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Life cycle assessment of cotton textile products in Turkey

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ABSTRACT

Cotton textile and clothing industry is a complex and multi-tiered system that consists of cotton cultivation and harvesting, fiber production, yarn manufacturing, fabric preparation, fabric processing that includes bleaching and dying sub-processes among others and fabrication of the final product. An array of environmental concerns are associated with this sector, the most significant of which are issues related to use of agrochemicals in the cultivation of cotton and water, energy and chemical consumption in the fabric processing stage. Textile industry is a significant contributor to the Turkish economy constituting 18% of total export volume in 2013 according to Turkish Statistical Institute. In the study, environmental impacts of Eco T-shirts produced from organically grown cotton and processed with green dyeing recipe were compared to that of conventional T-shirts, in terms of their contributions to global warming, acidification, aquatic and terrestrial eutrophication and photochemical ozone formation using life cycle assessment methodology. The results reveal that Eco T-shirts have lower impact potentials across all inspected categories, with the most dramatic reduction in aquatic eutrophication potential (up to 97%) due to elimination of nitrogen and phosphorus containing chemical based fertilizers. The results also show that global warming potential is by far the largest environmental impact for both conventional and Eco T-shirts with the main impact coming from use phase, followed by cultivation and harvesting and fabric processing phases. The results of the analysis underline the importance of utilizing sustainable raw materials in all life cycle stages of cotton textile products and the necessity of focusing on the consumer behavior and sustainable practices in the use phase of the products as well.

1. Introduction

The textile and clothing sector consists of a wide number of subsectors, from sourcing of raw materials (fibers) to semi-processed (yarns, woven and knitted fabrics with their finishing process) and final consumer products (carpets, home textiles, clothing and industrial use textiles). The complexity of the sector complicates a clear-cut classification system for the different activities involved (EC, 2001a,b). Fibers used in the textile industry are classified into two main categories: natural and man-made. The natural fibers are derived from vegetable or animal sources. In the year 2010, man-made fibers and natural fibers shared about 60.1% and 39.9% of global textile fiber consumption, respectively. Cotton is the most widely utilized natural fiber in the world, accounting for over 82% of global natural fiber consumption (FAO-ICAC, 2013). Approximately 32.4 million hectares of agricultural land area is allocated for cotton plant, grown in more than 75 countries. The latest figures for the 2013/14 season show world lint production at 25.6 million tons with six countries: China, India, USA, Pakistan, Brazil and Uzbekistan, accounting for about 80% of total production and the remainder is spread across a large number of smaller producers, with Turkey ranking 7th following Uzbekistan (FAO-ICAC, 2015; USDA, 2015).

Textile and clothing sector constitutes an important part of Turkey's economy with the export volume of 27.7 billion USD in the year 2013, which corresponds to 18% of all the total exports (TUIK, 2013). Cotton cultivation has also been constantly expanding to accommodate the growing demand of the textile industry, reaching 2.25 million ton production in 2013 (TUIK, 2013).

The complex nature of textile products' life cycle as well as impacts they have on the environment require comprehensive assessment methodology to evaluate potential environmental burdens in the context of sustainability approach. One such approach, namely life cycle assessment (LCA), provides successful interpretation associated with the whole cycles of selected products, services and processes. This methodology, standardized by ISO 14040:2006 and 14044:2006 is a decision support tool for evaluation of environmental impacts of products and services, required for a particular

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unit of function and includes compilation and meaningful evaluation of all inventory data associated with those products.

1.1. LCA of textile products

LCA methodology has been widely applied in textile industry to evaluate various aspects and life cycle stages of the products, from cultivation and fiber production up until fabric processing and disposal of used products. Barber and Pellow (2006) aimed to determine total energy use and carbon dioxide emissions of New Zealand merino wool. Results showed that merino wool fiber production required a total energy use of 46 MJ/kg half of which occurred on farm and that on-farm activities accounted for two thirds of carbon dioxide emissions. Morley et al. (2006) evaluated recycling/recovery/reuse options for second-hand clothing and observed that, in the context of the CO_2 emissions from waste management choices, the reuse of clothing has a significant benefit over recycling or disposal. It is stated that the maximum reuse benefits are of the order of 33 kg CO_2-eq/kg clothing for a sample of cotton and polyester clothes, compared to a maximum of about 8 kg CO_2-eq/kg of fiber recycling, citing the study conducted by Marks & Spencer that showed extracted energy of cotton product and fiber manufacture as 5.3 times greater than cotton manufacture alone and 2.9 times greater when comparison is done for polyester clothes. Woolridg et al. (2006) demonstrated that for every kilogram of virgin cotton displaced by second-hand clothing approximately 65 kWh is saved, and for every kilogram of polyester about 90 kWh is saved. University of Cambridge, Institute for Manufacturing evaluated cotton, viscose and nylon fibers with polypropylene and latex-foam backing with LCA methodology. Results of the study indicated that the key environmental impacts of the sector resulted from use of energy and toxic chemicals (Allwood et al., 2006). Chalmers University of Technology in Sweden conducted an LCA for three fabrics types for a sofa made of conventional cotton, Trevira CS (a flame retardant polyester) and wool/polyamide. The study concluded that Trevira CS was preferable in terms of minimizing environmental impact when choosing between the three fabric types and the cotton sofa cover was a less favorable choice. The results of the project indicated that the most significant impacts were from cultivation and wet treatment of the fabric (Dahllöf, 2004). Kalliala and Nousianinen (1999) compared and evaluated different hotel textiles: cotton and cotton–polyester sheets and concluded that cotton–polyester sheets in hotel use have fewer environmental impacts than cotton sheets. The reason was the higher durability as well as lower laundering energy requirements of cotton–polyester sheets.

LCA is also widely applied by the private sector to evaluate the impacts of not only technical and factory settings but also policy changes and user behavior and habits on the environmental performance of textile products. Marks & Spencer conducted LCA to assess the energy requirements for life cycle of a pair of pleated polyester trousers and a pack of men's cotton briefs. According to findings, consumer use corresponds to 76% and 80% of the life cycle energy needs, respectively (Collins and Aumônier, 2002). Design Mobel conducted a full LCA of products from raw material inputs, through manufacturing, to the use of waste by-products and design briefs. They sourced wood from sustainable forestry operations and used natural materials including bamboo, cotton, 100% natural latex and wool in natural manufacturing processes (SBN, 2008).

An integrated and holistic approach is necessary when assessing the sustainability of textile products since actions in one phase of product's life cycle can have direct and indirect effects in other phases and the overall environmental performance. An LCA study on bed-sheets conducted by Saxce et al. (2012) demonstrated that textile product quality parameters, such as lifetime of a product and ease of care that are determined in the manufacturing phase, can have significant influence throughout product's life cycle; removing the need for ironing and increased lifetime lead to overall decrease in environmental impacts, although the effect of prolonged lifetime are much prominent than that of other product parameters.

The goal of this study was to identify and compare the environmental impacts of conventional cotton T-shirt and three different variants of Eco cotton T-shirt that supply the same functional specification. Potential environmental impacts are assessed considering cultivation and harvesting, raw material supply, ginning, spinning, knitting followed by fabric wet processing and finishing for manufacturing, service/use and disposal stages of the selected cotton T-shirts. The products were compared by taking into account sustainable cultivation methods and eco-efficient dyeing recipes.

2. Methodology and selected scenarios

The functional unit of the LCA model was determined as 1000 items of knitted and dyed cotton T-shirt with a total weight of 200 kg and all results in the manuscript are expressed in terms of this common unit. The service life time of T-shirts was chosen as three years that covers 50 washing cycles at 60 °C temperature. Life cycle processes included in the analysis and system boundaries are illustrated in Fig. 1.

Organic cotton growth, organic farming productivity considerations and chemical substitution and reduction of dye-house applications constitute the main focus points in the analysis. Secondary products such as cotton-seed and fabric scraps are not taken into account in terms of neither on-site recycling nor industrial symbiosis due to lack of reliable data. Four different life cycle analyses were carried out for T-shirts. Developed scenarios were grouped into three key themes representing major changes in cotton T-shirt chain: changes in raw material selection, agricultural productivity and means of fabric wet processing (Table 1). The consequences of these differences are explored and measured for each scenario in accordance with life cycle perspective.

GaBi 5 LCA modeling software complemented with comprehensive, up-to-date inventory databases and impact assessment methods was used to conduct LCA for the selected products in this study. Internationally recognized impact assessment method, The Environmental Development of Industrial Products (EDIP) 2003 developed by the Institute for Product Development (IPU) at the Technical University of Denmark was implemented in the evaluation phase.

EDIP 2003 methodology is a problem-oriented approach, where the environmental impacts are modelled in the cause-effect chain. The methodology provides spatial differentiated characterization factors but, can be used both in a site-generic and in a site-dependent fashion (Hauschild and Wenzel, 2000). In this LCA study, site-generic characterization factors are applied to calculate environmental impact potentials of investigated cycles. The characterization factors for the global warming potential (GWP) are based on the IPCC recommendations. Organic substances and carbon monoxide from fossil fuels are included with the assumption that they will end up as carbon dioxide eventually. In calculating the acidification potential (AP), Regional Acidification Information and Simulation (RAINS) computer model is used to assess the fate of emissions and the exposure quantities to ecosystem. The same model is used in calculation of terrestrial eutrophication potential (TEP). Cause effect Relation Model to support Environmental Negotiations (CARMEN) model is used to assess the fate of nutrient emissions to water in calculating the aquatic eutrophication. The transport of nutrients from agricultural supply and atmospheric deposition through groundwater drainage and surface runoff or topsoil erosion to surface water is considered within the model. Photochemical ozone formation potential (POFP) resulting from