Check for updates

JOURNAL OF ENGINEERED FIBERS AND FABRICS

Review Article

Journal of Engineered Fibers and Fabrics
Volume 16: 1–8
© The Author(s) 2021
DOI: 10.1177/15589250211020387
journals.sagepub.com/home/jef
SAGE

Calculation and evaluation of industrial carbon footprint of cotton denim jacket

Yu Cheng[1] and Hui-e Liang[1,2]

Abstract

Carbon footprint (CFP) reflects the greenhouse gases (GHGs) produced by human activities or products throughout the life cycle, which is an important tool for assessing and managing greenhouse gas pollution. The reduction of Carbon footprint is an important topic today, and each of us needs to minimize our CFP in order to protect our planet. In this paper, the basic cotton denim jackets was played an research object roles to exploring the impact on the environment during the process of producing cotton denim jackets. Which based on the theory of industrial carbon footprint and combing with the production process chain of denim jackets, setting the accounting boundaries and functional units, the denim jacket can be divided into cutting, sewing, and finishing the three links in industrial production of carbon footprint. With the calculation and analyzation industrial carbon footprint of the denim jacket. The results show that the carbon footprint of denim jackets exceeds 1000 kg CO_2 during the cycle from cutting to sewing and finishing. The largest carbon footprint is generated in the sewing process, which are about twice as high as the cutting process. The carbon footprint emissions of each piece of denim jacket is 1.75 kg CO_2. Therefore, optimizing the production line in the sewing process, adopting high energy-efficient processing equipment and clean energy can better reduce the industrial carbon footprint of denim clothing. It also provided reference and basis for the supervision and evaluation of carbon emission by clothing manufacturers

Keywords

Carbon footprint, denim jacket, account, boundary, production process

Date received: 11 November 2020; accepted: 8 May 2021

Introduction

Global warming represents a threaten to the natural environment and human economic development. Many studies have shown that the main cause of global warming is the increase of greenhouse gas (GHGs) emissions that caused by human activities (Bevilacqua et al., 2011).[1] Carbon Footprint (CFP)[2] assessment is an important method for controlling and managing greenhouse gas emissions. Which is based on the life cycle concept and used to evaluate the greenhouse gas produced during the entire life cycle of the production or services or within a specified time or space (Brito de Figueirêdo, et al., 2013).[2] Carbon Footprint (CF) is one of the important concepts in the research field of "Footprint."[3] It was first appeared in the UK and developed rapidly under the promotion of academia, non-governmental organizations, and the news media.[4] However, regarding the concept of carbon footprint, Wiedmann and Minx[5] listed different definitions, defined and discussed the concept of carbon footprint.

[1]Jiang Nan University, Wuxi, China
[2]Wuxi Vocational Institute of Arts and Technology, Wuxi, China

Corresponding author:
Hui-e Liang, Wuxi Vocational Institute of Arts and Technology, Wuxi 214122, China.
Email: lianghe@jiangnan.edu.cn

Creative Commons CC BY: This article is distributed under the terms of the Creative Commons Attribution 4.0 License (https://creativecommons.org/licenses/by/4.0/) which permits any use, reproduction and distribution of the work without further permission provided the original work is attributed as specified on the SAGE and Open Access pages (https://us.sagepub.com/en-us/nam/open-access-at-sage).

Their definition of carbon footprint is: the amount of CO_2 emissions produced directly and indirectly in an activity, and it is clearly stated that the carbon footprint is a measure of the amount of CO_2 emissions and expressed in units of weight. Hammond[6] emphasized in "Nature" that carbon footprint is the "carbon weight" produced by a person or an activity, and suggested that carbon footprint should be called "carbon weight." JCR (Joint Research Centre Institute for Environment and Sustainability),[7] the Research institution of the European Commission defines carbon footprint as the total amount of CO_2 and other greenhouse gases emitted during the whole life cycle of a product or service. Scholars such as Hertwich and Peters,[8] Baldo et al.[9] define carbon footprint as the total amount of CO_2 and other greenhouse gas emissions produced by a product's supply chain or life cycle, etc.

Product Carbon Footprint (PCF) refers to the total carbon emissions of a product during its entire life cycle, that from raw materials to production, distribution, use, disposal, or reuse. As countries around the world pay more attention to the issue of carbon emissions, in recent years, there have been a number of standards on the carbon emission and carbon footprint evaluation of enterprises and products in related fields. Such as: GHG Protocol, PAS2050:2008 "Specification for the assessment of greenhouse gas emissions during the life cycle of goods and services" Greenhouse Gas Series Standards ISO 14064:2006, Greenhouse Gas Certification, etc.[10–12] As one of the most basic needs of human beings, clothing produces carbon footprints at every stage of the life cycle. The textile and garment industry involves a long and complex supply chain, creates a large carbon footprint and is a major source of greenhouse gas emissions.

In the research on the carbon footprint of textile and apparel products, there are many reference like Wenyan et al.[13] calculated the industrial carbon footprint of worsted wool fabrics, and obtained the carbon footprint of the wool top, spinning, weaving process, finishing and packaging stage, which improved the research on the carbon footprint of wool products. Yang et al.[14] combined the research with PAS2050 specifications to analyze the carbon footprint of hemp fiber products from the planting of raw materials to the product life cycle. The study found that the energy and chemical consumption in the process of production and processing constituted the main cause of greenhouse gas emissions. By analyzing the research status of carbon footprint in the textile and apparel industry. Tu et al.[15] conclude the concept of carbon footprint and relevant standards in the international market, and explains the current status of carbon footprint research and application in the textile at home and abroad. Gao et al.[16] calculated the energy consumption and carbon footprint in the carbon production process of cotton fabric and concluded that power consumption was the main factor that affecting production process of cotton fabric, and the power consumption of air compressor and loom accounted for a large proportion. Therefore, they proposed energy-saving and emission-reducing production measures. Li et al.[17] mentioned in the paper "Demonstration of jeans industrial carbon footprint accounting and evaluation" that the industrial carbon footprint within the jeans accounting boundary is 9.84 CO_2, and the water washing process is 7.55 kg CO_2, accounting for about 76.72%. The second is the sewing process, with an industrial carbon footprint of 1.67 kg CO_2, accounting for about 16.96%. The packaging process is the smallest, with 0.622 kg CO_2, accounting for approximately 6.32%. In summary, there have been many studies on the carbon footprint of the textile and apparel industry in domestic and foreign, but there are few studies on the carbon footprint of the denim apparel production industry This is also the main reason for me to analysis the Industrial carbon footprint of the denim clothing.

China is the world's largest producer and consumer of textiles. According to statistics from China Black Peony Group Co. Ltd., in 2018, the global production of denim is nearly 5.5 billion meters, and China's production accounts for almost half. The main producers of denim fabrics and clothing are concentrated in China and India. With the statistics of clothing sales in 2020 on "Tmall Shopping," the largest online shopping platform in China, denim jackets, jeans account for the largest proportion among denim clothing, which jeans account for 51.5% of the total number of pants, accounting for more than half of the market. Except for suits, denim is the only clothing that has been popular for a century, which has a wide popularity in the world, especially favored by young consumers. Due to the particularity of the clothing itself, denim consumes a lot of water resources and energy in the production process, and the waste water the exhaust gas has a serious pollution impact on the environment. Therefore, accounting carbon production of denim garment has positive effects on reducing environmental pollution. In additions, denim jackets are relatively traditional jacket styles with classic styles and representative production processes, so that it is more easy for calculation.

This paper takes the basic style denim jackets as research object, summarizing the production process chain, the output data with the theory of textile industry carbon footprint, and combining with the carbon footprint accounting model to calculate and evaluate the industrial carbon footprint of the denim jackets. With it, we can better give suggestions on carbon emission control for the industrial production of denim clothing.

Product information

Takes the conventional M size ladies denim jacket as an example to conduct quantitative analysis and

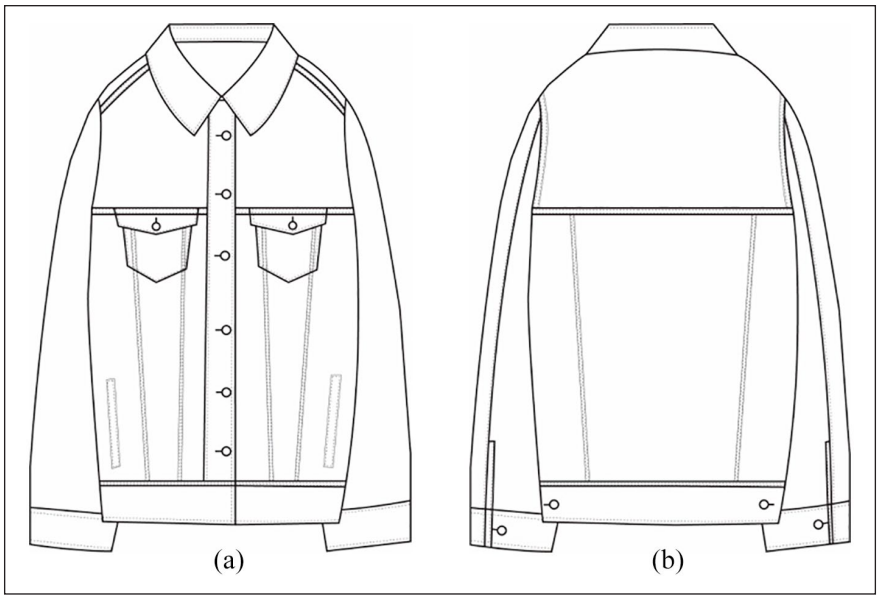


Figure 1. Painted by the author: (a) front and (b) back.

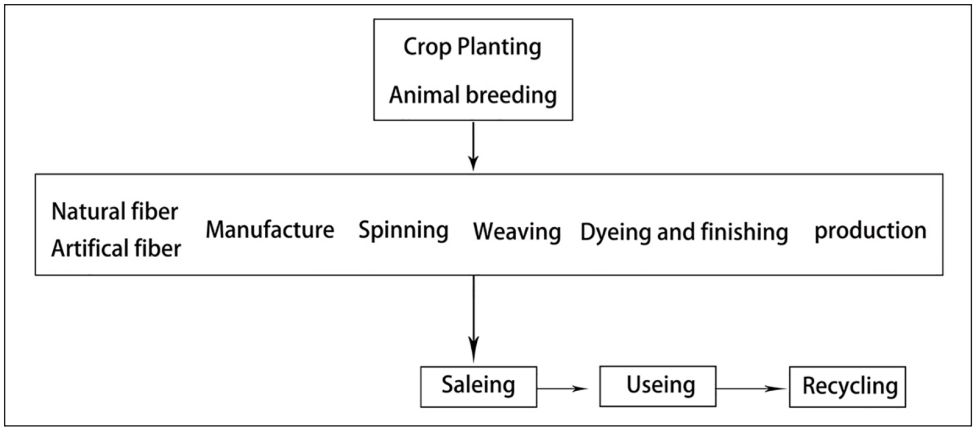


Figure 2. The life cycle of textile products.

calculation of carbon emissions. Its styles contains: lapel, long sleeves, exposed placket, two left and right chest pockets, two diagonal open pockets, overlock stitching, two-line series, six buttons on the placket, two buttons on the pockets, three buttons on the cuffs, two buttons on the hem. The jacket has a shoulder width of 49.5 cm, bust of 128 cm, sleeve length of 60.5 cm, and a back middle length of 59.5 cm. The style is shown in Figure 1

Accounting boundaries, functional units, methods, and data

Concept of industrial carbon footprint

The whole life cycle process of textile products can be summarized into five stages, the agricultural production (fabric (such as cotton) planting, animal (such as sheep) breeding), industrial production and processing (fiber production, spinning, weaving, dyeing and finishing, etc.) sales, using and recycling processing. Textile industrial carbon footprint is the cause of greenhouse gas emissions in industrial production of accounting and evaluation. The current definition of textile industry's carbon footprint, is the amount of greenhouse gas emissions directly and indirectly caused by textiles during the industrial processing stage.

Accounting boundary and functional unit

According to the PAS2050:2008 specification, two types of data are required to calculate the carbon emissions of an apparel manufacturing process: activity level data and emission factors.

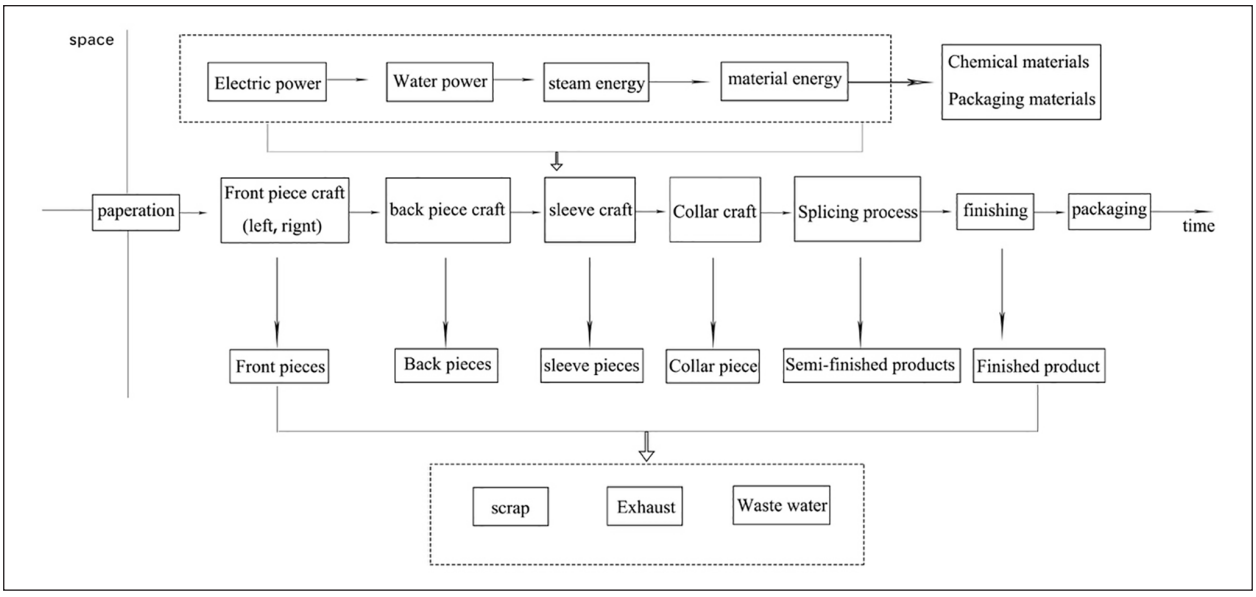


Figure 3. Basic cotton denim jacket accounting boundary and input.

Activity level data refers to all raw materials and energy (material input and output, energy use, transportation, etc.) involved in the garment production process. The carbon emission of clothing production is a B2B (business-to-business) model, in which the whole process only includes the material from the cutting department through the production line to the inspection and packaging department, and it does not include the additional production steps, retail, consumer use, post-disposal, etc.

The research of this paper is the carbon footprint of the industrial production of cotton denim jackets, excluding the production of fabrics and accessories. Therefore, the calculation scope does not include the carbon emissions generated by the raw materials.

The carbon emissions included in the life cycle are:

1. All production processes
2. Transportation and storage related to production
3. Emissions related to production sites
4. All materials produced in the production process (including products, waste, waste gas and wastewater, etc.)

The basic production process of denim jacket includes dyeing, spinning, weaving, fabric inspection, preshrinking, cutting, sewing, washing, ironing, and packaging. The calculation boundary of product carbon footprint can be divided into time boundary and space boundary.[18] According to standards such as PAS2050, the carbon footprint calculation boundary of denim jacket in this article is divided into time boundary and space boundary. The time boundary for calculating the industrial carbon footprint of denim jacket production is the process chain from cutting, sewing to packaging, while the space boundary is the production input of water, electricity, steam, packaging materials, chemical additives, and other materials consumed in the selected process chain segment, as shown in Figure 3 below.

A functional unit is an input and output reference that provides a mathematically unified measurement, it is the standard for the calculation of carbon emissions in the whole process.[19]

This article collected 800 pieces of women's jackets produced per day as the functional unit for emissions calculations. And summarized the processes and steps involved in the life cycle of the jacket production link, which can be briefly summarized as fabrics entry, production and processing, inspection and packaging, and the final product delivery. As shown in Figure 4 below, the process diagram includes the carbon emissions involved in the production process of women's denim jackets, the calculation boundary omits the process with small carbon emissions.

Data collection

According to the PAS2050:2008 specification, two types of data are required to calculate carbon emissions in a certain apparel manufacturing process: activity level data and emission factors. Activity level data refers to all raw materials and energy involved in the garment production process (material input and output, energy use, transportation, etc.)

Take the M size denim jacket as an example. Within the carbon footprint calculation boundary, the relevant data are divided into three levels: cutting carbon emissions,

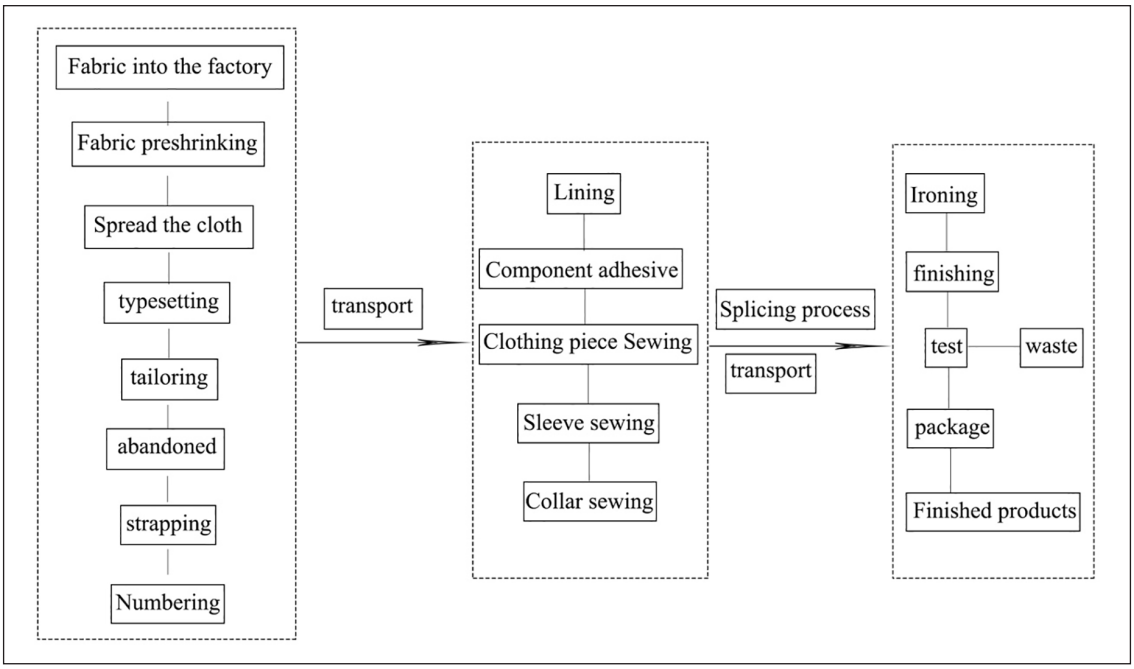


Figure 4. Women's jacket production process.

sewing carbon emissions, and finishing carbon emissions. Whose composition is shown in Table 1 below. The data of energy and material consumption in the packaging process adopt comprehensive average data collected from reference and enterprise research.

In this study, the relevant data involved are the core of the calculation of denim jacket's carbon emission. In production process of denim jacket, some primary data are obtained from reading a large number of books and relevant reference as well as summarizing survey of the factory. Therefore, most of the emission factor data involved are theoretical data. In the process of data collection, for the carbon emission factors of all materials required in the production process of denim jackets or for a certain material, it is impossible to trace its subdivision material types, such as emission factors of different components of raw materials and emission factors of different accessories, etc. Therefore, the average value of the data results of the material under a known material is the emission factor of the material.

The emission factor of some materials (f_i/kgCO_2e is shown in Table 2 below).

Carbon footprint accounting method

Combine the carbon emission of clothing in the three links of cutting, sewing, and finishing, the industrial carbon emission of denim jacket production are calculated. This article divides the carbon emissions in the tailoring process into three parts: equipment energy consumption, material energy consumption, and manpower energy consumption. The tailoring equipment mainly includes cloth inspection machines, cloth stretching machines, cutting equipment, etc., and most of them are continuous after the equipment starts to operate.

According to the PAS2050 standard, calculate the carbon emission value corresponding to a certain activity. The calculation method is: carbon footprint = activity data (mass/volume/kWh/km)×emission factor (CO_2e/unit). Therefore, the result of continuous working equipment carbon emission is the sum of equipment energy consumption and the corresponding electric energy emission factor. In the tailoring process, the remaining corner fabrics are the rags after layout cutting. The tailoring rags are the largest source of waste in the cutting process. Its single area is small and different in shape and size, and cannot be directly used or used for other purposes. Therefore, the maximum utilization rate of the discharge material is inversely proportional to the carbon emissions generated by the waste cloth. The greater the utilization rate, the smaller the corresponding carbon emissions will be.

The carbon emission model for Tailoring is:[20]

$$C_c = f_d \times \sum_{i=1}^{n} p_i \times t_i + K_1 \sum_{u=1,r=1}^{n} t_u \times n_r \times N_r + \left(\sum_{m=1}^{n} E_m \times f_m \right) \times (1-\eta_m) \quad (1)$$

(1): C_C is the carbon emission produced by the tailoring process $kgCO_2$; Pi is the rated power of the equipment W; t_i is the production time h; f_d is the carbon emission factor

Table 1. Composition of industrial carbon footprint data for the apparel products.

	Level 1 (carbon Footprint of cutting process) Cutting equipment consumption (cloth inspection machine, cloth spreading machine, cutting machine), manpower consumption, carbon footprint caused by material consumption.
	Level 2 (carbon footprint of sewing process) Sewing equipment energy consumption (lockstitch sewing machine, overlock sewing machine, automatic thread trimmer), auxiliary material consumption (sewing thread, buttons, adhesive interlining, tag, etc.), clothing, auxiliary material transmission, product waste disposal.
	Level 3 (carbon footprint of finishing) Ironing (electricity, water, steam), inspection, delivery, packaging materials

Table 2. Part of energy-related carbon emissions factors of production.

Energy category (E_i)	Emission factor (f_i)/kgCO_2e	Energy category (E_i)	Emission factor (f_i)/kgCO_2e
Water	0.116	Plastic button	20.136
Electricity	0.824	Steel alloy button	15.596
Cotton fabric	10.750	Metal zipper	0.147
Copper button	17.586	Plastic zipper	0.101
Aluminum alloy button	15.546	A4 printing paper	0.013 piece
Sewing thread	46.287	The burning of waste	0.917
Printed label	45.860	Steam	2.530
General standard	45.863	Landfill waste	0.015
PVC film	1.620	Packaging carton	1.038

kgCO_2e represents the amount of CO_2 released by consuming unit mass of energy or material.

of electric energy $kgCO_2e$ (e is the abbreviation of emission); K_1 is the carbon emission per hour of breathing produced by a person when working statically $kgCO_2$; t_u is the time h for the worker to do a specific process; n_r is the number of times the process is repeated in the production of clothing per unit of output; N_r is the number of workers in the corresponding type of work, u and r is for different process types, E_m is the mth energy consumption kg required to produce the fabric per unit output; f_m is the corresponding energy carbon emission factor $kgCO_2e$; η and m are the emission rate% of the corresponding fabric.

The sewing process is an important link in garment production. The whole sewing process mainly includes the sewing of main materials and the assembling of auxiliary materials, such as adhesive interlining, sewing thread, buttons, zippers, lace, tag, and so on. Sewing equipment mainly includes flat sewing machine, overlock sewing machine, automatic thread cutting machine, and so on. In the sewing process, carbon emission sources mainly include energy consumption of sewing equipment, energy release of auxiliary materials, energy consumption of finished products and semi-finished products, waste emission and treatment consumption, as well as different carbon emissions generated by respiration of workers in working state and static state.

The carbon emission model of the sewing process is:[20]

$$C_F = f_d \sum_{p=1}^{n} \left(p_y \times t_y + p_w \times t_w \right) + \sum_{q=1}^{n} G_q \times \delta_q + \left(K_2 \sum_{r=1}^{n} \frac{d_r \times N_r}{v_r} + W_e \sum_{e=1}^{n} \frac{d_e \times N_e}{v_e} \right) + K1 \sum_{u=1,r=1}^{n} t_u \times n_r \times N_r \quad (2)$$

(2): C_F is the carbon emission produced by the sewing process $kgCO_2$; f_d is the carbon emission factor $kgCO_2e$ of electric energy; p_y is the effective working efficiency W; t_y is the effective working time; p_w is the idling working

power; t_w is the idling working hours h; Gq is the consumption of various auxiliary materials required by the production unit in kg; $\delta\ q$ is the carbon emission factor of the corresponding auxiliary materials $kgCO_2$; q is the types of different auxiliary materials. $K2$ is the carbon emission $kgCO_2$ produced by breathing under dynamic working conditions; d_r and d_e are the distance between adjacent stations m; Nr and Ne are the number of the same separation distance; Vr is the human transmission rate under dynamic working conditions m/h; V_e is the mechanical transfer rate m/h; W_e is the rated power W of the mechanical equipment.

After the tailoring and sewing process, the finishing process is an essential process before the garment is transformed into saleable goods. Conventional garment finishing includes ironing, inspection, and product packaging. Among them, the energy consumption of the ironing machine, the energy consumption of the transmission and transportation equipment during the inspection process, the carbon emission of the workers' breathing in the static and dynamic work and the carbon emission of the packaging materials in the packaging link are the total carbon emission of the finishing process. Denim finishing is an important step before packaging and selling. According to the construction project of Dongguan Ouyi Garment Washing Co., Ltd. as a reference, 225 pieces of jeans were washed annually as the standard, and the total output of drainage wastewater corresponding to the project was 708.62t/d,[21] it was calculated that the average discharge consumption of washing water for a jeans garment was 114.95 kg and the carbon emission was 22.3 kg.

The carbon emission model for the finishing process is:[20]

$$C_H = n \times P_z \times t_z \times f_d + \sum_{q=1}^{n} G_q \times \delta_q + \left(\sum_{r=1}^{n} \frac{d_r \times N_r}{v_r} + W_e \sum_{e=1}^{n} \frac{d_e \times N_e}{v_e} \right) + K1 \sum_{u=1,r=1}^{n} t_u \times n_r \times N_r \quad (3)$$

According to the calculated results of the model, $K1$ and $K2$ were used to calculate the carbon emissions from human respiration. The human labor state was divided into static working state and dynamic working state. Static work refers to the activities generated in the quiet breathing state, while dynamic work refers to the activities generated in walking and other daily activities. Set the breathing frequency of a normal adult in a quiet state to 16–20 breaths/min, which is 960–1200 times per hour, and exhale 0.25 L of carbon dioxide per minute in a resting state, which means that 15 L of carbon dioxide is emitted per hour. Normally, the lower carbon dioxide density is 1.96 g/L, therefore, about 0.0294 kg of carbon dioxide is emitted per hour, So, the $K1$ setting value in this article is 0.029. It is assumed that a normal adult exhales 1 L of carbon dioxide per minute in the state of daily activities, that is, 60 L of carbon dioxide is emitted per hour, with a mass of 0.117 kg, that is, the set value of $K2$ in the text is 0.117. Substituting into the model, we can get the results of carbon emissions during the production of women's denim jackets as shown in Table 3.

Table 3. Fabric parameters.

Fabric parameters	
Main material	Cotton 100%
Fabric width／m	1.5
Spreading length／m	1.5
Layout efficiency／%	88.7
Fabric surface density／（g.m^2）	308.9

Table 4. Calculations of carbon emissions in female jacket production.

Production processes	Result before substituting K value	The result after substituting the K value
Tailoring	367.094 kg + 178.445 K_1	372.269 kg
Sewing	760.290 kg + 8.077 K_2	761.235 kg
After finishing	244.633 kg + 22.3 kg	266.933 kg
Merge	1.374 t + 178.445 K_1 + 8.077 K_2	1.4004 t

It can be seen from the Table 4 that the carbon emission of denim jackets is the largest in the sewing stage and the smallest in the finishing stage. The carbon emission of denim jackets in the sewing stage is about two times that of the cutting stage. The industrial carbon footprint of denim jacket within the accounting boundary is 1.4004 t CO_2, of which the carbon footprint of the sewing process is the largest 761.235 kg CO_2, accounting for about 54.4%. The second step is cutting, and the industrial carbon footprint is 372.269 kg CO_2, accounting for about 26.7%. The last finishing link was the smallest, with the industrial carbon footprint of 359.583 kg CO_2, accounting for about 19.06%. If 800 denim jackets are produced in 1 day, the carbon emission of one denim jacket produced in 1 day is 1.4004t/800 = 1.7505 kg.

Conclusion

(1) The carbon emission model of the production link is mainly composed of equipment energy consumption, material consumption, and manpower

consumption. The use of equipment is divided into two situations: idling and full rotation. Transmission is divided into two modes: manpower and mechanical. The materials are mainly used for clothing accessories and exhaust materials.

(2) The carbon emissions of women's denim jackets in the production process of cutting, sewing, and the whole process exceed 1000 kg CO_2. Among them, the carbon emissions are the largest in the sewing process, which is about two times of the carbon emission in the cutting process. Therefore, controlling the industrial carbon emissions of garments in the sewing production process is the key direction of energy saving and emission reduction in industrial production.

(3) From the calculation results, it can be seen that controlling the material, equipment selection, personnel arrangement, and high-efficiency and energy-saving processing equipment in the garment sewing process is the key to reducing carbon emissions. To a certain extent, the calculation results can provide a certain reference for energy saving and emission reduction in the production of denim clothing, and make comparisons for subsequent research and analysis.

(4) The calculation results in this paper show the industrial carbon footprint value of the denim jacket during the production process. The calculation results provide a reference for the comparison of the carbon footprint of similar products and also provide data support for the realization of full life cycle accounting.

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: The authors acknowledge the financial supports from "Postgraduate Research & Practice Innovation program of Jiangsu Province" (KYCZ20_1804).

ORCID iD

Yu Cheng https://orcid.org/0000-0001-5091-3068

References

1. Bevilacqua M, Ciarapica FE, Giacchetta G, et al. A carbon footprint analysis in the textile supply chain. *Int J Sustain* Eng 2011; 4: 24–36.
2. Brito de Figueirêdo MC, Kroeze C, Potting J, et al. The carbon footprint of exported Brazilian yellow melon. *Clean Prod* 2013; 47: 404–414.
3. Gill A, Wiedmann T, Ercin E, et al. Integrating ecological, carbon and water footprint into a "footprint family" of indicators: definition and role in tracking human pressure on the planet. *Ecol Indic* 2012; 16: 100–112.
4. Wiedema BP, Thrane M, Christensen P, et al. Carbon footprint: a catalyst for life cycle assess? *J Ind Ecol* 2008; 12(1): 3–6.
5. Weidmann T and Minx J. A definition of 'carbon footprint'. *Ecol Econ Res Trends* 2008; 1: 1–11.
6. Hammond G. Time to give due weight to the 'carbon footprint' issue. *Nature* 2007; 445(7): 256.
7. Ec. Carbon footprint-what it is and how to measure it [Z]/2007,3-24.
8. Hertwich EG and Peters GP. Carbon footprint of nations: a global, trade –linked analysis. *Environ Sci Technol* 2009; 43(16): 6414–6420.
9. Baldo G, Marino M, Montani M, et al. The Carbon footprint measurement tookit for the EU Ecolabel. *Int J Life Cycle Assess* 2009; 14(7): 591–596.
10. Zhao R, Huang X and Zhong T. Research on carbon emission intensity and carbon footprint of different industrial spaces in China. *Acta Geogr Sin* 2010; 65(9): 1048–1057.
11. Carbon Trust. Carbon footprint measurement methodology. *Carbon Trust* 2007; 1: 27–34.
12. Yang H. Progress in IPCC guidelines for energy sector inventories and its impacts on China. *Adv Clim Change Res* 2006; 6: 273–276.
13. Wenyan F, Qingjuan Z and Ding X. Carbon footprint calculation of worsted wool fabric industry. *Wool Spinning Technol* 2015; 43(5): 137–140.
14. Yang Z, Zhang J, Zhang H, et al. Carbon footprint measurement and analysis of hemp fiber products based on PAS2050 specification. *Text J* 2012; 8: 54–57.
15. Tu L and Liu Y. Analysis on the status quo of carbon footprint research in the textile and apparel industry. *Text Sci Technol Prog* 2012; 03: 19–21+45.
16. Gao X, Lu J, Zhu J, et al. Calculation and analysis of comprehensive energy consumption and carbon footprint of cotton fabrics. *Shanghai Text Technol* 2016; 10: 44–46.
17. Li Y, Wang J and Wang L. Demonstration of carbon footprint calculation and evaluation of jeans industry. *Modern Text Technol* 2017; 6: 58–61.
18. Wang L, Ding X and Wu X. Research progress on carbon footprint of textile and clothing. *J Text Res* 2013; 34(6): 113–119.
19. Yu L, Wang L and Chen Y. Accounting of carbon emissions during clothing production. *J Text Res* 2016; 37(04): 160–164.
20. Yu L, Wang L and Chen Y. Calculation model of carbon emission in garment production processes. *J Text Res* 2016; 37(03): 156–159.
21. Announcement of the environmental impact assessment report: engaged in washing denim garments, 2.25 million pieces of denim garments Environmental assessment, http://www.docin.com/p-2084491022.html