Journal of Cleaner Production xxx (2016) 1–9

Contents lists available at ScienceDirect

Journal of Cleaner Production

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

A comparative lifecycle assessment of rural parboiling system and an integrated steaming and drying system fired with rice husk

E.M. Kwofie, M. Ngadi*

Department of Bioresource Engineering, McGill University, 21,111 Lakeshore Road, Ste-Anne-de-Bellevue, QC, Canada

ARTICLE INFO

Article history:
Received 2 November 2015
Received in revised form
24 May 2016
Accepted 1 June 2016
Available online xxx

Keywords:
LCA
Rural parboiling system
Integrated parboiling system
Rice husk
Paddy steaming and drying

ABSTRACT

The study presents a comparative life cycle assessment of the current rural parboiling system (RPS) used in a rural village setting and a newly developed integrated steaming and drying system (ISDS). With a functional unit of 1 tonne of paddy processed, the environmental impact of the two systems was evaluated. Four environmental indicators namely climate change, terrestrial acidification, particulate matter formation and photo-oxidant formation were considered and were applied to the ReCiPe version 1.08 evaluation method available in the GaBi 6 LCA software. The normalized environmental impacts were at least 68.2% higher for RPS than ISDS in all impact categories. Overall, up to 80% reduction in total environmental impact can be achieved by replacing the existing process with ISDS. The sensitivity of the results has been examined using an alternative evaluation method, TRACI version 2.1, and a variation in rice husk availability.

1. Introduction

Rice has become a staple food for many individuals in Sub-Saharan Africa and its production at the rural level has huge implication for the livelihood of the many small-scale farmers (Kula and Dormon, 2009; Ministry of Food and Agriculture, 2009). There have been several national and international efforts to improve local production, although, they are geared towards cultivation (Kula and Dormon, 2009). Along the value chain, energy supply and use has always been a major challenge for parboilers. These women travel several kilometers in search for wood or purchase fuel from wholesale wood vendors for the hydrothermal processing known as parboiling. The three-stage process has been found to improve the physical, chemical and nutritional value of the processed rice (da Fonseca et al., 2011; Luh and Mickus, 1991; Tolaba et al., 2006).

As the quest to provide food in a safe environment and concerns about natural resource depletion and environmental degradation increases, conscious effort is required in developing systems which result not only in resource savings but also have the ability to minimize the impact on health and wellbeing of those involved in it. For instance, the current open field of rice husk from the rice processing poses risk to the processors and the entire community. Besides the difficulty in controlling open field burring due to variable winds, there is also the danger of skin, nose and eye irritation due smoke and particulate matter (Burritt et al., 2009). In response to improving rice quality within the region, an integrated steaming and drying system powered with rice husk was developed. This system is expected to improve energy, minimize deforestation, reduce overall emissions and improve the health of the parboilers. However, to what extent has this anticipated environmental impact been reduced?

Different assessment tools have been developed to analyze the environmental impact of different product systems (Höjer et al., 2008). Life cycle assessment (LCA) is one of such internationally recognized tools used for controlling technical activity development and for assessing the environmental performance of products and processes (Rousset et al., 2011). The standard LCA guidelines provided by the International Organization for Standardization (International Standard Organization (ISO), 2006) in the ISO 14040 and 14044 defines the LCA process as ‘the compiling and evaluation of the inputs and outputs and the potential environmental impacts of a product system during a product lifetime’. It covers all stages in the life cycle of the product or process including raw material acquisition, manufacturing, use/reuse/maintenance as well as the end of life (recycle/waste management) (Berg and Lindholm, 2005; EPA, 2006).

LCA have been employed in evaluating the environmental impact of different aspects of the rice value chain by several

* Corresponding author.
E-mail address: michael.ngadi@mcgill.ca (M. Ngadi).

http://dx.doi.org/10.1016/j.jclepro.2016.06.008
0959-6526/

authors. For instance, Wang et al. (2010) and Blengini and Busto (2009) reported on the environmental impact of the rice value chain from seedling to milling, but excluded parboiling from the system boundary; Xia and Yan (2011) reported the LCA of nitrogen use in rice systems; Roy et al. (2009) reported the Life cycle inventory (LCI) of different forms of rice consumed in households in Japan. Roy et al. (2007) used life cycle analysis to evaluate the challenges and choices of rice production and discussed resource use, energy use, environmental emissions (CO_2 emissions) and solid waste (ash) production for parboiling in Bangladesh. However, the paper did not make quantitative measurements of emissions or evaluate the impact of the systems on the environment. Other researchers have suggested parboiling negatively impact the environment and suggested that a new route rice processing was required to reduce energy and resource consumption as well as environmental pollution (Roy et al., 2004). There is no fully evaluated life cycle impact assessment report on local parboiling process especially in sub-Saharan Africa where wood is used as energy.

The objective of the study is to determine the environmental impacts of a newly developed integrated steaming and drying system and to compare the results with the impact of current paddy parboiling system used in northern Ghana using Life Cycle Assessment (LCA).

2. Materials and methods

2.1. Goal and scope of study

Rice parboiling is practiced in the West African sub-region using traditional methods and energy from wood. The husk generated during the milling process is treated as waste and disposed of by open fire burning. In finding an alternative energy supply system, and ways to improve both energy use and product quality, an improved integrated parboiling system was developed. However, the extent of environmental improvement can be judged by comparing it with the system being used currently. The goal of this LCA is, therefore, to determine the life cycle environmental impact of the new integrated system in comparison with the current local parboiling system over selected impact categories using a functional unit of 1 tonne of paddy processed.

In this study, a cradle-to-grave approach was considered for each scenario to provide an overview of the entire rice processing process (soaking, steaming, drying and milling). The system boundaries, therefore, included system fabrication, system utilization and disposal of rice product (rice and husk). For each system boundary, all the input and output flows including energy resource, raw materials, and waste have been considered. Considering the fact that, this study is a comparative LCA of two different rice processing energy systems, the emissions from all processes with similar impact for both systems have been excluded. These include the cultivation of paddy, milling system fabrication and disposal, rice marketing and consumption. Hokazono and Hayashi (2012) presents a variability in the environmental impacts of different rice cultivation systems.

2.2. System description and boundaries

2.2.1. Rural parboiling system (RPS)

For the purpose of this study, local parboiling process as practiced in Ghana has been used (Kwofie and Ngadi, 2016). Thermal energy for the process is supplied by wood combustion in a three-stone fire (TSF) system. The process occurs in a three-stage process namely soaking, steaming and drying. During the soaking process, cleaned paddy is poured into the soaking vessel containing hot water (75–80 °C) and covered. After about 20–22 h, the soaked paddy is transferred to the steaming vessel containing hot water (80–85 °C). The steaming vessel is then covered with jute sack and placed on the TSF for 20–30 min. The steamed paddy is dried in the sun for 6–7 h. The parboiling process is completed when a moisture content of about 14–15% is achieved.

The system boundary for the RPS is shown in Fig. 1. It includes the wood transport and combustion process, all three stages of parboiling as well as milling. Like other biomass combustion LCA (Afrane and Ntiamoah, 2011, 2012; Nguyen et al., 2013; Rousset et al., 2011; Roy et al., 2005), wood production was excluded. Since the stove used is made from three stone collected around the parboilers' homes, its impact was neglected. For wood transport, only diesel consumption has been considered without emissions from diesel production. Thermal energy and associated emissions from wood combustion have been used. Rice husk generation and disposal are the only processes considered during milling. To enable consistency in the two systems, the sun drying process has also been considered.

2.2.2. Integrated steaming and drying unit

The multi-fuel system uses rice husk as primary fuel (but could use wood in the absence of rice husk) to generate hot water and steam for parboiling. It also uses the waste heat from the flue gas to heat air through a fire tube heat exchanger, which is used to dry paddy in a simplified Louisiana State University (LSU) recirculating dryer. The system boundary for the ISDS evaluation shown in Fig. 2 includes the construction of the system (taking into account raw materials and energy input), fuel combustion (rice husk and wood), drying process (electrical energy for blower) and milling (product, by-products and energy).

2.3. Inventory data collection

2.3.1. RPS data collection

The inventory data of the RPS were collected during a study to assess local parboiling energy dynamics in Sishiagu, located in the new district of Sagnarigu in the Northern Region of Ghana (N9° 24.288′ W0° 52.805′) (Kwofie and Ngadi, 2016). During the study, the authors collected primary data on the parboiling process, materials and equipment, energy supply and consumption, as well as rice husk availability and use.

In the RPS scenario, a tonne of paddy will be parboiled in 20 batches of 50 kg (average parboiling capacity within selected region) with 2680 MJ of thermal energy. The inventory includes data for stove construction, wood collection and transport, energy for soaking and steaming and solar energy for dying. The input materials for the RPS construction includes stones, aluminum for the pot, jute sack, and concrete for the drying floor. The average water use for parboiling was estimated to 0.84 and 0.089 kg/kg of paddy for soaking and steaming, respectively. About 5 ± 1.23% of ash is generated after wood combustion which is disposed of at backyard dumping site.

Different types of wood are used in the RPS, hence, the five main types of wood used in the selected area as shown in Table 1 have been used for the LCA. The average moisture content, density, and heating value are estimated as 5.6%, 630 kg/m^3 and 18,932 kJ/kg, respectively (Brown, 1997; Dhillon et al., 2008; Günther et al., 2012; Venture Renewable Energy, 2012). The total wood consumption for parboiling a tonne of paddy with the RPS was estimated to be 974 kg. This was based on a linear regression model developed for soaking and steaming energy estimation (Kwofie and Ngadi, 2016). Considering the fact that, local parboilers collect 35% of the wood from the surrounding forest (average round trip distance of 6.2 km) and buy the remaining from bulk wood vendors, only 633 kg have been associated with wood transport and considered for the