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Prospective life cycle assessment of an antibacterial T-shirt and supporting business decisions to create value

B. M. Krishna Manda[a,*], Ernst Worrell[a], Martin K. Patel[b]

[a] Utrecht University, Copernicus Institute of Sustainable Development, Heidelberglaan 2, 3584 CS Utrecht, The Netherlands
[b] University of Geneva, Institute for Environmental Sciences and Institute F.-A. Forel, Energy Group, Route de Drize 7, 1227 Carouge/Geneva, Switzerland

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ABSTRACT

Global production and consumption of textiles is increasing and as a result putting pressure on the environment. In the EU-25 countries for example, 2–10% of environmental impacts are associated with clothing consumption, with washing during the use phase as one of the most significant contributors. Antibacterial textiles, which prevent undesirable odours, may reduce the number of washing cycles, thus offering an opportunity to reduce environmental impacts. This article assess to what extent different antibacterial T-shirts offer opportunities. Life cycle assessment (LCA) is used to assist the producer in making business decisions to create value during product development process. To this end, we conducted an LCA for an antibacterial T-shirt made in Europe from bio-based man-made cellulose fibres (modal). The antibacterial property is obtained by silver nanoparticles that are produced with colloidal techniques such as the sol–gel process and in-situ formation. It was found that the T-shirt made of 50% antibacterial fibres with the in-situ process (50AB in-situ) caused 15–20% lower cradle-to-gate CO_2 emissions than commercial antibacterial T-shirts. The cradle-to-grave comparison with non-antibacterial modal T-shirts showed that the 50AB in-situ T-shirt exhibited better environmental performance, resulting in 20–30% lower impacts in key categories such as climate change, freshwater toxicity and eutrophication. LCA demonstrated value creation opportunities such as lower environmental impacts, lower costs and risks. Moreover, the product's environmental performance can be transparently communicated to customers, which helps differentiating with competing products in the market, thus offering the producer a competitive advantage.

1. Introduction

The global population is steadily growing and may reach around 9.3 billion by 2050 (UN, 2011). Due to economic prosperity and higher per capita income, per capita consumption is also increasing in emerging economies such as Brazil, Russia, India, China, Mexico and South Africa. This growth will spur the consumption of food, clothing, energy and housing. According to the EU EIPRO project (Tukker et al., 2006), clothing accounts for 2–10% of the environmental impacts of consumption in the EU-25 countries. A study by Nijdam et al. (2005) found similar results for The Netherlands. Widespread disparities exist between clothing consumption in developing and developed countries. The per capita consumption of textile fibres in India and China is 4 kg and 6 kg, respectively, in contrast to Europe and the US, which have a per capita consumption of around 19 kg and 34 kg, respectively (FAO and Bank of Japan, 2000; Terinte et al., 2014). This suggests that the per capita consumption in developing countries may substantially increase as income rises.

To satisfy the basic needs of the billions of people in the developing countries while simultaneously reducing the current and impending impacts on our society, the material and energy efficiency of all sectors including the textile sector need to be further improved, hence calling for continuous innovations. Previous research has demonstrated that there are several stages in the product chain during which these improvements and innovations should take place. First, the environmental impacts of fibre production should be reduced (IMPRO, 2014). For example, compared to other fibres, cotton cultivation is known to cause higher toxicity and eutrophication impacts, and involves greater water consumption (Shen et al., 2010a,b; Cotton Inc, 2012). It was found that lower productivity of cotton cultivation and lack of crop rotation cause higher environmental impacts (Bevilacqua et al., 2014). According to Ismail et al. (2011), ginning contributes to 6–17% of the life cycle GHG emissions of cotton from Australia.

* Corresponding author. Tel.: +31 30 2533145; fax: +31 30 2537601.
E-mail addresses: b.m.k.manda@uu.nl (B.M.K. Manda), e.worrell@uu.nl (E. Worrell), martin.patel@unige.ch (M.K. Patel).

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The importance of land use and biodiversity and water use impacts of cotton and wood based fibres have been highlighted by Sandin et al. (2013). Second, in the fibre to garment stages, the environmental footprint of the manufacturing stages should be further reduced by means of more efficient processes (IMPRO, 2014). Energy consumption of spinning and weaving is inversely proportional to yarn thickness (Van der Velden et al., 2014), thus requiring better process development for products made from thinner yarns such as shirts. Dyeing nowadays still significantly contributes to water pollution and to other, energy-related impacts of textile manufacturing (Ren, 2000). It was found that manufacturing processes and conditions can affect the life time of the product and thus influence the environmental impacts of textiles such as cotton bed sheets (De Saxce et al., 2012). This finding is also relevant for apparel such as T-shirts because similar manufacturing processes, such as combing, carding, dyeing and easy care finishes, are required for both home textiles and apparel. Similarly, Bevilacqua et al. (2014) concluded that the most critical impacts of cotton yarn production are due to spinning and yarn dyeing. Third, the impacts of consumer use and disposal stages should be substantially reduced. The use phase is the largest contributor to the impacts of the whole textile life cycle (Walser et al., 2011; Steinberger et al.; 2009; IMPRO, 2014). Moreover, it is possible to conserve virgin materials and reduce the associated impacts of their production through end-of-life recycling of fibres (Woolridge et al., 2006; IMPRO, 2014). Fourth, with regard to the chemicals used for manufacturing and consumer use, it is necessary to develop new textile chemicals like dyes, finishing and laundry chemicals that have lower environmental impacts during their production and use, but also help improve the manufacturing and use phases of textiles by needing fewer resources and further improving process efficiency (Allwood et al., 2008). These improvements not only benefit environment and society but also reduce resource scarcity which poses risks to business operations. In order to ensure that innovation and sustainability go hand in hand, sustainability should be integrated in business decisions during the product innovation and development phases.

It is expected that there will be a sharp increase in environmental impacts during product manufacturing and use (e.g. from washing), due to the potentially huge future consumption of textiles in the emerging economies as well as the extant current consumption patterns of developed countries. Furthermore, the trend of global temperature raise due to climate change might also requires us to change consumption behaviour such as increasing number of washing cycles due to sweat/odour. A growing number of companies may offer products such as antibacterial textiles (also referred to as antimicrobial) as mainstream products, provided consumers are keen to reduce washing cycles as well as lower the associated costs and impacts (Windler et al., 2013). It is prudent to assess the impacts of antibacterial textiles and the associated technology before these become mainstream.

Antibacterial fabrics are presently used for T-shirts, sportswear, socks, underwear, bedding, mattresses and mattress covers in order to prevent undesirable odours, and for hospital gowns and wound dressing to prevent bacterial activity on the skin (Windler et al., 2013). The antibacterial chemicals used that are most prevalent are silver (including metallic Ag and AgCl nanoforms), triclosan, silane quaternary ammonium compounds (Si-QAC) and zinc pyrithione (ZnPT) (Windler et al., 2013). These can be applied to a limited number of fibre material types. The possibility of blending different fibre materials is therefore limited. Nanotechnology has been used to impart the antibacterial property by various synthesis techniques such as solid phase, liquid phase and gas phase syntheses (Şengül et al., 2008). Making use of these innovative finishing materials and techniques, antibacterial T-shirts are emerging products in the textile sector.

Walser et al. (2011) investigated the production of silver nanoparticles (NP), from gas phase techniques such as Flame Spray Pyrolysis (FSP) and plasma polymerization with silver co-sputtering, their application on polyester garments such as T-shirts, and the environmental impacts of silver nanoparticles throughout the complete lifecycle, including the use phase. The behaviour of different types of antibacterial textiles during washing has also been studied, including NP loss and their characterization (Geranio et al., 2009; Lorenz et al.; 2012; Windler et al., 2013). However, liquid phase NP synthesis techniques such as colloidal techniques using water as a solvent, the application of NP on modal fibre, and the resulting environmental impacts of antibacterial clothing have not been reported so far. The SurFunCell project (2012), an EU FP7-funded project, has developed liquid phase synthesis techniques and application technologies for NP on products as a result of collaboration between academia and industry. A yarn producer was a research partner in the SurFunCell project who intends to expand their product portfolio with antibacterial textile yarns.

In the present article, the silver NP produced by precipitation and sol–gel techniques will be coated onto bio-based fibres such as modal fibres, as opposed to the application on the final fabric or garment by other technologies that has been used so far. The coating of NP at the fibre stage makes it possible to blend the modal fibres with other fibres such as cotton and polyester, depending on the type of end product. There are several advantages in improving the finishing process, i.e. coating at the fibre level. First, there is an increase in the flexibility of application or end product configuration to achieve the desired functionality. Second, coating the whole fabric with anti-bacterial compounds can be avoided, which reduces the wasteful use of resources and decreases cost. Another advantage is that antibacterial compounds are coated on fibres, i.e. contained in the yarn matrix, which may lead to lower loss during use and possibly to an increased lifetime of the textile's antibacterial activity. This may also reduce the concentration and quantity of the antibacterial compounds needed per garment, compounds which are usually both resource and energy-intensive. A disadvantage might be the loss of silver during fibre finishing, fabric dyeing or the washing stages of T-shirt production; however, this can be addressed by developing efficient silver-coating processes at the fibre-finishing stage. Therefore, the antibacterial T-shirt is an innovation which may well have the potential to improve the environmental performance of such textiles during their entire product lifecycle.

Life cycle assessment (LCA) is a comprehensive and systemic tool that helps to identify environmental hot-spots and can show improvements throughout product life cycles during product innovation and development. It can therefore help guide decisions in business. A few studies have published inventories and impacts of textile value chains and innovative dyeing, finishing approaches and their influence on the use phase (Steinberger et al., 2009; Walser et al., 2011; Terinte et al., 2014). Most of the studies describe the application of LCA to assess alternative products and processes at a given point in time, as an impact calculating tool, rather than its iterative use in the course of an R&D and product development trajectory to support decision-making (Sandin et al., 2014). To the best of our knowledge, no article has described the contribution of LCA to product innovation of antibacterial T-shirts made by liquid phase synthesis techniques. Thus, the main objective of this article is to understand the environmental impacts of various types of antibacterial T-shirts and to show how LCA can guide business decisions during innovation and new business development to improve the product's environmental performance and, thereby, creating value for business.