Journal of Cleaner Production 108 (2015) 464–475

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Carbon footprint of textile throughout its life cycle: a case study of Chinese cotton shirts

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ARTICLE INFO

Article history:
Received 28 September 2014
Received in revised form
26 May 2015
Accepted 31 May 2015
Available online 9 June 2015

Keywords:
Carbon footprint
Textiles
Life cycle
Cotton shirts
China

ABSTRACT

The carbon footprint (CFP) reflects the greenhouse gases (GHGs) generated throughout the life cycle of a human activity or product, and is therefore an important tool for assessing and managing GHG emissions. At the level of an individual product, a carbon-labeling scheme that provides more information for consumers could play an important role in encouraging a shift to low-carbon consumption. China is the largest textile and garment producer and consumer in the world. Studying the carbon footprint of textiles is therefore important domestically, for the management of domestic greenhouse gas emission and, internationally, for the communication of carbon information and relevant trade negotiations. For establishing the product carbon labeling system in China, this paper constructed an operable and comparable CFP assessment method and framework at product level and presents a complete case for pure cotton shirts made in China. Based on investigations of several Chinese textile companies and the observation of every production sub-process, the system boundary and methods of assessing textile product CFP were established. We then estimated Chinese CFP conversion factors for relevant energy sources and materials, and calculated the actual CFP for the life cycle of a pure cotton shirt. The average CFP of a pure cotton shirt produced in China, throughout its life cycle, is estimated as 8.771 $kgCO_2e$. Of this, direct CFP is 0.347 $kgCO_2e$, whereas indirect CFP is much higher, at 8.423 $kgCO_2e$. The industrial production stage accounts for the highest proportion of the CFP, and overall production (including agricultural and industrial production) accounts for more than 90% of the total CFP. Approximately 96% of CFP throughout the product life cycle is indirect CFP, which is embedded in the use of energy and materials in each process. Within the industrial production stage, the transportation and weaving sub-processes account for nearly all the direct CFP (0.347 $kgCO_2e$). Energy consumption, especially of electricity, is the main contributor to the CFP of textile products. These results could facilitate comparison between different products, and for the same products from different producers, In order to reduce the CFP throughout the entire textiles sector.

1. Introduction

Global warming represents a threat to the natural environment and human economic development. Many studies have shown that global warming primarily results from the increasing emission of greenhouse gases (GHGs) as a result of human activities (Brito de Figueirêdo et al., 2013; Heijungs et al., 2010; Jamali-Zghal et al., 2013; Zhao et al., 2012). The carbon footprint (CFP) assessment is an important approach for the control and management of GHG emissions. CFP is based on the life cycle concept, and is used to assess the GHGs generated during the production of goods or services, either throughout their entire life cycle or within specified temporal or spatial boundaries (Brito de Figueirêdo et al., 2013; Dias and Arroja, 2012; Dormer et al., 2013). Carbon labeling

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http://dx.doi.org/10.1016/j.jclepro.2015.05.127
0959-6526/

application systems at product level can provide consumers with information on the carbon emissions associated with every process throughout the product life cycle. By providing quantitative CFP labels for each process involved in the manufacture of a product, carbon labeling application systems can help improve social low-carbon consciousness and promote enterprises that carry out emission reduction activities. The unified and comparable product CFP assessment with the associated framework, methods, and foundation database is the basic premise for effectively applying the carbon labeling application system.

Textiles are important consumption goods and international trade products. Chinese textile companies collectively produced nearly 30% of the textile products for the global market in 2010. The scale of domestic textile consumption within China is also very large (Muthu et al., 2012). The CFP assessment of textiles helps to understand the basic conditions associated with the emission of GHGs during their production and consumption. This not only helps to analyze GHGs emitted during specific processes of the life cycle (Chen and Wang, 2006, 2009; Tang and Wan, 2003), but also plays an important role in communicating information about the environmental performance of Chinese goods and manufacturing, which is important to textile carbon labeling and international trade (Sun et al., 2011; Wang et al., 2012; Huang et al., 2011).

The application and promotion of carbon labeling require data, assessment methods, and CFP framework at product level, which are more specific, impartial, and comparable (Dai et al., 2011). The general understanding of the concept of product CFP is to estimate the total GHGs emitted over the full life cycle or individual processes (Herva et al., 2012; Wiedmann and Minx, 2008). CFP assessment is mainly based on international standards and regulations, such as PAS 2050 published by the Carbon Trust, BSI, and Defra; ISO 14067 published by the International Standardization Organization (ISO); etc. As the first standard for CFP assessment, PAS 2050 focused on GHG emissions during the product life cycle. However, the assessment methods and concepts of the Carbon Trust used to perform CFP assessment and calculations can be affected by differences in production data and are difficult to compare with other similar products (BSI et al., 2011). The ISO 14067 standard contains two parts that are ISO 14067-1 Quantification and ISO 14067-2 Communication. ISO 14067 provided the general CFP assessment framework of products with universality. However, for specific product CFP assessment, relevant data collection, system boundary definition, and CFP conversion factors still need more research and studies on their practical application (Standardization, 2013).

With the development of these organizations and standards, there have been lots of CFP assessment cases at product level faced to the application of carbon labeling system. However, bound by different system boundaries and the limitation of data collection, previous CFP assessments at the product level were mainly based on the top-down methodology and established through statistics and macro data distribution in the entire organization, which have difficulty to compare among different assessments due to the difference of system boundary and difficulty to disassemble and reassemble. Therefore, the CFP assessments at the product level needs more precise assessment method and data system for comparing with different manufacturer, different technique. The bottom-up assessment methodology which uses direct data from detailed process in life cycle and has clarifying the specific system boundary. Result of CFP by such methodology can be disassembled and reassembled, which make it possible to compare the results from different assessments of similar products. However, so far, there are several obstacles to application of the bottom-up assessment methodology, such as difficulty to trace and monitor detailed processes of production, lack of primary data and so on, that's why there are few CFP assessment cases by such methodology till now. This paper proposed a comparable CFP assessment framework, calculation systems, and basic databases for textile products with the aim of applying product carbon labeling. We constructed a more comparable and operable product CFP assessment method and data system that is based on the bottom-up assessment methodology, and present case study of the textile products in China. Based on detailed data collection, we conducted a complete case study to testify and demonstrate this method, and we hope it would be meaningful and helpful to relevant researchers.

In this research, we constructed comparable CFP assessment methods, frameworks, and standards for general textiles and collected production data by investigating numerous textile enterprises in China, including the individual industrial production processes and CFP conversion factors of basic energy resources. We hope to provide a comparable bottom-up CFP assessment method and basic database for the carbon labeling application system of Chinese textiles. This paper focused on pure cotton shirts made in China, investigating the complete life cycle in order to demonstrate the applicability of the CFP assessment methods, framework, and basic database. Calculation data were from investigation of several Chinese textile companies, observations of every production process, and some statistical data. What's more, to reflect the difference of energy resources in China, CFP conversion factors for energy resources were estimated by calculation of the CFP in each process of production, transportation, transformation (Pennington et al., 2004; Rebitzer et al., 2004). The results provide general indications of the CFP scenario for Chinese cotton shirts on some extent, and provide a specific example and reference for relevant researchers, managers, and stakeholders.

2. Material and methods

There are two basic CFP assessment methodologies for product CFP assessment, top-down and bottom-up. Combined with input–output analysis, the top-down CFP assessment measures and analyzes the GHG distribution process and flow direction of departments and products. The bottom-up CFP assessment is based on process analysis and focuses on the GHG emissions of each process. Therefore, the bottom-up CFP assessment provides the CFP of each process in the product life cycle. It also has further advantages in terms of being able to compare and reflect the variance in processes and impact factors.

2.1. Case study and functional unit

The study case consists of a pure cotton shirt that is produced entirely in China. In terms of the main production sub-processes—spinning, weaving, and clothing—we investigated several large-scale textile enterprises during 2009–2010, during which we observed the usage of every form of energy, material, equipment, and so on.

In the present study, a pure cotton shirt of average weight 0.28 kg is used as the functional unit when observing the industrial production and in investigating the other main life cycle process, such as sourcing raw materials, transportation and distribution, product usage and disposal. In the actual calculation, we need to consider the quality loss in production and other processes, such as the normal material loss and the loss by quality.

2.2. Assessment framework and system boundary

The assessment framework is an important and deterministic part of product CFP assessment. The methods presented in the IPCC