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Assessing eco-innovations in green chemistry: Life Cycle Assessment (LCA) of a cosmetic product with a bio-based ingredient

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ABSTRACT

Enhancing and promoting eco-innovation solutions in cosmetic industry requires robust methods for assessing the environmental impacts and reducing burden shifting amongst life cycle stages and typology of impacts. This study aims at comparing the environmental profile of eco-innovation options for a cosmetic product by means of Life Cycle Assessment (LCA) methodology. We present a case study in which synthetic ingredients are replaced by others derived from natural compounds, following green chemistry principles. A C16–18 triglycerides mixture (INCI name "palmitic/stearic triglycerides") derived from olive oil industry by-products is used both as single ingredient (Innovation I) and as part of a preformulated one (Innovation II), replacing the starting formulation (Benchmark) caprylic/capric triglyceride. Options are compared through LCA applying International Life Cycle Data impact assessment focusing the analysis to water and energy consumption, sources of raw materials and previous manufacturing stages thereof. In order to test the robustness of the results, we performed a set of sensitivity analyses: i) changing assumptions about transports and irrigation of olive trees; ii) comparing results of the application of two life cycle impact assessment methods (CML and IMPACT 2002). The results show that the impacts derived from the selection of ingredients are more significant than those due to water and energy consumption. Applying different methods, results show significant differences, especially in toxicity-related impact categories. Overall, an alleged "eco-friendly" ingredient (such as a natural by-product derived one) could result in a less preferable environmental profile if assessed in a life cycle perspective. This supports the need of adopting life cycle based methods to ensure that green chemistry options respond to the need of reducing environmental in all life cycle stages.

1. Introduction

1.1. Background and state of the art

Cosmetics industry is a growing economic sector worldwide. The European cosmetics industry employs in Europe more than 1.5 million people and European sales are in excess of 70 billion EUR (Cosmetics Europe, 2013). According to current European regulation on cosmetics (EC, 2009), "cosmetic product means any substance or mixture intended to be placed in contact with the external parts of the human body (epidermis, hair system, nails, lips and external genital organs) or with the teeth and the mucous membranes of the oral cavity with a view exclusively or mainly to cleaning them, perfuming them, changing their appearance, protecting them, keeping them in good condition or correcting body odors". Cosmetic products are important consumer products with an essential role in everyone's life and cosmetic companies need to improve products constantly in order to stay ahead in a highly competitive market where more choice and ever greater efficacy are expected by the consumer.

In Europe, the substances used in cosmetic products are subjected to the application of the REACH regulation (EC, 2006).[1] This implies that, for each substance in a cosmetic formulation,

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[1] REACH is the Regulation on Registration, Evaluation, Authorization and Restriction of Chemicals. It entered into force on 1st June 2007. It streamlines and improves the former legislative framework on chemicals of the European Union (EU).

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environmental and human health risk assessment should be conducted. Specifically for personal care products and cosmetic, there is evidence of their potential environmental impact on water toxicity and the need of introducing ecodesign and green chemistry strategies for their production and use (Muñoz et al., 2008). Indeed, beyond the evaluation of each single substance, there is a growing attention to safer and sustainable cosmetic products and ingredients. For instance, Cosmetics Europe (the Personal Care Association) is working with its members to engage cosmetics manufacturing companies, particularly SMEs, in sustainability activities and to promote good sustainability practices (Cosmetics Europe, 2012), including the adoption of Life Cycle Assessment (LCA) and ecodesign of products (Cosmetics Europe, 2013). Several Research and Development (R&D) activities in the field of pharmaceutical and cosmetic ingredients have been focused on improving the environmental profile of products. In fact, pharmaceutical ingredients production may have significantly more environmental impacts than basic chemical production in a kilogram-per-kilogram basis. Moreover, in order to address different pillars of sustainability (economy, society and environment), cosmetic producers are increasingly adopting methodologies for environmental assessment, for social footprinting and for ethical sourcing of raw materials (Sahota, 2013). Additionally, following the promotion of the bioeconomy (European Commission, 2012), there is an increasing interest in substituting fossil-based substances with renewable, bio-based ones. For example, Pereira de Carvalho and Barbieri (2012) assessed the induction process of technological innovations driven by proactive companies in order to achieve economic, social and environmental benefits throughout the supply chain. In this case, environmental concerns were addressed by the adoption in 2008 of a Program for the Certification of Ingredients, with the goal of promoting sustainable cultivation and management of natural resources through the certification of native plantation and forests by third-party agents.

Some studies (Balmer et al., 2005; Brausch and Rand, 2011) report the occurrence and the toxicity of cosmetic ingredients (e.g. fragrances, preservatives and UV filters) in wastewater effluent, surface water, and fish tissue. However, they report incompleteness of data available about the effects of this occurrence and especially of bioaccumulation and biomagnification of chemical UV filters.

To comprehensively assess environmental impacts, LCA studies on detergents and cosmetics have been conducted, even if the literature on the topic is still relatively limited for both fine chemicals and cosmetic products. Koehler and Wildbolz (2009) investigated nine products in the range of personal care products and home detergents, encompassing household-cleaning agents (kitchen, window, and bathroom cleaners), detergents (liquid and powder detergents, detergent booster), soaps (liquid and bar soaps), and a toilet-care product. According to their results, both climate-change impacts and Eco Indicator 99 LCIA method scores of detergents and soaps are substantially driven by the raw material supply chain (>53% of total impacts). A number of studies, either published in the scientific literature or commissioned by corporations, refer to detergents, such as laundry detergents (Dewaele et al., 2006; Saouter and van Hoof, 2002; Van Hoof et al., 2003) and fabrics liquids (Unilever, 2001). The results of these studies show that the main environmental impacts in a LCA perspective come from the use phase, especially when there is the need of rinsing the product, followed again by the raw material supply chain and by the final disposal of the products. Other studies present the results of LCA of ingredients used in cosmetics, such as shea butter (Glew and Lovett, 2014) and surfactants used as emulsifier (Guilbot et al., 2013). In addition, several industries have developed some simplified methods to perform internal LCA studies of their products (Curzons et al., 2007; Jimenez-Gonzalez et al., 2011; Mata et al., 2012; Tufvesson et al., 2012).

LCA studies on fine chemicals production processes are relatively few (Geisler et al., 2004) and this limits also the possibility to find reliable background life cycle inventory (LCI) data for modeling the ingredient production within LCA studies about cosmetics (Hischier et al., 2005; Muñoz, 2012; Wernet et al., 2009). Tufvesson et al. (2012) made a thorough review of LCA of chemicals and found that for fossil-based platform chemicals several LCAs exist but the number of LCAs is limited for fine chemicals, i.e. high value chemicals produced in small to moderate quantities for specialized applications, especially if produced with industrial biotechnology or from renewable resources (with the exception of biofuels). They also found a significant difference in the environmental performance of bulk and fine chemicals, especially because fine chemicals normally generate more waste during production than bulk chemicals and involve a higher Cumulative Energy Demand. Similarly, Saouter and van Hoof (2002) in their LCA study of laundry detergents obtained that, aside consumers use, the majority of energy consumption occurs in the manufacturing of the ingredients.

Due to this known problem about LCI data availability, several methods were proposed to overcome the lack of LCI data on fine chemicals production. Hischier et al. (2005) illustrate the procedure used for LCI of chemicals in the ecoinvent database, which is based on a three level approach, depending on the quantity of information available: i) in the case of good data availability, the general quality guidelines of ecoinvent can be followed; ii) if adequate unit process data are not available, a procedure for the translation of aggregated inventory data (cumulative LCI results) from industry into the ecoinvent format is used; iii) a procedure for estimating inventory data using stoichiometric equations from technical literature as a main information source is proposed. Similarly, Geisler et al. (2004) propose a method for estimating mass and energy flows for fine chemicals production using a small amount of input data (the reaction stoichiometry and some basic characteristics of the process steps such as mass, yield, solvents used, etc) whereas default data are established for inputs which are unknown. Wernet et al. (2008, 2009) define a model to provide estimates for inventory data and environmental impacts of chemical production based on the molecular structure of a chemical and without a priori knowledge of the production process.

In Wernet et al. (2010), between 65% and 85% of impacts were found to be caused by energy production and use and the fraction of energy-related impacts (e.g. in human health, ecosystem quality, resources depletion and global warming potential) increased throughout the production process. Jimenez-Gonzalez et al. (2011) highlighted that the production of Active Pharmaceutical Ingredients (APIs) can generate more environmental impacts, especially due to the raw materials used (bulk and fine chemicals, including solvents), than the production process of the final pharmaceutical or cosmetic product. Similar results are presented by Koehler and Wildbolz (2009) in a LCA study of nine detergents and personal care products.

Concerning the use of bio-based ingredients, there is a growing body of literature about bio-processes (e.g. Henderson et al., 2008; Kim et al., 2009) and the substitution of fossil based chemicals with others coming from renewable feedstock (e.g. Dunn, 2012). Nevertheless, several researchers highlighted that using raw materials from renewable feedstock or following green chemistry principles is not always sufficient to ensure a better environmental performance from a LCA perspective (Jimenez-Gonzalez et al., 2011). So, a comprehensive evaluation through LCA is needed to assess potential benefits coming from bio-processes and bio-based materials compared to traditional synthetic routes and fossil based