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Modelling energy and environmental impacts of traditional and improved shea butter production in West Africa for food security

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HIGHLIGHTS

- Employs and compares three methods: human energy, EIO-LCA, and process-based LCA
- Mechanization reduced women's energy without large increase in total energy
- Quantifies environmental impact from traditional to improved shea butter processes
- Improved cookstoves reduce global warming potential of shea butter process by 78%
- First known study to compare EIO and process-based LCAs in a developing country

GRAPHICAL ABSTRACT

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ABSTRACT

This study improves the global application of methods and analyses, especially Life Cycle Assessment (LCA), that properly incorporates environmental impacts of firewood and a social sustainability indicator (human energy) as tools for sustainable human development. Specifically shea butter production processes, common throughout sub-Saharan Africa and crucial to food security, environmental sustainability, and women's empowerment, are analyzed. Many economic activities in the world rely on firewood for energy and labor that aren't included in traditional LCAs. Human energy (entirely from women) contributed 25–100% of shea butter production processes (2000–6100 kJ/kg of shea butter) and mechanized production processes had reduced human energy without considerably greater total energy. Firewood accounted for 94–100% of total embodied energy (103 and 172 MJ/kg of shea butter for improved and traditional shea butter production processes respectively) and global warming potential and 18–100% of human toxicity of the production processes. Implementation of improved cookstoves modeled in this study could reduce: (1) global warming potential by 78% (from 18 to 4.1 kg CO_2 eq/kg and 11 to 2.4 kg CO_2 eq/kg of shea butter for the traditional and improved processes respectively), (2) the embodied energy of using firewood by 52% (from 170 to 82 MJ/kg and 103 to 49 MJ/kg for the traditional and improved processes respectively), and (3) human toxicity by 83% for the non-mechanized traditional and improved processes (from 0.041 to 0.0071 1,4 DB eq/kg and 0.025 to 0.0042 1,4 DB eq/kg respectively). In addition, this is the first study to compare Economic Input-Output Life Cycle Assessment (EIO-LCA) and process-based LCA in a developing country and evaluate five traditional and improved shea butter production processes over

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different impact categories. Overall, this study developed a framework to evaluate and improve processes for achievement of the United Nation's Sustainable Development Goals for 2030 particularly to obtain food security.

1. Introduction

The second goal of the Sustainable Development Goals (SDGs) is to eradicate hunger, obtain food security and proper nutrition, and foster sustainable agriculture (United Nations, UN, 2015). Unfortunately, one in nine people in the world are undernourished (United Nations, UN, 2015) and the highest percentage reside in sub-Saharan Africa (World Food Program, WFP, 2015). Furthermore, agriculture is the most common form of livelihood worldwide and is also one of the largest contributors to anthropogenic greenhouse gas emissions (Soussana, 2014; World Food Program, WFP, 2015). Assessing the sustainability of current and future improved agricultural processes requires a framework that properly evaluates the environmental impacts and the contribution of human energy (a measure of social sustainability). Human energy is a critical component to incorporate because a decrease in environmental impact may place an increase of human energy on others, particularly farmers and poorer populations. Expending excessive human energy without adequate compensation and nutrition is a human health concern (Loake, 2001) and can lead to malnutrition and exhaustion and consequently a compromised immune system and sickness (Kau et al., 2011).

Life Cycle Assessment (LCA) is a tool that quantifies the environmental impacts of a product or process from extraction of resources through end-of-life disposal. It is seeing increased use in developing world settings (e.g. Cornejo et al., 2013; Musaazi et al., 2015) but there are limited applications reported for food security (Efole Ewoukem et al., 2012). LCA has however been recognized as crucial to achieving sustainable food systems, one reason being Western diets incorporate ingredients that may originate from many countries (Soussana, 2014). LCA has been utilized to quantify and compare the environmental impacts of oil crops (e.g. Mattsson et al., 2000; Achten et al., 2010; Schmidt, 2015); however, most of these studies exclude the human energy involved and focus on limited impacts. Giampietro et al. (1992a) did employ energy analysis to compare cattle systems that included human labor but this has not been conducted for edible oil crops. Oil crops such as oil-palm, soybean, cocoa and shea butter have a high food energy content and are crucial to food security as well as economic livelihoods (Ntiamoah and Afrane, 2008). Also, the oil crop sector has been growing twice as fast as the rest of the global agriculture sector and oil crops are estimated to contribute 45 of every future 100 kcal added to food consumption in developing countries (FAO, 2002).

Shea trees (*sp*. *Vitellaria paradoxa*) cover a 3.4 million km^2 area across 23 sub-Saharan African countries (Naughton et al., 2015) that bear fruit encasing a nut and kernel from which shea butter can be extracted after processing. In fact, shea butter contributes up to 60% of fat and oil supplies in some countries (Tano-Debrah and Ohta, 1995) with large international exports and considerable potential as a cocoa butter equivalent. Shea fruit is hand-picked from the ground below trees, then the fruit pulp is removed and the remaining shea nuts are boiled or roasted. The shea nut is then dehusked, leaving the kernel that is then ground into a paste to which water is added and mixed vigorously to extract the fat. Shea butter is also unique because the process is primarily controlled by an estimated 18 million women (Naughton et al., 2015) and profits supplement household expenditures (Pouliot, 2012). Furthermore, shea butter may be a more environmentally friendly oil because it doesn't require intensive changes in land use and fertilizer inputs like palm and soy (Glew and Lovett, 2014). However, the production process is labor and energy intensive and utilizes firewood that contributes to deforestation and negative health impacts (Glew and Lovett, 2014; Jasaw et al., 2015).

Although a carbon footprint analysis was conducted on the improved shea butter production process for cosmetic use (Glew and Lovett, 2014), to date, there is no other LCA of shea butter production including variations of the process, human energy, and environmental impact categories than carbon dioxide. Moreover, shea butter provides an example of a production process undergoing change from traditional to improved methods with mechanization in developing countries and these changes need to be modeled to quantify their environmental and social impacts (Giampietro and Pimentel, 1992b). Therefore, the primary aim of this study is to assess the differences in traditional and improved shea butter production and how technological improvements impact the environment and amount of human energy expended to identify areas of improvement for sustainable oil crop production. A combination of field measurements, energy analyses, and different life cycle inventory methods (Economic Input-Output (EIO) and process-based) and sensitivity analyses are utilized and compared in this study.

2. Materials and methods

LCA entails four major steps: (1) goal and scope definition, (2) life cycle inventory (LCI), (3) life cycle impact assessment, and (4) interpretation (ISO, 2006). Two approaches have been used in life cycle inventory analysis: processed-based (bottom-up) and Economic Input Output (EIO) (top-down). Additionally, several studies have also conducted human energy analysis throughout processes that were often excluded in LCA (Loake, 2001; Grimsby et al., 2012; Held et al., 2013). This study employed, compared, and evaluated the processed-based LCA, EIO-LCA, as well as a human energy analysis of five shea butter production processes that incorporated embodied energy and emissions from firewood and a four-part sensitivity analysis from in-depth data collection in the field and literature.

2.1. Shea butter production processes

There are nine major steps in West African shea butter production (see Fig. 1): (1) harvest the shea fruit, (2) depulp the fruit, (3) heat the shea nuts, (4) dry the shea nuts, (5) de-husk the nuts to extract the kernels, (6) macerate the kernels, (7) mill the macerated kernels, (8) extract the oil from the kernels, and (9) refine the oil. For the rest of this manuscript the specific production step referred to is provided in parentheses. Traditionally, shea butter production is performed manually though there is increasing access to technology for mechanization of three steps: macerating (6), milling (7), and extraction (8). Furthermore, there are variations of production steps throughout West Africa. For example, in much of Mali the shea nuts are heated (3) and dried (4) using traditional roasters while in other parts of Mali and throughout Burkina Faso and Ghana, shea nuts are heated (3) by boiling over a three-stone fire and then sun dried (4). There has been an effort by non-government organizations and industry to promote the "improved" shea butter process of boiling and sun drying because it is believed to yield higher quality butter, use less firewood, and have a higher extraction rate. Thus, as part of the study aim, five different shea butter production processes were analyzed:

A. Traditional process: Completely manual where traditional roasters are used to heat (3) and dry (4) the shea nuts.
B. Mechanized traditional process: The traditional process A with substitution of mechanized maceration (6) and milling (7).
C. Improved process: Completely manual with substitutions of boiling for heating (3) and sun drying (4).