to stimulate markets for recycled fibers in developing countries whose main economic industries are textile and clothing production and export. Fortunately, some brands are taking action to support researches about microfiber release, which will be the beginning to provide some new methods to reduce microfiber shed at sources(Liu et al. 2019a, b, c, d).

5.2 Shift in consumer behavior

Measures to control microfiber pollution need to occur at multiple levels and different scales from individuals to retailers, and from local to international governments. However, the shift in consumption behaviors of individuals contributes to the sustainability of textile and fashion to decrease microfiber shedding (McNeil and Moore 2015). One of the shifts is switching to a thrifting system, which enables a community of thrifters to find affordable, quality secondhand apparel for the whole family. Online thrift stores would make it easier than ever to find out suitable secondhand or like new clothes for sustainable usage and keep millions of items out of incineration and landfills to prevent microfiber release in environment. Another of the shifts is toward slow fashion, which ensures quality manufacturing to lengthen the life of the garment and emphasizes sustainability in the fashion industry, which may be considered as an action against the fast fashion movement (Jung and Jin 2016). High quality, well-designed, and well-produced clothing, especially that with cultural connection will encourage consumers to retain garments longer and perceive more value for what they buy rather than discarding them shortly after purchase (Jung and

Jin 2014). Meanwhile, consumers will also spend more time on the care of garments to prolong their life and maximize their value. Currently, consumers, especially the middle classes in developed countries, are willing to buy fewer garments at a higher and more durable quality. Classic and timeless styles of some luxury brands at a comparatively low price are the goods in great demand and endure beyond a couple of fashion seasons. The design of slow fashion offers clothes made of environmentally friendly materials and provides a sustainable model for the fashion industry (Smith et al. 2017). Accordingly, we would select slow fashion as an appealing alternative to achieve sustainability by prompting consumers to change consumption patterns. The shift in consumption patterns from fast fashion to slow fashion will directly reduce textile and garment consumption volumes and will indirectly migrate microfiber pollution. Meanwhile, socially responsible behavior such as community awareness and improved education about microfiber release during washing will be successful in making public conscious of microfiber pollution(Singh et al. 2020). Consumer's perceptions and positive attitudes toward microfiber pollution in environment will be helpful to correct the habit to discard used textiles and worn clothes at will, which will be an effective action to control microfiber pollution at an individual level(Herweyers et al. 2020).

Consumers are encouraged to select textiles and clothes made of recycled fibers rather than virgin ones. The proportion of recycled polyester has increased and will reach at least 25% by 2020 in the UK, which has been initiated by the Textile Exchange Program (HOC Environmental Audit Committee 2019). General education about technology and craft of fiber, yarn, fabric, and textile and garment production will also facilitate shifting consumption behavior to control the release of microfiber at the wearing and washing stage. Consumers are encouraged to select suitable washing mode, such as soft washing mode, hand washing mode, and water-saving washing mode, to reduce the release of microfiber during laundry(Kelly et al. 2019). Meanwhile, fostering the repairing, washing, and care skills for clothes will also lengthen their lifecycle and shift consumption patterns (Yun et al. 2017). Education for social responsibility regarding textile waste and collection will give the public the knowledge to understand the social and environmental cost of microfiber pollution and to support the sustainable development of the textile and fashion industries from the individual level.

5.3 Retailer recycling programs

The majority of the used clothes and home textiles are sent to landfills or incinerated as solid waste, which accounts for nearly 85% of textiles consumed by Americans (Bick et al. 2018). To minimize the negative impact of used clothes and textiles on the environment, some brands, such as H&M and Levi Strauss & Co., have partnered with solution providers, such as I:CO, to facilitate collection and recycling of aged clothes and discarded textiles. The collected textiles and clothes are identified and subsequently separated. Some wearable items are kept and sold as secondhand goods. The fast fashion culture dictates the short lifecycle of clothes, which will affect the quality of clothes in the secondhand market.

Unwearable clothes will be shredded and made into insulation material for the automotive and construction industries. Some synthetic fibers, such as polyester, nylon, polyamide, spandex, and acrylic, will be regenerated and recycled into yarns that are then channeled back into the manufacturing process to make more garments. When compared with the original fibers, recycling polyester requires less energy, increases environmental compatibility and brand value and has been used in more brands of clothing. More than 95% of all

textiles can be recycled or reused. However, less than 1% of the materials used in clothes and textiles are recycled ones (Foundation 2017). The reuse of used textiles and clothes can effectively reduce environmental pollution caused by landfill and burning.

Retailers recycling programs feed the concept of extended producer responsibility, which means the manufacturer must consider the product's after life. For many stores, customers can get store credit and discounts for sending in used clothing. This increases the recycling of used clothes and textiles. However, this also encourages consumers to buy more clothes because of the recycling program reward mechanism. Although traditional strategies for waste management, such as landfill and incineration, can reduce the environmental pollution caused by improper disposal of discarded textiles and clothing, recycling as an emerging industry will regenerate the used textiles and clothing into useful productions, such as thermal insulation materials, acoustic materials, and decoration materials.

Except for the recycling programs, fashion retailers are also responsible to test and publish figures for fiber shedding of garments on sale or to be designed. The retailers, as one vital link in the fashion supply chain, can collaborate with fashion brands, designers, and textile and clothes production factories to limit microfiber emissions at the stage of fashion design, textile production, and finishing. Retailers contribute to solving the problem of microfiber pollution from fiber, yarn, fabric, garment producer, and fashion brands.

5.4 Government behaviors

The sustainable development of the textile and fashion industry needs not only investment and advanced technologies but also the transformation of business models and political and economic policies. Some positive initiatives to develop environmentally friendly textiles and control microfiber pollution have been proposed by nonprofit organizations and institutes, such as the United Nations Environment Program (UNEP) (Kershaw 2016), and the Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMEP) (GESAMP 2016). However, the sustained increased demand for clothes and other textile goods will steadily aggravate the environmental situation. So, the governments should assess the need for the improvement of legislation to better consider microfiber pollution on environmental and human impact including the sustainability of textile and fashion industry.

Despite the variety of efforts by different countries, currently, there is not a comprehensive approach to address all aspects of textile and fashion sustainability from the perspective of microfiber pollution. Some reward policies established macroscopically by governments, such as reducing value-added tax (VAT) based on sustainable, certifiable, and recycled fibers, will also encourage migration to earth friendly circular fibrous materials(Le 2017). Reforming taxation is an effective measure to reward fashion companies that design products with lower environmental impacts and penalize those that do not. Moving from conventional to organic cotton and from virgin polyester to recycled PET would help to reduce the negative impact of the clothing industry(Liu et al. 2019a, b, c, d). In 2019, MPs of the UK pushed for a fast fashion tax to make fashion retailers take responsibility for the waste they create and reward companies that take positive actions to reduce waste (HOC Environmental Audit Committee 2019). A charge of one penny per garment on brands and retailers, such as H&M, Zara, and ASOS, could raise £35 million to invest in better clothing collection and sorting. In 2020, some researchers suggested that some effective and feasible devices should be developed and implemented on washing machines to capture microfibers and reduce the release to environment(Napper et al. 2020). Government

guidance and intervention will speed up the installation of microfiber capture devices on washing machines and control the microfiber discharge through domestic laundry.

Governments play a key role to ensure all actors in the textile and fashion industry are held accountable for the true cost of microfiber pollution to nature and people. Supporting related research on microfiber pollution and publishing research figures will make the sustainability crisis of the textile and fashion industry transparent to the public. Governments contribute, but education and information are essential. The government should accelerate fundamental research and public education about the relative environmental performance of different fibrous materials, particularly concerning properties of microfiber pollution and biodegradability. The governments should encourage the development of the textile and fashion recycling industry, and encourage consumers to shift their consumption model from fast fashion to slow fashion. It should encourage fashion retailers to take responsibility for the waste they create by introducing extended producer responsibility schemes for textiles. The government should facilitate collaboration between fashion retailers, wastewater treatment plants, and washing machine manufacturers and take a lead in solving the problem of microfiber pollution. Meanwhile, the improvement of waste management infrastructures in the manufacturing chain of textiles and clothing in some developing countries, such as treatment systems for wastewater and solid waste discharged by textile factories and domestic laundering is paramount and will be a sustainable solution to control microfiber pollution from the sources.

6 Conclusions

This review elucidates that microfibers have been globally recognized as an emerging environmental contaminant. The comprehensive research on their potential sources and designing collaborative approaches to control microfiber pollution at multiple stages are fundamental and necessary measures to meet the sustainability needs of the textile and fashion industry. Systemic solutions using strategic and tactical interventions are required to stop microfiber pollution at its source, and bold actions from a broad range of stakeholders are needed across the full fibrous material lifecycle to implement these interventions. How to inform a multi-industry approach to solve microfiber pollution at different scales including fiber, yarn, and textile producer, fashion brands, washing machine manufacturers, consumers, retailers, wastewater treatment plants, and government is a systematic project.

Progress towards managing the sources for microfiber shedding during the full textile and fashion lifecycle is an effective approach to control microfiber pollution. The intervention of fashion brands at the stage of fiber selection, yarn spinning, and fabric design can effectively improve the sustainability from the material source to the end-of-life recycling. The shift in consumer behavior from fast fashion to slow fashion will directly decrease the disposal of textiles and fashions and mitigate microfiber emission during laundering. Retailer recycling programs will minimize the negative impact of used clothes and textiles on the environment and advocate for a shift to a circular economy to create a more sustainable industry. Collaboration at all levels from individuals to the whole supply chain of textile and fashion industry, and from local to international governance, will take the lead on solving the problem of microfiber pollution and meet the sustainability needs of the textile and fashion industry.

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