Journal of Cleaner Production 166 (2017) 988–997

Contents lists available at ScienceDirect

Journal of Cleaner Production

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

A cradle-to-gate assessment of environmental impacts for production of mustard oil using life cycle assessment approach

Poonam Khatri [a], Suresh Jain [a, *], Suneel Pandey [b]

[a] Department of Energy and Environment, TERI University, Delhi, 10, Institutional Area, Vasant Kunj, New Delhi 110 070, India
[b] Green Growth & Resource Efficiency Division, The Energy and Resources Institute (TERI), India Habitat Centre, Lodhi Road, New Delhi 110 003, India

ARTICLE INFO

Article history:
Received 27 May 2017
Received in revised form
11 August 2017
Accepted 13 August 2017
Available online 14 August 2017

Keywords:
Mustard oil
Environmental impacts
Life cycle assessment
Processing scales
Extraction methods

ABSTRACT

The present study evaluated the environmental impacts of edible mustard oil production using Life Cycle Assessment (LCA). The study aimed at identification of environmental hotspots and also studying the influence on LCA results due to system variables including oilseed processing scales, extraction methods and allocation choice. The assessment was performed at both midpoint and endpoint levels using ReCiPe method. The LCA results clearly identified the agriculture stage as the hotspot having dominating share in all the environmental impact potentials. Within agriculture stage, the major contribution came from use of electricity, fertilizers production, field emissions, and transport of agriculture inputs. Inclusion of biogenic uptake of CO_2 from atmosphere during photosynthesis contributed in net benefits for the climate change potential impact category. In industry subsystem, small scale processing showed to have higher environmental impacts. In comparison to small-scale processing, the environmental impacts of medium and large-scale were reducing by around 4% and 8%, respectively. However in large scale processing, the benefits of high oil extraction, and more efficient use of raw materials and energy were overshadowed by longer transport distances. In the comparison of environmental impacts of extraction methods, full pressing technology (FPT) showed lower impacts than solvent extraction combined with pressing technology (SEPT). Though, the percent difference in average environmental impacts was found statistically significant ($P < 0.05$). Further, the results were significantly influenced by the method used for allocation of environmental impacts between products and co-products in both agriculture (seed and straw) and industry (oil and cake) subsystems.

1. Introduction

In recent years, the sustainability of agri-food systems has received a great attention of policy makers worldwide (Garnett, 2014; Ericksen, 2008). They are facing an interconnected challenge of increasing food production while minimizing the resources use and environmental impacts (Soussana, 2014). Food system activities (agriculture production, industry processing, storage, distribution and use) account for ~20–35% of worldwide total energy consumption (Sanjuán et al., 2014; Hertwich and Peters, 2009). In view of the increasing population and concomitant demands, a shift towards sustainable agri-food systems becomes essential. Tukker and Jansen (2006) in a study on environmental impacts of economic activities described that food contribute in 20–30% of total impacts. Edible oils belong to the top-list of food product groups with largest environmental impacts (Tukker and Jansen, 2006). Several studies have indicated the need of increasing research efforts for understanding the environmental interactions of food system activities which at present are partially understood (Garnett, 2014; Soussana, 2014; Ericksen, 2008). These environmental interactions occur at multi-levels with respect to time and space accompanied by interconnect with the nutritional quality (Heller et al., 2013; Ericksen, 2008). Interdisciplinary approaches using a composite of perspectives (production efficiency, changing consumption, and system transformation) are required to understand the environmental interactions between and among the food system activities (Garnett, 2014; Soussana, 2014). And, the case studies employing systematic analysis can assist in finding determinants of these interactions.

This study applies Life Cycle Assessment (LCA) on mustard oil production in India whose edible oil sector has undergone a great

* Corresponding author.
E-mail addresses: sureshjain_in@yahoo.com, sureshj@teriuniversity.ac.in (S. Jain).

http://dx.doi.org/10.1016/j.jclepro.2017.08.109
0959-6526/

shift largely due to the trade liberalization. India has transformed from almost self-sufficient in edible oils (during the period of Technology Mission on Oilseeds, 1987–1995) to import dependent (Post period of the Agreement of Agriculture, an international treaty, of the World Trade Organization in 1995) for meeting the domestic consumption demands (Hegde, 2012; Reddy and Bantilan, 2012). The first research problem identifying the need of this study is the existing demand-supply gap (>50%) in edible oils production. This implies several challenges in both agriculture and processing stages, which must be dealt with in an environmentally responsible manner (Reddy and Bantilan, 2012). The causal factors of present situation can be identified as an amalgam of ineffective policy interventions and inefficiencies identified in oilseed production and processing stages of edible oil systems (Hegde, 2012; Reddy, 2009). Though various research efforts on developing new crop varieties with different characteristics such as improved yield, nutritional quality, disease and stress tolerant (Chauhan et al., 2002), and analysis of technical efficiencies (Reddy and Bantilan, 2012; Mruthyunjaya et al., 2005) and policy implications (Thomas et al., 2013; Reddy, 2009; Persaud and Landes, 2006) are on-going, yet to the best of authors' knowledge, no study so far has envisaged the assessment of environmental impacts. Mustard oil was selected due to the special place it has among other oils in terms of nutritional value (fatty acid composition) and its potential to reduce the import burden as India ranks third in the production of mustard seeds worldwide (USDA, 2017). Mruthyunjaya et al. (2005) in a study on technical inefficiencies in production and processing stage of four major edible oils in India (including mustard oil) reported ~50–65% technical inefficiencies which if reduced can almost double the country's edible oil production.

ISO 14040 standard for LCA provides a basic framework for sustainability management of agri-food systems (Notarnicola et al., 2012). LCA involves compilation and evaluation of the inputs, outputs and potential environmental impacts associated throughout the products' life cycle (ISO 14040, 2006). Such information on the environmental impacts for life cycle of products is increasingly being used to support policy decisions (Notarnicola et al., 2017; Roy et al., 2009). There are several examples of LCA application in edible oil systems such as for identification of environmental hotspots (Tsarouhas et al., 2015; Salomone and Ioppolo, 2012; Avraamides and Fatta, 2008), comparison of different edible oil production or waste treatment options (Nucci et al., 2014; Stichnothe and Schuchardt, 2010), and setting of environmental requirements for edible oil supply chain (Iraldo et al., 2014). Though, the large data gaps in terms of availability as well as quality impede the applications of LCA (Hellweg and i Canals, 2014), which are of aggravated concern in developing countries (Wernet et al., 2011). In view of the rapidly globalizing food systems, the compilation of life cycle data with regional representativeness would help in establishing the much coveted linkages between resource utilization patterns and food security (Notarnicola et al., 2017; Heller et al., 2013). Thus, LCA can help in better understanding of the environmental interactions of its food systems subsequently advancing the policy relevant knowledge. LCA in agri-food products is a relatively new area of application against its established use in industrial product systems (Mourad et al., 2007). Considering the complexities of environmental interactions of agri-food systems, they require a separate viewpoint on methodological choices (Khatri and Jain, 2017). Therefore in order to arrive at consensual methodological choices in context of edible oil systems (mustard oil in this study), a comprehensive systematic analysis of previous LCA studies on edible oil systems available in Khatri and Jain (2017) has been used. This analysis pointed out level of harmonization and analogy among the studies. In defining of goals most of the studies (~70%) aimed at identification of environment impacts which is in agreement with the ultimate aim of an LCA as per ISO 14040 (2006). In the choice of functional unit, mass based selection (1 kg, 1 tonne) was found to be most iterative. Further, the life cycle stages mostly covered in the previous edible oil LCA studies include: oilseed crop cultivation, oil extraction stage and the transportation in between. On the other hand, allocation criteria was found to have most heterogeneous choices. The percent application rate of different allocation choices followed the order: system expansion (28%) > mass allocation (19%) > economic allocation (14%) where no single choice could fit all studies. The present study shall be considered a timely attempt providing first comprehensive overview of the environmental impacts of edible oil systems in Indian conditions using life cycle approach. The environmental impacts of mustard oil production are assessed by conducting a cradle-to-gate LCA following ISO framework (ISO 14040, 2006; ISO 14044, 2006). Ultimately, this study aims at answering following research questions:

1. Which unit processes in the production of mustard oil give rise to most significant environmental input-output flows i.e. hotspots?
2. How do the system variables such as processing scale, oil extraction method and methodological choices in carrying out LCA influences the environmental impacts?

2. Methodology

2.1. Goal of the study

The goal of this LCA study was to evaluate the potential environmental impacts of producing mustard oil with different oilseeds processing scales and extraction methods. In addition, the study evaluated the influence of allocation choices on impact assessment results.

2.2. Product system and system boundary

'Mustard oil' was studied in context to the quality characteristics as described in Indian Standard for mustard oil (BIS, 2004). The mustard oil product system comprises two subsystems: agriculture production and industry processing (Fig. 1). The details on how the LCA model was developed for this study are available in the supporting information (SI) (Section S1, Fig. S1). The geographic scope of the study intended to be limited to Alwar District in Rajasthan (India). Alwar is the leading producer district of mustard in Rajasthan which in turn takes the lead as the largest producer at national level. The mustard seed yield was applied as the yield in 2014 calculated from linear regression of average yields from 2001 to 2014 (SI, Fig. S2) using the data from Indiastat (2014). Industrial processing subsystem involved two extraction methods: full pressing (mechanical extraction) technology (FPT) and solvent extraction combined with pressing technology (SEPT). All industries are located within the Alwar Oil Mills Cluster wherein ~30 are FPT based and four with SEPT. Three processing scales were studied in FPT: small, medium and large with respective oilseed crushing capacity of ≤50, 50–120 and > 120 tonnes per day (BEE, 2008). Additional Information on criteria used for defining system boundary in this study is provided in the supporting information (SI, Section S2, Table S1).

2.3. Functional unit (FU)

Depending on the goal and scope of the study, the FU chosen for this study was the production of 1 kg of mustard oil. All the input-