# Chapter 9
# Low Carbon and Clean Design for Garment Industry Based on Environmental Footprint Accounting

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**Abstract** Due to its long industrial chain and wide variety of commodities, the garment industry with high carbon emissions and high pollution cannot effectively achieve low-carbon and clean production by upgrading a specific technology. Considering that the impact of the garment industry on the environment is mainly carbon emission, wastewater pollution and chemical pollution, this paper analyzes and lists three kinds of environmental footprints that should be considered most by the garment industry from the perspective of environmental footprint, namely, carbon footprint, water footprint and chemical footprint, and gives the calculation models of the three kinds of footprints. Finally, this paper takes carbon footprint as an example to analyze the carbon footprint of Xiangyun yarn fabric, linen fabric and worsted wool fabric, and gives some suggestions on the low-carbon upgrading of the garment industry. The results show that the worsted fabric has the highest carbon footprint, 24.809 $kgCO_2e/kg$, and its spinning process and post-treatment process are the two processes with the largest carbon footprint, accounting for 70.6% of the total carbon emissions. This means that for the worsted wool fabric, the improvements of spinning and post-treatment related processes can greatly reduce the level of carbon emissions in the production process and contribute to the low-carbon upgrading of the garment industry.

**Keywords** Garment industry · Low carbon design · Carbon footprint

## 9.1 Introduction

In recent years, with the frequent occurrence of extreme weather disasters around the world, people pay more and more attention to environmental protection, energy conservation and emission reduction. Clothes, as the most common items in life, tend

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to cause a lot of carbon emissions and environmental pollution in their entire life cycle. Due to its huge scale and long supply chain, the garment industry produces about 10% of the total carbon emissions and 20% of the industrial wastewater each year (Leal et al. 2022; Kant 2012). In addition, throughout the life cycle of clothing, there will be a series of problems such as chemical pollution and textile waste accumulation (Niinimaki et al. 2020).

Obviously, the high carbon emissions and high pollution of the garment industry can not be ignored at present. In terms of reducing carbon emissions, due to the long industrial chain of the garment industry, a single technological improvement measure is far from effectively promoting the realization of the carbon dioxide emission reduction target of the industry at the macro level. Therefore, considering that the garment industry involves a large number of countries and regions and a wide variety of technical links, it is an effective means to reduce emissions of the garment industry by quantifying carbon emission targets and finding the carbon emission entry point in the life cycle of the garment industry based on carbon footprint accounting. This is because, firstly, it has become an international consensus to jointly promote the reduction of greenhouse gas emissions, and many countries have made up their minds to tackle these problems and set corresponding carbon reduction targets. Germany, for example, plans to reduce carbon emissions from its clothing sector to 65% below 1990 levels by 2030 (Black et al. 2021). Vietnam plans to reduce carbon emissions in the garment sector by 85% below 2014 levels by 2030 (Do and Burke 2021). Secondly, carbon footprint accounting also provides the possibility for the garment industry to fundamentally implement carbon emission reduction, because it can cover all aspects of the garment industry's life cycle, from raw material acquisition to recycling. Therefore, the use of carbon footprint accounting method can provide strong support and guidance for the low carbon upgrading of the garment industry. Similarly, in terms of pollutant emissions, corresponding environmental footprint accounting methods can also be adopted to help the garment industry achieve a clean transition.

Based on the above content, this paper focuses on carbon emission reduction, wastewater emission reduction and chemical pollution, and expounds the method to solve the low-carbon and clean development of the garment industry from a macro perspective, that is, the method to rely on environmental footprint estimation. And this paper analyzes and lists three kinds of environmental footprints that the clothing industry should consider most, namely, carbon footprint, water footprint and chemical footprint, and the calculation models of the three kinds of footprints. With the help of the corresponding footprint accounting, it is helpful to conduct a comprehensive investigation of the environmental indicators of the whole life cycle of the garment industry, and can effectively provide a reference for the optimization direction of the low-carbon and clean development of the garment industry.

## 9.2 Accounting for Environmental Footprint

### *9.2.1 Conceptual Definition of Environmental Footprint Accounting in the Garment Industry*

Environmental footprint refers to the series of impacts on the environment during the life cycle of a product, including direct and indirect impacts from raw material acquisition, finished product production, use and maintenance, recycling and disposal processes. For the garment industry, during the life cycle of a specific product, the impact on the environment mainly comes from carbon dioxide emissions, water pollution and chemical pollution. Therefore, for the garment industry, it is necessary to conduct carbon footprint accounting, water footprint accounting and chemical footprint accounting for the garment life cycle.

### *9.2.2 Accounting Boundary*

Before calculating the environmental footprint of a product, it is necessary to determine the product accounting boundary. The accounting boundary of a certain product in the garment industry can be divided into time boundary and spatial boundary. For the garment industry, the time boundary of the environmental footprint can be all units of activity between raw material acquisition and recycling, the main units of activity are shown in Fig. 9.1. The spatial boundaries of the environmental footprint refer to the required energy and resource inputs and waste outputs in the areas necessary for these activities. For example, the water and electricity consumed in the garment processing plant, the discharge of industrial wastewater, greenhouse gases and chemical pollutants.

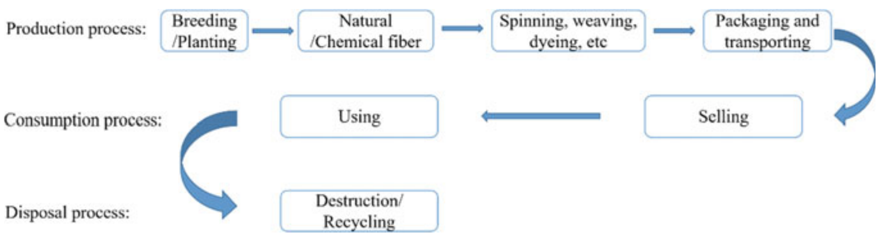


**Fig. 9.1** The life cycle of typical products in the garment industry

### 9.2.3 Carbon Footprint Accounting Model

The carbon footprint calculation is the sum of the carbon dioxide emission ns of the product within a certain accounting boundary, including the direct and indirect part, and other greenhouse gas carbon footprint calculation also needs to be converted to carbon dioxide equivalent, that is, $CO_2e$. In the calculation process of specific carbon emissions, the emission factor method can often be used, which can usually be calculated by the following formula (Wiedmann and Minx 2009):

$$S_{cf} = \sum_{i=1}^{n} (Q_i + k_i) \tag{9.1}$$

where $S_{cf}$ is the carbon footprint of a product; $Q_i$ is the amount of input or output of a certain activity unit of a product (statistical units, such as kg, $m^3$, KWh, etc.); $k_i$ is the carbon emission factor ($CO_2e$/ statistical unit).

### 9.2.4 Water Footprint Accounting Model

Since the concept of water footprint was proposed by Hoekstra (2009) in 2002, water footprint has become an essential index for evaluating the load of water resources. According to ISO 14046 (Environmental management-water footprint-principles, requirements and guidelines), water footprint can be divided into two categories: water scarcity footprint and water degradation footprint. The water footprint is defined as consumption and an indicator of potential environmental impacts associated with water. The water scarcity footprint is a measure of the amount of fresh water consumed by a product or service over its life cycle in terms of water consumption. The water degradation footprint is the potential environmental impact related to water quality, which can be subdivided into water eutrophication footprint, water acidification footprint, water ecological toxicity footprint, etc.

The water scarcity footprint can be calculated as follow (Ridoutt and Pfister 2010):

$$S_{wsf} = \sum_{i=1}^{n} \left( \frac{WPI_i}{WPI_G} \times V_i \right) \tag{9.2}$$

where $S_{wsf}$ is the water scarcity footprint of a product ($m^3$ $H_2Oe$); $WPI_i$ is the water pressure index of a certain unit; $WPI_G$ is the global average water pressure index.; $V_i$ is the water consumption ($m^3$).

The water degradation footprint is mainly considered as the water eutrophication footprint, the water acidification footprint and the water eco-toxicity footprint, which can be calculated respectively by the following formula (Wanwen et al. 2017):

$$S_{wdf-eu} = \sum_{i=1}^{n} \left( S_{eu,i} \times c_{eu,i} \right) \tag{9.3}$$

$$S_{wdf-ac} = \sum_{i=1}^{n} \left( S_{ac,i} \times c_{ac,i} \right) \tag{9.4}$$

$$S_{wdf-ec} = \sum_{i=1}^{n} \left( S_{ec,i} \times c_{ec,i} \right) \tag{9.5}$$

where $S_{wdf-eu}$ is the water eutrophication footprint ($kgPO_4{}^{3-}e$ or $kgNO^{3-}e$); $S_{wdf-ac}$ is the water acidification footprint ($kgSO_2e$); $S_{wdf-ec}$ is the water eco-toxicity footprint ($m^3H_2Oe$); $S$ and $c$ are the quality of pollutants and the characteristic factors of corresponding pollutants, respectively; The subscripts $eu$, $ac$ and $ec$ are the water eutrophication footprint, the water acidification footprint and the water eco-toxicity footprint, respectively.

### 9.2.5 *Chemical Footprint Accounting Model*

The chemical footprint was proposed by Panko and Hitchcock (2011) in a commercial report in 2011. After years of development, chemical footprints can effectively evaluate the environmental load of chemical use. At present, it is considered feasible to calculate chemical footprint with the help of eco-toxic impact characterization factors, which is typically represented by the $USE_{tox}$ model, calculated as follow (Bjorn et al. 2014):

$$S_{chf} = f \times \sum_{i=1}^{n} \left( chf_i \times m_i \right) \tag{9.6}$$

where, $S_{chf}$ is the chemical footprint, representing the score of potential toxic effects on human ecology (Cases) or the score of potential toxic effects on ecology (PAF $m^3$ day); $f$ is the correction factor for estimating the absolute environmental impact, with a value of 290; $chf_i$ is the characteristic factor (Cases/kg or PAF $m^3$ day/kg); $m_i$ is the mass of the corresponding pollutant (kg).

## 9.3 Low Carbon Clothing Industry Life Cycle Design

The production link refers to all the links from raw material acquisition to processing into products, such as cotton planting, fiber synthesis, weaving, dyeing, packaging, etc. For the garment industry, raw materials, as the most basic component, are directly related to the carbon emissions of the entire production link, so it is crucial to study the carbon footprint of a certain raw material in a specific unit. As shown in Table 9.1, the raw materials of the garment industry can be roughly divided into three categories, namely natural fibers, recycled fibers and synthetic fibers. Among them, natural fibers exist in nature and can be directly obtained, which are divided into plant fibers, animal fibers and mineral fibers according to their sources. Among them, natural fibers exist in nature, that is, plants, animals and minerals exist in nature, which can be divided into cotton fabrics, hemp fabrics, silk fabrics and wool fabrics. Both regenerated fibers and synthetic fibers are chemically synthesized fibers. Among them, the recycled fiber is made of textile fiber after chemical processing with substances containing natural fiber or protein fiber, such as wood, soybean protein fiber and other fiber raw materials that have lost the value of textile processing. Synthetic fibers are made by chemical synthesis and mechanical processing from substances that do not contain cellulose or protein themselves, such as oil, coal, and natural gas.

Due to differences in the origin, processing technology, and management methods of processing enterprises for different fabrics, it is difficult to gradually investigate and obtain information for various fabrics. Therefore, this paper refers to "Greenhouse gas emission coefficient set for the entire lifecycle of Chinese products" (China Product Whole Life Cycle Greenhouse Gas Emission Coefficient Set 2022). The carbon footprint of Xiangyun yarn fabric, worsted wool fabric and linen fabric was collected and analyzed again. Moreover, since the processing technology of each fabric is not completely consistent, it is necessary to make classification when comparing the carbon footprint of different fabrics. In this paper, it is divided into three parts, including raw material acquisition, processing, and other classes, as shown in Fig. 9.2. When judging the carbon footprint of a fabric alone, as shown in Fig. 9.3, the carbon footprint of each process can be listed in order to analyze the optimization direction of the fabric production and promote the low-carbon upgrading of the industry.

Figure 9.2 shows the comparison of the Carbon footprint of three fabrics: the Xiangyun yarn fabric, the worsted wool fabric and the linen fabric. As shown in the figure, the worsted wool fabric has the highest carbon footprint of 24.809 $kgCO_2e/kg$ among the three kinds of fabrics, and the lowest is the Xiangyun yarn fabric of 18.7 $kgCO_2e/kg$. It can also be seen from Fig. 9.2 that in the process of processing raw materials into finished products, the Carbon footprint of the worsted wool fabric is 22.36 $kgCO_2e/kg$, which is 4.97 times of 4.5 $kgCO_2e/kg$ of the Xiangyun yarn fabric and 2.58 times of 8.66 $kgCO_2e/kg$ of the linen fabric respectively. This indicates that the current processing technology of the worsted wool fabrics has a high carbon emission footprint and may have a large carbon reduction potential. Figure 9.3 shows the

**Table 9.1** The main categories of raw materials for the garment industry

| Natural fiber | Regenerated fiber | Synthetic fiber |
|---|---|---|
| Cotton fabric, linen fabric, silk fabric, woolen fabric | Regenerated cellulose fiber, regenerated protein fiber | Dacron, acrylic fiber, polypropylene fiber, etc |

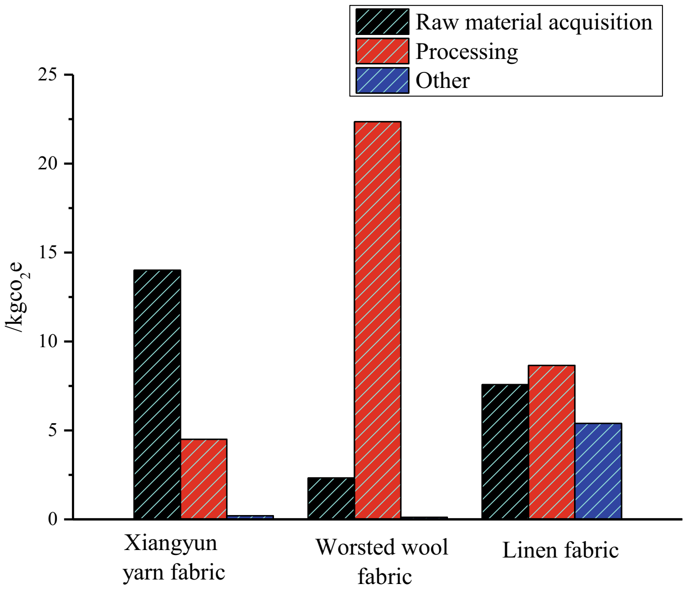


**Fig. 9.2** Comparison of the carbon footprint of different fabrics

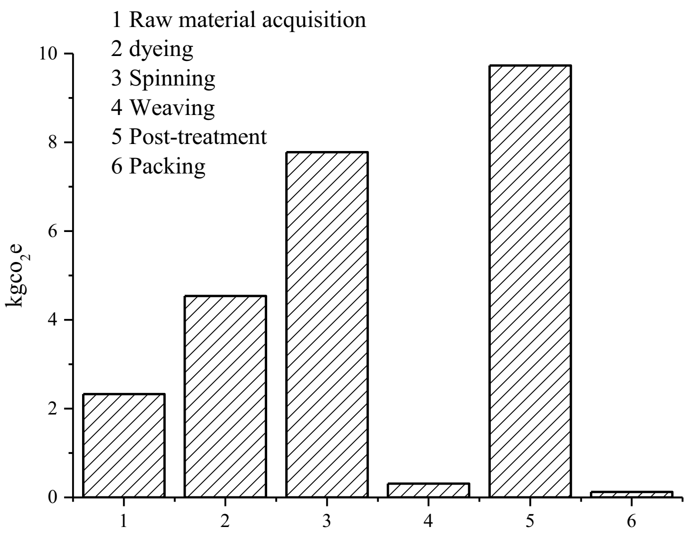


**Fig. 9.3** Composition of the carbon footprint of the worsted wool fabric

corresponding carbon footprint of each process of the worsted wool fabric. It can be seen from the figure that the production processes of the worsted wool fabric specifically include raw material acquisition, dyeing, spinning, knitting, post-treatment and packaging. The carbon footprints are 2.329, 4.54, 7.78, 0.31, 9.73 and 0.12 respectively. The processes with the highest carbon emissions are spinning and post-treatment, accounting for about 31.4% and 39.2% respectively, with a total carbon emission of 70.6%. This means that for upgrading the low-carbon industry of worsted wool fabrics, priority can be given to improving spinning and post-treatment related processes.

## 9.4 Conclusion

The long industrial chain and wide variety of goods in the garment industry determine that the industry needs to analyze and trace the source from the perspective of environmental footprint, so as to hope to fundamentally solve the low carbon and cleanliness of the garment industry. The carbon footprint evaluation results of the worsted wool fabric showed that the carbon footprints of spinning and post-treatment accounted for the largest proportion, which was 70.6% of the total carbon footprint of 24.809 kg$CO_2$e/kg in the production process. This shows that optimizing the spinning and post-processing related processes has great emission reduction potential for this product. Similarly, the carbon footprint, water footprint and chemical footprint verification of the garment industry can help to provide optimization direction and ideas for the low-carbon and clean development of the industry.

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