IOP Conference Series: Earth and Environmental Science

PAPER • **OPEN ACCESS**

Haode Evaluating the Life-cycle Environmental Impacts of Polyester Sports T-shirts

To cite this article: Zequan Wu 2020 *IOP Conf. Ser.: Earth Environ. Sci.* **474** 022017

IOP Conf. Series: Earth and Environmental Science **474** (2020) 022017 doi:10.1088/1755-1315/474/2/022017

Haode Evaluating the Life-cycle Environmental Impacts of Polyester Sports T-shirts

Wu Zequan[1]

[1] Shanghai American School, Shanghai, 201200, China

No. 1600, Lingbai Rd., Pudong, Shanghai, China;

Corresponding author's e-mail:quan01pd2020@saschina.org

Abstract. Polyester fibre has a series of excellent properties and it has a wide range of uses. Recently China has become the largest producer and consumer of polyester in the world. The purpose of this paper is to analysis the environmental impacts of polyester shirts. Applying life cycle assessment to polyester textiles, through the analysis and research of resource utilization and environmental emissions during the life of polyester textiles, looking for opportunities to reduce environmental pollution, and providing reference for environmental management departments to develop environmental regulations and environmental emission reduction plans. The declared unit of this paper is a piece of T-shirt 100% made of polyeater fibre. Following the principles and guidelines of ISO series, this study collected both measured data of the client's processes and secondary data. The data in this paper mainly comes from the literature, life cycle assessment (LCA) databases, and emission registration database of the government. The results of the study show that PET production, yarn manufacturing, and use-phases are the procedures that contribute the most environmental impacts. The total life-cycle energy use of a polyester sports shirt is 109 MJ, with 2882 litres of cumulative water use and contribution to global warming equivalent to 81.62 kg of CO2. The shirt's use phase contribute the highest resources used, accounting for 65.5% of energy use, 86.71% of water use, and 84.31% of the global warming potential. The shirt production phase accounts for 30.85% of the energy use, 13.14% of total water use, and 12.99%of the global warming potential. Disposing phase contribute less among these process. The results of the study show that PET production, yarn manufacturing, and use-phases contributes to the majority of all environmental impacts. Polyester production and yarn manufacturing are steps that require the highest amount of energy. Utilizing recycled polyester fibres can reduce the net resource utilization and environmental impacts. A large amount of energy and water are used in the use-phase of a shirt. Improving the equipment efficiency can decrease the input energy and water consumption.

1. Introduction

China has become the largest textile producer, consumer, and exporter globally[1]. China's textile and apparel domestic demand market has shown a relatively rapid growth trend recently. According to the National Bureau of Statistics, the retail sales of clothing, shoes, hats and needles in the national limit was 1.2 trillion yuan in 2018 [2]. According to China Customs Express data, from January to December 2018, China's textile and apparel exports totaled US$276,731 million [3].

Polyester fibre has a series of excellent properties such as high breaking strength and modulus of elasticity, moderate resilience, excellent heat setting effect, and good heat resistance and light resistance. It has a wide range of use and industrial use. In recent years, the polyethylene terephthalate granulate (PET) fibre production capacity has developed rapidly. In 2017, China's fibre production was 47.14 million tons, accounting for 71% of the world's chemical fibre production, ranking first in the world [4].

The production of polyester produce a huge environmental burden[5,6]. Fibers made from petroleum require a lot of resources. Fossil fuel based petrochemical products are the main raw materials for polyester production[7]. Creation involves a long string of heterogeneous operations, including yarn manufacturing, weaving, dyeing, and cutting and sewing. These textile manufacturing processes produce a lot of waste and consume a lot of water[8]. Laundering consumes a lot of resources, especially energy and water.It also indirectly generates pollutants through energy, and directly generates pollutants through the use of cleaning chemicals in the washing process and the removal of chemicals and dirt from washed clothes. At the end of its service life, these products are usually discarded in landfills.It is necessary to systematically evaluate the impact of polyester textiles on the environment from the perspective of life cycle in order to find potential opportunities to improve the sustainability of textiles.

Climate warming refers to the rise in greenhouse gas emissions in the global atmosphere due to human activities, causing an increase in Earth's temperature. The serious consequences of this problem have attracted the attention of the United Nations and governments. The textile industry is one of the most significant contributors to the emission of greenhouse gas due to its size and scope. The production of fibres, fabrics and garments consumes a lot of energy. It is estimated that clothing and fabrics account for 10% of the total carbon emissions. The carbon footprint measures the cumulative amount of greenhouse gases, particularly carbon dioxide, emitted by a product or process over its entire life cycle. The carbon footprint is calculated using the life cycle assessment method, a method that measures data from the cradle to the grave, and counts the entire production chain, including the development and acquisition of raw materials, processing, transportation, final use and exhaust gases[9,10].

Life cycle assessment (LCA) is a systematic method to quantify and assess the resource use and environmental impact of industrial systems in the whole life cycle [10,11], from raw material acquisition to manufacturing, use, use and disposal (i.e from cradle to grave), because it is related to the established goal and scope of the project [12].The perspective of this method offers a more thorough vision on the environmental impacts of textile products and operations at various points in the life cycle, which are great hints that can help better reduce the environmental burdens from one stage of polyester manufacture to another.

There exist multiple studies conducted on a variety of textile categories. Ponder et al. [13] conducted a study on medical textile, Blackburn et al. [14] proceeded life cycle analysis of cotton Towels. While some studies focus on the assessment of partial special procedure [6], Yuan et al. [15] evaluated the life cycle environmental impacts of dyeing industry, while Pakula et al. [6] focused on electricity and water consumption for laundry washing procedure. Chen[16] et al study the thermophysiological comfort properties of polyester. Wang et al [17] use life cycle assessment and willingness to pay of waste polytester recycling. Chard et al [18] used life assessment of a urethane methacrylate/unsaturated polyester resin.

While previous studies have paid more attention to cotton as cotton products are known for being relatively environmentally destructive, with the wild use of polyester, the environment concerns raised by polyester also is increasing rapidly. We hence chose 100 % polyester textile to conduct a thorough life cycle assessment. The goal of this project is to quantify and assess the life cycle environmental impacts of a piece of T-shirt 100% made of polyester. To accomplish these goals, the project will focus on energy consumptions, water suage, and greenhouse gas (GHG) emissions.

2. Method

This project proceeds a LCA of a piece of shirt made of 100% polyester. This LCA study quantifies the energy, water inputs, and the atmospheric impacts throughout the life cycle of a shirt: from raw material acquisition and manufacturing of the shirts to the laundry and landfill disposition where the shirt retires from service.

In order to achieve the objectives of this study, only the use of energy and water will be quantified, and the only indicator examined is the global warming potential (GWP) from greenhouse gas emissions, in kilogram carbon dioxide equivalent. This LCA study uses the environmental design of industrial products (EDIP) 2003 life cycle impact assessment (LCIA) method to characterize greenhouse gas emissions. Check the integrity and consistency of LCA results, and conduct uncertainty analysis. The knowledge gained from the LCA study will then be aggregated and advice given to the client's decision makers based on the objectives and scope of the project.

There is a need for a thorough and comprehensive understanding of the resource consumption and climatic effects brought by the polyester textile life cycle. This study includes an analysis on a system of processes from raw material extraction for shirt production to the disposal of shirts. This is the purpose and significance of establishing a life cycle assessment model for polyester textiles.

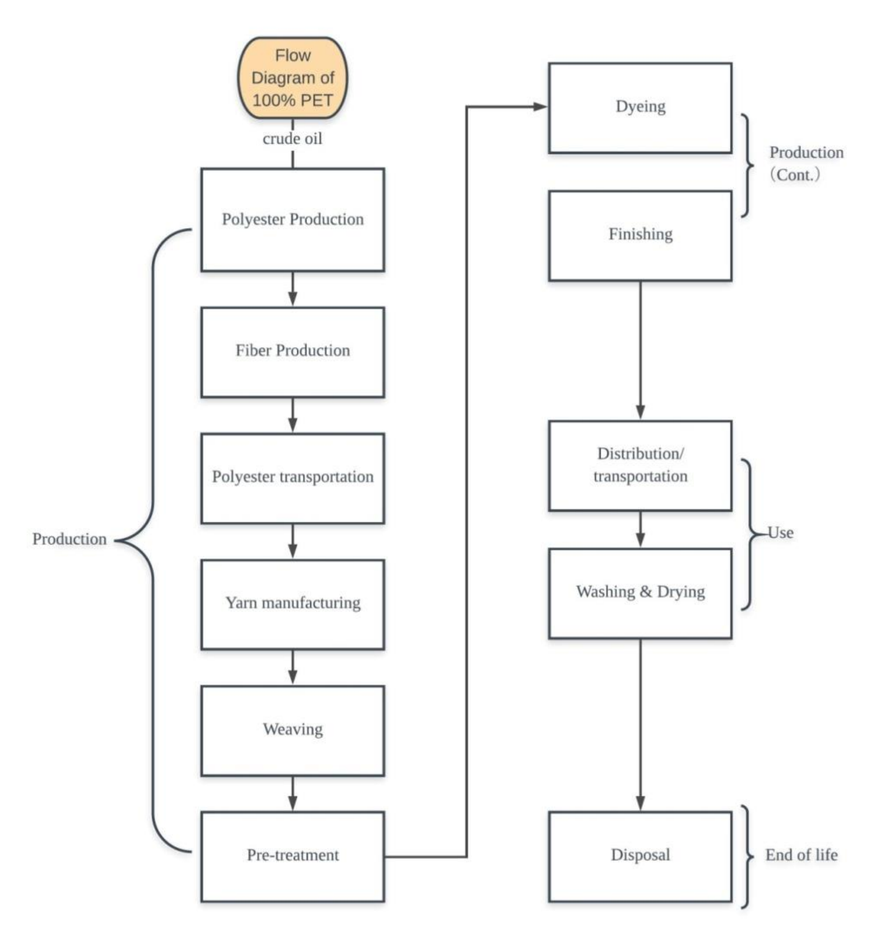

Figure 1. System boundary and processes for the polyester sports T-shirt

The procedures can be divided into three main phases: production, use (or washing), and end-of-life (or disposal). Within each phase are individual processes discussed below as relevant to the LCA. Literature review method is used to get to the numbers of LCA. Accordign to different process the input energy, imission and waste are calculated, then analysis the LCA.

2.1. Polyester production

For the polyester production stage, this study uses the aggregate input and output streams provided by the Gabi professional database through dimethyl terephthalate (DMT), which includes the process from fossil fuel extraction to pet particle manufacturing.

Production of polyester fiber: the unit process includes all processes from PET production to polyester filament production, and then it is transported to the fabric factory.

Yarn manufactory: Produced polyester filament is assembled into yarn by process including carding, combing, and spinning. The textile mill studied in this LCA sources its polyester fibres both domestically and international. Although the surplus fibre can be further used to produce lower quality yarn, it is assumed in this discussion that the fibre is not re-circulated.

Weaving: The fabric is formed in this step by weaving the manufactured yarn.

Pre-treatment: Prior to fabric dyeing, fabric must be prepared by removing wax, pesticide residue, lubricating oils from the yarn, and scouring them in an alkaline solution under high pressure and temperature.

Dyeing: The fabric is dyed with color using the method of dispersion dyes and materials including carrier solvents and dyes without heavy metals.

Finishing: This step includes the treatment of a softening agent to improve the sewability of the fabric, enhancing the presentation, feel and performance of the textile.

Transportation: At this point, fabric is shipped to where reams of fabric are cut and sewn into a shirt by a combination of mechanized and human labour. Travel distances between the fabric mill and the two cut-and-sew operations are relatively close so only the distance.

Washing: With two years of average life span, a shirt is assumed in this paper to be laundered 52 times throughout its entire usage. After the wash cycle, cleaned shirts are dried in either a tunnel dryer or an industrial-scale dryer and an individual steam press. Finally, the freshly laundered shirts are once again distributed to mission Linen Supply's clients.

Disposal: A shirt is retired from service once it is no longer presentable for customer to wear and discarded in a landfill.

Functional unit: The determination of functional units in the life cycle evaluation of polyester textiles is mainly based on the weight of polyester textiles. For the convenience of research, the waste quality from the production of poly-cooled fibres to polyester textiles is assumed to be constant. This article uses polyester textiles as a functional unit for life cycle assessment. The environmental impact in each stage of the polyester fabric life cycle is evaluated separately. Firstly, the green degree of each stage is grasped, and the results are combined and calculated to analyze which factors have the greatest impact on the environment, thus becoming a polyester textile. The ecological design provides direction and ideas. The data on the processing, manufacturing, transportation and disposal of polyester textiles in this paper are derived from a large number of related literatures.

The stages covered by the polyester textile life cycle are determined by the type of data to be collected for each stage, such as electricity, fuel input, product and energy for each stage. The output of thermal energy generated by incineration and the discharge of various pollutants included in the process output.

3. Result

The results shown in this section show the life cycle energy consumption, global warming potential (GWP) and water consumption of shirt life cycle. Statement unit selection is 100% polyester sports T-shirt. The T-shirt weighs almost 0.15 kg.

LCA results show that the production, use and disposal of sport shirt consume a total of 109.9 MJ of energy, resulting in a global warming potential of 81.62 CO2 equivalent (as a result of burning 1 gallon of propane) and 2882.9 L water. In the use stage of shirt, the used resources and contribution to global warming are the highest, accounting for 65.5% of energy use, 89% of water use and 84% of global warming potential, respectively. Shirt production stage accounts for 30.85% of energy consumption, 13% of total water consumption and 13% of global warming potential. In the three processes, the contribution of shirt processing is the least.

Table 1. LCI for one polyester T-shirt.
Data are extracted and calculated based on literature[19-22]

	Input energy (MJ)	Suspended particle (kg)	Hydro-carbon (kg)	Water Consum (L)	CO2 (Kg)	NOx (mg/m3)	SO2 (mg/m3)	CO (mg/m3)
PET production	4	0.007	0.050	5	1.102	0.017	0.023	0.022
Polyester manufacturing	18	0.007	0.002	8	3.854	0.606	0.210	0.103
Polyester transportation	1.2	0.001	0.001	2	0.060	0.001	0.011	0.091
Yarn Manufacturing	6.0	0.004	0.004	300	1.960	0.575	1.495	0.196
Weaving	1.1	0.013	0.016	50	1.046	0.026	0.042	0.008
Pre-treatment	0.9	0.003	0.004	1	0.190	0.007	0.001	0.006
Dyeing	1.8	0.009	0.006	11	0.890	0.001	0.003	0.004
Finishing	0.9	0.003	0.007	0.9	0.981	0.026	0.008	0.021
Transportation	0.021	0.002	0.006	1	0.530	0.004	0.015	0.001
Washing& drying	72	0.213	0.350	2500	68.812	1.172	1.881	0.205
Disposal	4	0.007	0.009	4	2.196	0.078	0.005	0.009

Table 2. Overall LCA results for the three phases

	Shirt production	Shirt use	Shirt disposal	Total
Input energy use(MJ)	33.92(30.85%)	72(65.50%)	4(3.64%)	109.92(100%)
Global warming (KgCO2equa)	10.61(12.99%)	68.81(84.31%)	2.196(2.69%)	81.62(100%)
Total water use(L)	378.9(13.14%)	2500(86.71%)	4(0.14%)	2882.9(100%)

In the production phase, the polyester production process accounts for the highest energy consumption (nearly 18MJ). Yarn manufacturing and PET production are subsequent energy intensive procedures after polyester production. The finishing, pre-treatment and weaving stages consumes the lowest energy.

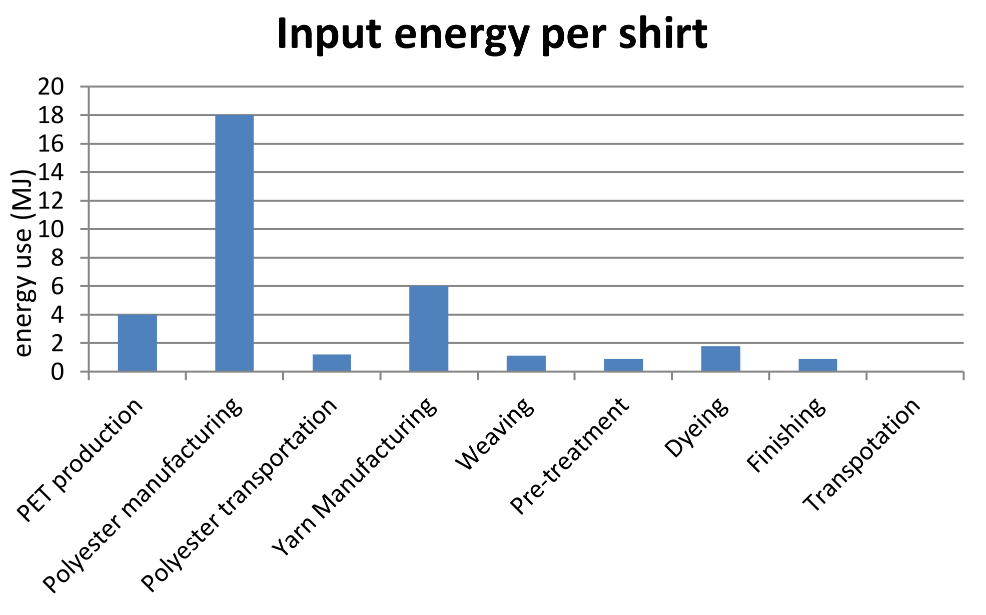

Figure 2. Energy input per shirt by process in the shirt production phase.

In the production phase, the polyester production process accounted for the highest energy use (nearly 18 MJ). The subsequent energy intensive unit processes are yarn manufacturing and PET production. The lowest energy uses occur in the finishing, pre-treatment and weaving stages.

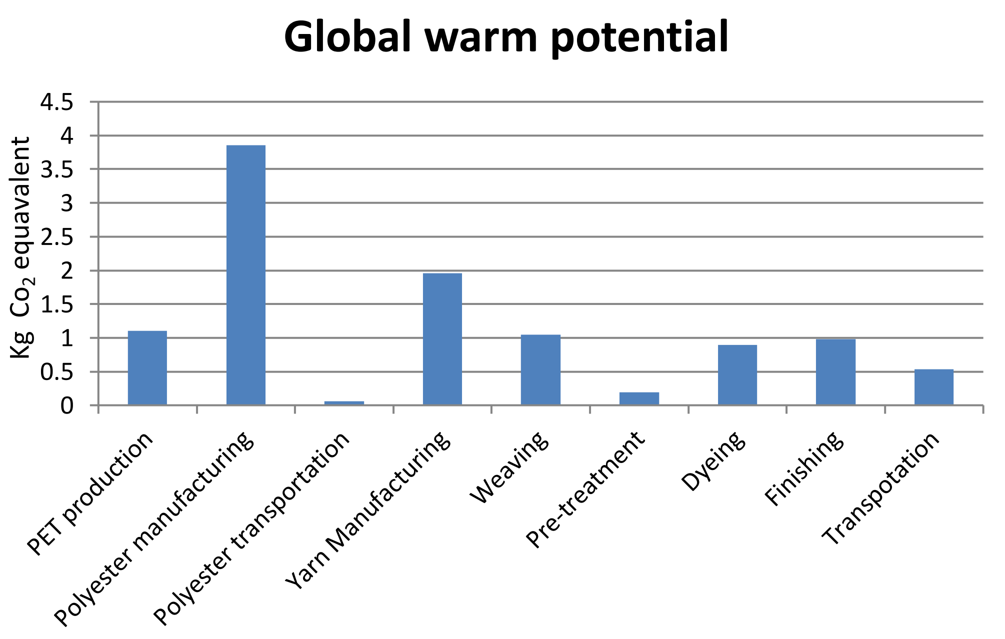

Figure 3. Global Warming Potential(GWP) per shirt by process for shirt production phase

In the production phase, polyester production requires the most energy out of all unit processes, while also contributing the most to GWP with 3.8KgCO2-equivalent--both numbers are high due to the significant amount of energy used to extract and refine crude oil to make polyester. In addition to the polyester production, the yarn manufacturing process also requires a lot of energy, and thus represents the next highest GWP at 2.0 KgCO2-equivalent. The lowest GWP occurred in the transportation and pre-treatment stages, at 0.06 KgCO2-equivalent and 0.19 KgCO2-equivalent respectively. The GWP correlates closely with the amount of energy used for each unit process.

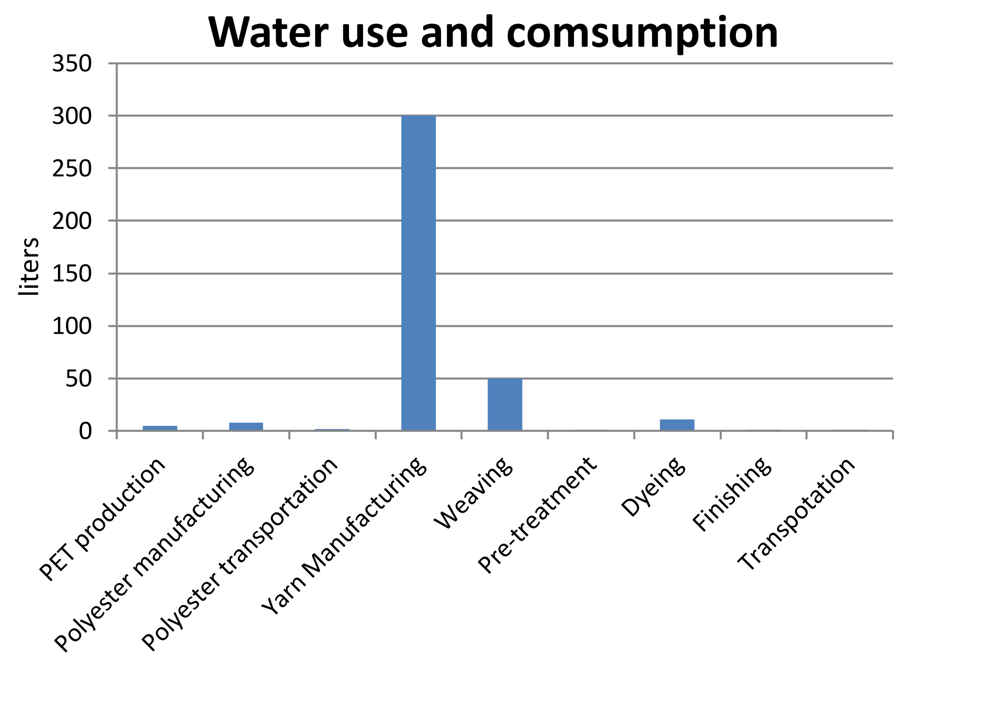

Figure 4. Water used per shirt by process for the shirt creation phase(L)

In the production phase, the yam manufacturing accounted for the highest water use (nearly 300 litre). The finishing, pre-treatment and weaving stages consumes the lowest energy.

4. Discussion & Conclusion

In the study, we present a cradle-to-grave LCA of 100% polyester T-shirt. It includes the cradle-to-gate processes of the production chain from raw material extraction to manufactured fabric for PET, as well as the gate-to-grave processes for textile products made out of these materials. The data is mainly based on publication in literature. To assess the environmental impacts, the methodology applied consisted of conducting on-site mills investigation and data evaluation.

With the rapid growth of the global PET industry and the fact that petroleum is a non-renewable resource, China's PET fibre is the world's largest producer. The amount of waste water and waste air produced in PET and textile processes is also relatively large. Being a strategic goal for national development is an important way to address ecological pollution and promote sustainable development of the industry.

The results of this life cycle assessment exhibit that the use-phase of a shirt is the stage that generally causes the most damage to the environment—it consumes more energy, uses more water non-consumptively, and contributes more to the global warming potential than either the shirt creation or disposal phases (Table 1).

In the shirt creation stage, the largest use of energy occurs during the production of polyester fibres, production of yarn, and cotton production phase. The production of polyester fiber depends heavily on the use of fossil fuels. Therefore, it is also the biggest contributor to global warming potential in the shirt manufacturing stage. It also uses crude oil, natural gas and electricity for polyester production, which consumes a lot of energy. However, polyester production only requires a small amount of water. It should be noted that the polyester content of shirts is almost twice that of cotton, so polyester has a greater impact on the environment based on the weight distribution method. The yarn manufacturing process uses a large amount of electrical energy to power the machine. Therefore, after producing polyester fiber, yarn making technology is the second largest contributor of GWP. The energy consumed in shirt disposal or EOL stage mainly comes from the transportation of used clothes to the landfill and the operation and maintenance of the landfill.

Implication For the PET manufacturing, the core solutions involve controlling the use of energy. To reduce the environmental emissions from the production process, it is crucial to better control the consumption and recycling of energy and materials [23,24]. On-site management should be strengthened by promoting energy-saving performance appraisal with education in order to reduce coal and electricity consumption. To control the environmental effects of washing and drying of textile shirts, it is also important to alter the washing habits of consumers by further prioritizing their environmental education. Furthermore, more municipal wastewater treatment plants should be built in villages to lower the emissions of CO2, nitrogen, and phosphorus to the environment [25].

Limitation of our study In our study, we looked at many materials to collect the data, but we found some data varied a lot depending on different condition. For example, the washing habit affected the used energy and carbon emission. The changes of washing time and machine-washing proportion mainly affect the contribution of use-phase to EP, owing to the wastewater discharge, which indicates that wastewater treatment could reduce this type of environmental impact. Another problem is some of our data from china, and some other data from America or Europe, there would be some difference between different country. The distinction of production technology between China and European countries may result in uncertainties. Hope all these limitations can be avoided in the next study. LCA results of textile products over the whole value chain are case dependent, especially when dyeing, finishing, the use phase, and the end-of-life stage are all included in the analysis. Further LCI data studies on textiles and garments are urgently needed not only to reduce the uncertainties in contemporary LCA of textile materials, but also to give us a more comprehensive knowledge of the environmental impacts brought by these products, which is crucial in order to make progress towards a healthier global environment.

References

[1] China's clothing industry sees tremendous changes since reform and opening up. People's Daily Online, October 17. 2018

[2] National Bureau of Statistics of China 2019 China statistical statistical yearbook 2018. China Statistics Press. Beijing

[3] Ministry of Industry anf Information Technology of the People's Republic of China 2018 Twelfth Five-year Plan for Texile Industey http://www.miit.gov.cn /n11293472/n11293832/ n11293907/ n11368223/14439904.html.

[4] Kostka G. Moslener U. Andreas J 2013 Barriers to increasing energy efficiency:evidence from small-and medium-sized enterprises in China. J Clean Prod. 57:59-68

[5] Terinte N, Manda BMK, Taylor J, Schuster KC, Patel MK 2014. Envirmental assessment of coloured fabrics and opportunities for value creation:spin-dyeing versus conventional dyeing of modal fabrics. J Clean Prod. 72:127-138

[6] Pakula C, Stamminger R 2010 Electricity and water consumption for laundry washing by washing machine worldwide. Energy Effoc. 3:365-382

[7] Wu GH 2012 Calculation and analysis of fossil energy consumption carbon emissions-taking Jinan as an example. Theory J: 61-65(in Chinese)

[8] Velden NM, Patel MK, Vogtlander JG 2014 LCA benchmarking study on textiles made of cotton, polyester, nylon, acryl or elastane. Int J Life Cycle Assess 19:331-356

[9] Weidema BoP, Thrane M, Christensen P, et al. Carbon footprint. A catalyst for life cycle assessment. 2008 Journal of industrial ecology,12(1): 3-6

[10] Pandey D, Agrawal M, Pandey JS. Carbon footprint: current methods of estimation. 2011 Environ Monit Assess, 178, issue1-4:135-160
[11] Cartwright J, Cheng J, Hagan J, Murphy C, Stern N Williams J. 2011 Assessing the environmental impacts of industrial laundering: life cycle assessment of polyester/cotton shirts. Bren School of Environmental Science and Management, University of California, Santa Barbara
[12] ISO 2006 ISO 14040 Series:environmental life cycle assessment principles and framework. International OrganizatioPonder CS 2009 Life cycle for Standardization Geneva
[13] Ponder CS 2009 Life cycle inventory analysis of medical textiles and their role in preverntion of nosocomial infections. University, North Carolina State
[14] Blabkburn R and Payne JD 2004 Life Analysis of cotton Towels: Impact of Domestic Laundering and Recommendations for Extending Periods Between Washing. Green Chemistry, 2004,6,G59-G61
[15] Yuan ZW, Zhu YN, Shi JK, Liu X, Huang L 2012 life-cycle assessment of continuous pad-dyeing technology for cotton gabrics. Int J Life Cycle Assess 18:659-672
[16] Chen, Q., Tang, K.-P.M., Ma, P., Jiang, G., Xu, C. 2017 Thermophysiological comfort properties of polyester weft-knitted fabrics for sports T-shirt. Journal of the Textile Institute, 108 (8), pp. 1421-1429
[17] Wang, Q., Tang, H., Ma, Q., Mu, R., Yuan, X., Hong, J., Zhang, J., Zuo, J., Mu, Z., Cao, S., Liu, F. 2019 Life cycle assessment and the willingness to pay of waste polyester recycling. Journal of Cleaner Production, 234, pp. 275-284.
[18] Chard, J.M., Basson, L., Creech, G., Jesson, D.A., Smith, P.A.2019 Life cycle assessment of a urethane methacrylate/unsaturated polyester resin system for composite materials. Sustainability (Switzerland), 11 (4), art. no. 1001.
[19] Laursen SE, Hansen J et al 2007 EDIPTEX—environmental assessment of textiles. Working Report No. 24, Danish Technological Institute
[20] Cartwright J, Cheng J et al 2011 Assessing the environmental impacts of industrial laundering: life cycle assessment of polyester/cotton shirts. M.Sc. thesis, Bren School of Environmental Science &Management, University of California
[21] Ma Su. 2007 Life cycle assessment of terylene textile.Master disseration thesis, Donghua Univerdity
[22] Velden NM, Patel M and Vogtländer JG 2014 LCA benchmarking study on textiles made of cotton, polyester, nylon, acryl, or elastane. Int J Life Cycle Assess 19:331–356
[23] Kiran-Ciliz N 2003 Reduction in resource consumption by process odifications in cotton wet processes. J Clean Prod 11:481-486
[24] National Renewable Energy Laboratory (NREL) 2011 Federal Renewable Energy Screening Assistant(FREScA) Software Package. Retrieved fron http://analysis.nrel.gov/fresa/
[25] Ting C 2011 Building a sustainable a sustainable supply chain:an analysis of corporate social responsibility(CSR) practices in the chinese textil and apparel industry. J Tect Inst 102:837-848