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Review

Environmental life cycle assessment of edible oils: A review of current knowledge and future research challenges

Poonam Khatri, Suresh Jain*

Department of Energy and Environment, TERI University, 10, Institutional Area, Vasant Kunj, New Delhi 110070, India

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A B S T R A C T

Edible oils constitute an import commodity in terms of food, trade and environmental impacts. This paper discusses the application of life cycle analysis (LCA), an environment management tool, in edible oil systems. Enhancing their environmental performance can play an important role in making a shift towards sustainable agri-food systems. The aim of this review is to collate the LCA studies conducted on edible oil systems, performing a qualitative analysis to identify trends among the key methodological choices in order to assess the level of harmonization and analogy among studies. In addition, the areas worth of further investigation in future LCA applications are highlighted. The review carried out is qualitative and seeks to identify general pattern in the environmental impacts of edible oil systems. The key conclusion of the review is that increased comprehensiveness and harmonization of the methodological considerations is needed for future LCAs in this area. Defining of goals, functional unit and system boundary were having most iterative choices, while allocation criteria was found to have most heterogeneous choices. This attempt at understanding the current research trends of edible oil LCA studies would be useful in responsible addressing of the future research challenges in the area.

Contents

* Corresponding author. Tel.: +91 11 7180 0222.
E-mail addresses: sureshjain_in@yahoo.com, sureshj@teriuniversity.ac.in (S. Jain).

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1. Introduction

The agri-food systems are presently facing an interconnected challenge of producing more food with reduced burden on energy, resources and environment (Foley et al., 2011; Soussana, 2014; Keairns et al., 2016). Considering this challenge, several governments have acknowledged sustainability of food systems as a top priority (Garnett, 2014). The concerns about sustainability of agri-food systems have recently aggravated in view of the growing population and associated pressure on resources essential for increased food production (Godfray et al., 2010; Garnett, 2014). Activities of agri-food systems (cultivation, industry processing, distribution, and consumption) have become much more energy intensive due to industrialization (Schau and Fet, 2008). Overall, food systems account for about 20–30% of natural resource consumption worldwide (Nonhebel, 2004). Therefore, a shift towards sustainable agri-food systems becomes essential (Soussana, 2014; Notarnicola et al., 2017a). More food needs to be produced in a way that cause minimal harm to environment and also enhance its nutrition value (Ericksen, 2008; Notarnicola et al., 2017a). This imposes an emerging challenge to policy makers along with the prevailing concerns of food security and social welfare (Ericksen, 2008). Life cycle thinking has been regarded fundamental for addressing the composite of challenges and research needs related to the sustainability of agri-food systems (Notarnicola et al., 2017a, b). Life Cycle Assessment (LCA) has emerged as a major tool to guide the shift towards sustainable food systems as evident from the recent increase in number of LCA studies on agri-food products (van der Werf et al., 2014). LCA, an internationally accepted and standardized method (ISO 14040 and ISO 14044), aims at the assessment of environmental impacts of a product using a systems perspective, i.e. analyzing the product' whole life cycle, identifying hotspots for improvement without shifting the burden from one stage to another (Hellweg and i Canals, 2014). The LCA framework comprise four stages: i) goal and scope definition, to establish the functional unit, system boundaries and quality criteria for data collection; ii) life cycle inventory (LCI) analysis, to collect the data on inputs of material and energy flows as well as outputs in form of environmental emissions; iii) life cycle impact assessment (LCIA), to convert the inventory flows into potential environmental impacts related with various processes in the products' life cycle; and iv) interpretation of results to draw conclusions for decision making. Each stage entails several choices which could influence the final results (Agrawal et al., 2014a, b; Sala et al., 2017).

The ISO 14040 standard for LCA provides the basic framework which can be used for the assessment of environmental impacts related to the activities of food systems (Notarnicola et al., 2012). Originally developed for analyzing the industry systems, the use of LCA in agri-food systems is rapidly increasing (Schau and Fet, 2008; Roy et al., 2009; Notarnicola et al., 2017a). This increase is driven by the growing concerns of environmentally conscious governments and consumers for sustainability of food products (Notarnicola et al., 2017a). The market preference attained by the products having claims of environment friendliness verifies this further. With the goal of reducing environmental impacts of food system activities, LCA has been applied for: i) identification of hotspots of environmental impacts (Avraamides and Fatta, 2008; Nucci et al., 2014), ii) comparison of food system activities related options to support in making the shift towards sustainability (Iriarte et al., 2010; Wiloso et al., 2015), and iii) assessment of impacts for future scenarios related to any change in the activities of food systems (Castanheira and Freire, 2013; Sala et al., 2017). There are several examples of application of LCA on different food products such as edible oils (Avraamides and Fatta, 2008; Chiew and Shimada, 2013; Fedele et al., 2014; Tsarouhas et al., 2015); tomato (Andersson, 2000; Bojacá et al., 2014), and milk (Cederberg and Mattsson, 2000; Mattsson et al., 2000; Meneses et al., 2012).

This paper focuses on edible oil systems. Table 1 provides a summary of different applications pursued in edible oil systems using LCA results. Edible oils make important constituent of food, trade, and fastest increasing food commodities worldwide (Schmidt, 2010). Tukker and Jansen (2006) listed edible oils in the top-lists of product groups causing largest total environmental impacts (including production and consumption) as well as impacts per monetary unit (Euro in the study). LCA in agri-food products is a new area of application against its established use in industrial product systems (Mourad et al., 2007). Several studies have indicated the need for increasing research efforts for understanding the environmental interactions of food system activities which at present are partially or unevenly studied (Ericksen, 2008; Heller et al., 2013; Garnett, 2014). Considering the complexities of environmental interactions of agri-food systems, they require a separate viewpoint on methodological choices and assumptions to be made while performing an LCA (Sala et al., 2017). There is presently no standard guidance on methodological choices pertaining to the issues which applied exclusively to agri-food systems. The missing aspects include a clear definition of the system boundaries between nature and technosphere, handling of multifunctional outputs, incomprehensiveness of LCIA methods to account soil fertility, increase in erosion, loss of biodiversity, and influence on ecosystem services (Notarnicola et al., 2017a). The variations in the assumptions, methodological choices, LCI data, and emission factors used by LCA practitioners contributing to wide-ranging results even for the similar products and subsequently affecting the comparability of the studies (Brandão et al., 2012). Further, this prevents a conclusive assessment to be of use to decision makers. Therefore, analysis of published LCA results to draw an analogy between the studies becomes essential (Lifset, 2012). Though there are LCA review studies on some agri-food products such as fruits (Cerutti et al., 2014) and milk (Baldini et al., 2017), there is, so far, no review study on edible oils to the best of authors' knowledge.

The aim of this review is to analyse the LCA studies conducted on edible oil systems, identifying trends among the key methodological choices in order to assess the level of harmonization and analogy among the studies. In addition to the current trends, the areas worth of further investigation in future LCA applications are highlighted. A qualitative analysis of different elements of LCA methodology and related choices has been undertaken to achieve the objectives of this study. This attempt of understanding the current research trends of edible oil LCAs would prove useful in responsible addressing of the future challenges in the area and would indeed benefit the researchers working in this field. Ultimately, through the review process, authors aimed at answering the following two key questions:

1. How LCA has been applied (with respect to its key elements) in identifying and evaluating the environmental impacts of edible oil systems?
2. Is it possible to derive some key conclusions regarding the assumptions and methodological choices made in reviewed LCA studies?

This paper is organized as follows. The section 2 briefly delineates the methodology adopted in the review process. Next, section 3 describes the outcomes of review process under two heads: first, describing the scope of reviewed studies where an analogy is drawn between the reviewed studies for the regional scope, type of analysis, scope of the study, and pattern found in reporting of LCA results, and second, discusses the systematic