3-12-2015

Carbon Dioxide (CO_2) Emissions, Human Energy, and Cultural Perceptions Associated with Traditional and Improved Methods of Shea Butter Processing in Ghana, West Africa

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by

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A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science in Mechanical Engineering
Department of Mechanical Engineering
College of Engineering
University of South Florida

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Date of Approval:
March 12, 2015

Keywords: Sustainable Development, Food Security, Gender, Energy Analysis, Millennium Development Goals, Improved Technology, Sub-Saharan Africa

DEDICATION

I would like to dedicate this paper to all who supported me throughout my Peace Corps experience in Ghana. I would have not endured the difficult times without the endless support of family, friends, and coworkers. Most importantly I am forever grateful to the Ghanaian families that treated me as their own kin. The hardworking men I cultivated fields with, the dedicated women who shared with me ancestral knowledge and practices to extract shea butter, the community I prayed with, the students who taught me more than I taught them, the community leaders that believed in me, and my best friend who was by my side through it all- Chef.

ACKNOWLEDGMENTS

I would like to take this opportunity to thank the following mentors and institutions that were instrumental in the completion of this project: The University of South Florida, the United States Peace Corps, my advisors Professor Durham and Dr. James Mihelcic and committee member Professor Deubel, as well as Ph.D. candidate Colleen Naughton who I had the pleasure of working with as she supported me throughout my research involving shea. Anna Perenic, the CEO of StarShea ltd who enabled my work in the shea industry. During my projects with StarShea ltd, I was able to see many diverse perspectives of the shea industry. I am grateful I was able to assist in the field and in the office; I will never forget the memories with my coworkers and amazing women of the StarShea Network. SeKaf Ghana ltd also provided support key to my success, the vision and enthusiasm of their leaders is admirable, and their staff is remarkable. Their assistance and resources greatly impacted the amount of data I was able to collect in a single shea season. Results in this study were obtained with assistance by community volunteers, community translators, Peace Corps Ghana Shea Committee members, StarShea ltd, and SeKaf Ghana ltd. Findings, conclusions, and recommendations expressed in this material are those of the author and do not necessarily reflect the views of the Peace Corps, StarShea Ltd, and SeKaf Ghana ltd. This material is based upon work supported by the National Science Foundation under Grant No. 0965743. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author and do not necessarily reflect the views of the National Science Foundation.

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ABSTRACT

The shea tree is indigenous to 21 countries in Sub-Saharan Africa and provides nuts from which oil (referred to as butter) can be extracted. Shea butter production in the Northern Region of Ghana is of socioeconomic importance to female processors who practice shea production. This study quantified the environmental effects of shea processing from carbon dioxide emissions and the human energy expended through the traditional, improved, and centralized methods of shea processing. Par-boiling accounted for up to 88% of total carbon dioxide emissions throughout the entire shea butter production process. A difference of $2.5 \frac{CO_2\ (kg)}{Shea\ butter\ (kg)}$ emitted observed between the traditional and centralized processing methods. The moisture content of 16 firewood samples collected at the centralized processing center found wood moisture to range between 9-34%. The largest amounts of human energy expended during traditional and improved processes take place during the nut collection process followed by manual crushing (40% and 20% of total energy expended during the traditional method, respectively). Women in the study area were found to travel an average of 10 km to pay for a corn mill to process their shea kernels into a paste, producers also expressed interest in mechanized crushing machines during household surveys. User perceptions of the improved roasting equipment were found to be positive, as well as adoption of the new technology was observed by all shea producers surveyed in the village of Tigla. The entirety of individual producers surveyed without access to improved roasters expressed interest in obtaining and

utilizing improved roasters to improve the traditional method currently practiced. The profit observed from shea kernel processing and sales was found to be higher than women practicing traditional shea butter processing and sales due to time, energy, and inputs required by completing the entire process. Butter producers at centralized processing centers have the opportunity to make up to 33% higher profits while utilizing less energy (54% reduction) by purchasing directly from kernel producers and implementing improved technologies in a centralized setting. The potential of shea production in northern Ghana has yet to be reached. Through adoption of improved technologies, women have the opportunity to save time and human energy, reduce material inputs such as firewood, and in turn are able produce an even greater amount of marketable shea products.

CHAPTER 1: INTRODUCTION

1.1 Background

The shea tree (*Vitellaria paradoxa*) is an indigenous and important economic and social asset in 21 African countries[1] (Lovett 2013) and is particularly abundant in the northern savannah areas of Ghana (Aniah et al. 2014). Its distribution across Sub-Saharan Africa is provided in Figure 1. According to the United Nations Development Program (UNDP 2010), the shea industry currently provides employment and income for approximately 900,000 women in the 3 regions of northern Ghana.

For many women, the main source of income is the production of shea nuts and butter therefore making shea manufacturing of great socio-economic importance to the local people (Collins 2014). The oil extracted from the shea nut is used for cooking, and income from selling shea nuts and/or butter typically belongs to women to spend as needed (e.g. purchase clothes or pay school fees). Profits from selling shea butter have also been found to account for at least 12% of poorer household income at a challenging time between the end of yearly food stores and before a new harvest (Pouliot 2012). In northern Ghana the fruits contribute to food security, particularly for the rural poor, especially because their ripening coincides with the lean season of food production (Fobil 2002).

[1] Benin, Burkina Faso, Cameroon, Central African Republic, Ivory Coast (Cote d'Ivoire), DRC, Ethiopia, Gambia, Ghana, Guinea-Bissau, Guinea-Conakry, Mali, Niger, Nigeria, Sierra Leone, Senegal, South Sudan, Sudan, Chad, Togo and Uganda.

Women form the backbone of the industry and are mainly involved in the initial stages of collecting and processing the shea nuts and butter (UNDP 2010). Thus for women who are required to work to supplement family income, the shea butter industry serves as a key avenue to escape from the poverty trap as it offers them the prospect to make a living (Collins 2014).

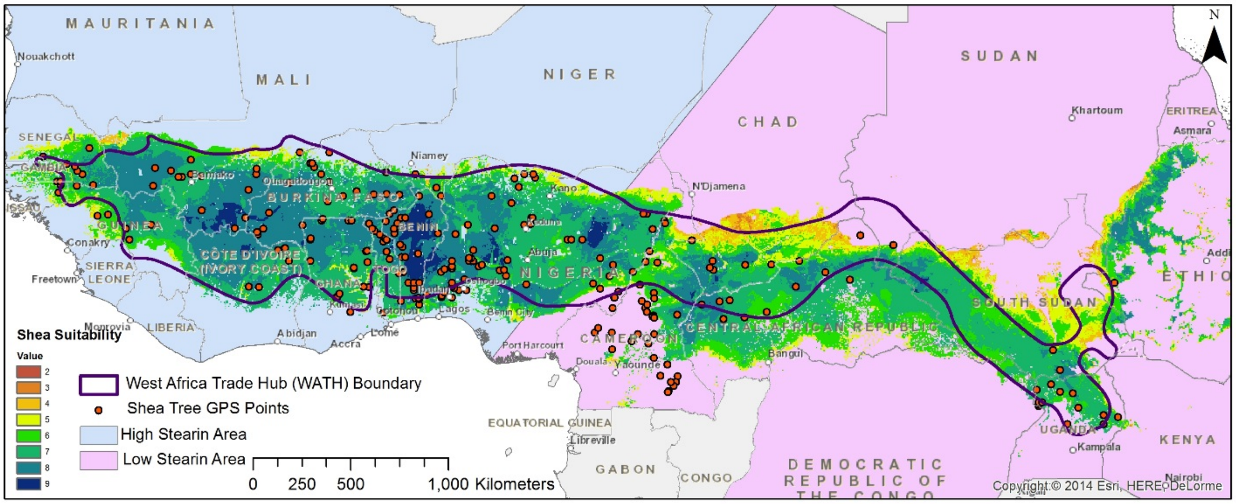

Figure 1. Shea tree distribution map generated using Geographic Information Systems (GIS) overlaid with the West Africa Trade Hub's (WATH) distribution and GPS coordinates of shea trees. Adapted with permissions by (Naughton et al. 2015).

The continued production of shea butter from dried shea kernels using manual traditional techniques is considered tedious and labor-intensive. The process is also resource inefficient and requires large quantities of water and firewood that creates a significant drain on scarce resources in the semi-arid areas where shea grows. In fact, the processing input of 18.5 kg of raw shea nuts is stated to require 48.0 kg of firewood ($2.59\frac{Firewood\ (kg)}{Shea\ nuts\ (kg)}$), and 67.0 liters of water ($3.62\frac{water\ (L)}{Shea\ nuts\ (kg)}$) (Addaquay 2004). In order to ensure environmental sustainability in Ghana, the Millennium Development Goal #7, Target a, aims to reverse the loss of environmental resources. Available data indicates that Ghana's forests are disappearing rapidly; between 1990 and 2010, Ghana annually lost an average of 1.96% of forest cover (UNDP 2010). According to Vijay et al.

(2003), rural energy occupies center-stage in rural development issues. Accessibility and availability of cooking fuels at affordable prices is becoming more challenging for the poor of whom many do not have access to electricity. In Ghana, rural wood users have access to a more abundant and more affordable source of energy (Pascaud et al. 2014). Therefore, the rural impoverished population relies on locally sourced wood and energy inefficient open fires. Greenhouse gas (GHG) emissions are associated with different activities of the shea butter processing methods and after they are determined, can be converted to a carbon footprint (see methods of determining a carbon footprint in Mihelcic and Zimmerman (2014)). Understanding the source of these emissions is important in order to reduce them (BSI 2008). In fact, a study in Ghana (Glew et al. 2014) concluded that during the entire life cycle of the shea butter process, the emissions resulting from wood burning were by far the greatest contributor to carbon dioxide (CO_2) emissions (and thus the carbon footprint).

Currently several methods in Ghana are used to produce shea butter and each has diverse material and human inputs and emission outputs. Rural-based women typically use a traditional method of processing that predominates other production processes in West Africa (Addaquay 2004). The traditional method, as well as semi-mechanized method, both produce handcrafted shea butter. Women engaging in traditional handcrafted butter production do not have access to improved roasters, crushing machines, and mills, making it a labor and time intensive process. Large companies have access to use of an expeller, a fully mechanized method of oil extraction available in cities for industrial processing of shea butter. Industrial kneading is a mechanized method of production where different machines are used throughout each step of the production process. Expelling and industrial kneading of shea butter are efficient ways to process shea, but require expensive imported machinery, technically skilled operators, and intensive maintenance.

A semi-mechanized system is often seen in Ghana where women extract the oil by hand but have access to some labor saving machinery such as improved roasters, mills, and crushers in the early processing steps.

1.2 Objectives

The overall goal of this research was to observe traditional and improved processes for shea butter production to improve understanding of the different human and material variables that affect the processing of shea and associated CO_2 emissions in northern Ghana. This research has four objectives:

1. Quantify human energy and material inputs for traditional and improved processing stages of shea butter processing methods.
2. Calculate CO_2 emissions for traditional and improved processing technologies utilized for shea butter production.
3. Assess users' perceptions of improved roasters for shea butter processing.
4. Compare traditional and improved processing methods of shea butter production; and make culturally, economically, and socially appropriate recommendations for shea butter processing methods.

A recent study on global distribution of the shea tree estimated that the potential annual production of shea kernels is 2.4 million tons, yielding an estimate yield of greater than 800 thousand tons of shea butter (Naughton et al. 2015). By quantifying human energy as well as material inputs used during traditional and improved processing technologies, the differences can be compared to assess the impact that improved technologies have on resource consumption, carbon emissions, and user benefits. Calculating the firewood used to process shea kernels at each stage of the shea butter process will help determine where reductions in carbon emissions can be obtained as well as which of the improved technologies has the greatest potential to reduce carbon emissions and/or human energy to improve environmental sustainability. Assessing users' perceptions of improved technology and practices is also important to ensure sustainability, as this will influence their adoption of the technology. This study will also provide culturally, economically, and socially appropriate recommendations for varying production methods to improve the shea butter process in northern Ghana as the industry and production rates of shea butter expands.

1.3 Motivation

The motivation for this research is based on the author's experience in the Northern Region of Ghana as a Peace Corps volunteer as part of the Master's International Program (http://cee.eng.usf.edu/peacecorps/ and Mihelcic et al. 2006) from 2012-2015. The author underwent 3 months of intensive language, cultural, and technical training before integrating into her village for 2 years of service. During her time in Tigla, a village comprised of 16 compounds in the Northern Region, it was evident that shea plays an important role in the daily lives of community members. The author was inspired by other researchers working in shea, and collaborated with a Master's International colleague, Colleen Naughton, conducting shea related research in Mali (for example, see Naughton et al. 2015).

With a background in mechanical engineering and a passion for sustainable development and renewable energy, the author chose to focus her research thesis on studying the human and material energy involved in the production of shea butter. As a health volunteer in the Peace Corps, the author was partnered with a primary school feeding program and focused her time on food security issues and empowering the women of her village through the creation of a shea producer women's group. The author's involvement as an officer of the Peace Corps-Ghana Shea

Committee lead to her attendance at shea conferences supported by the Global Shea Alliance as well as organizing shea quality training for Peace Corps Volunteers and community members. After completing her service in August 2014, she extended as a volunteer for StarShea ltd (http://www.starshea.co/) to continue working with female shea producers and collecting data for this research study. StarShea ltd is a social business that provides a fair trade market to over 10,000 women who created the StarShea network (StarShea 2014). During her final shea season in Ghana with Peace Corps and StarShea, the author of this thesis witnessed the different methods for processing shea butter and developed a deeper understanding of the industry and the women it depends on. The author also witnessed the effects of improved technology for rural shea producers by supporting the community of Tigla to compose a Feed the Futures (FTF) grant for a grinding mill and improved shea kernel roasters with the goal to alleviate community food security issues. While spending time in communities varying in access to electricity, transportation, improved shea processing technology, training, education, and shea market access, the author realized the importance of shea and its role in the livelihood of the communities she worked in. As a result, she dedicated her time to working with the women producing shea nuts and butter.

Shea is not only used as a staple food but also provides women with additional income to subsidize family needs. Extracting the oil from the kernels is a difficult task and consumes copious amounts of time and human energy. Appropriate technological equipment such as improved stoves, roasters, solar dryers and milling machines have been introduced in the past 20 years as a means to reduce difficulties associated with the processing of shea butter and also improve production efficiency (Collins 2014). Researchers have concluded that there exists significant opportunities for in-country mechanical processing of shea kernels (Lovett 2004).

Although many non-government organizations (NGO's) and companies are working to improve access to education and resources for shea producers, most communities in northern Ghana have not had access to educational training or new technologies. As the shea industry continues to expand and investors aim to empower the shea producers, it is important that the needs of these women are fully understood. Shea butter producers have mentioned lack of capital, inadequate equipment, access to water, and high cost of fuel wood and production difficulties due to the use of largely manual production tools as the major constraints of processing activities (Esinam 2010). However, despite the global attention the product has garnered, there remains a lack of understanding about the contextual factors that enable and prevent households, and more specifically their female members, to participate in shea butter processing and sale (Pouliot et al. 2013). Investigating labor expenditures throughout shea processing can identify which steps in the process of producing shea kernals and butter require high human energy inputs. In addition, comparing the firewood used during traditional and improved roasting and milling methods creates an opportunity to quantify the material inputs in order to analyze how they correlate to the expelled human energy of collecting firewood.

CHAPTER 2: BACKGROUND AND LITERATURE REVIEW

2.1 Northern Regions of Ghana

Ghana is a developing country with a low-income economy where over 80% of the population lives in poverty (Less than US$1.25 (GH¢ 4.37), where the national daily minimum wage is ((GH¢ 1.35, US$ 0.29) (Fobil 2002; GSS 2008). The country of Ghana has 8 regions; the 3 northern regions are outlined in see Figure 2. Northern populations experience poverty rates 2-3 times the national average, and chronic food insecurity remains a critical challenge (IFAD 1998a). Food expenditure is the highest average annual household cash expenditure (43.2% of household income).

In fact, poverty is so endemic in the 3 northern regions that it will be difficult to achieve the Millennium Development Goal to halve the proportion of people whose income is less than $1.25 a day in these areas by 2015. This is because poverty in this area continues to remain widespread, with extreme poverty impacting 11.7% of the population in the Northern Region and even 41.8% in the Upper West Region (UNDP 2010). A dry savannah region covers roughly 2/3 of Ghana's northern territory. Unlike the southern parts of the country, where there are 2 growing seasons, the northern plains are drought-prone, vulnerable to climate change and present limited economic opportunities (IFAD 1998a). The Northern Region experiences 1 rainy season typically from May to October; April and May are known as the "hungry season" in the 3 northern regions when the population is at a higher risk for food shortages (Esinam 2010). The

Northern Region also lacks infrastructure and ability to produce the majority of income generating crops that provide food security to the people in South of Ghana.

Figure 2. Ghana, West Africa with the Northern Region outlined (adapted from the U.S. Central Intelligence Agency (2007)).

The author spent over a year in the Savalugu-Nanton district that borders the Northern Regional capital Tamale as a Peace Corps volunteer. After completing her Peace Corps service the author then spent 4 months as a volunteer in Tamale. The Tamale Metropolis is located at the center of the Northern Region of Ghana. The strategic location of Tamale attracts many NGO's, financial organizations, and industrial organizations all of which work to provide various health, agricultural, and educational services to the residents of Tamale and surrounding districts

(Collins 2014). This surrounding area is the homeland of the Dagomba people; in the Northern Region of Ghana the Dagomba people inhabit the northeast Tamale area and have a total population of about 800,000 (Lewis et al. 2014). The area constitutes 7 administrative districts in present day Ghana: (1) Tamale Municipality, (2) Tolon/Kumbungu, (3) Savelugu/Nanton, (4) Yendi, (5) Gushegu/Karaga, (6) Zabzugu/Tatali, and, (7) Saboba/Cheriponi. The district inhabitants are primarily subsistence farmers who depend on rain-fed agriculture during a single season for the production of food crops (Fobil 2002).

Household food insecurity is a seasonal problem in this area of Ghana, occurring annually between February and July (IFAD 1998b) when food and money storages diminish and new crops have yet to grow. Subsistence farmers in these poor rural areas also have limited access to the assets that would facilitate a shift from subsistence farming to modern or commercial agriculture. Some constraints to their livelihoods include lack of infrastructure and insufficient access to equipment – such as agricultural inputs, new technologies, storage facilities, and marketing agricultural products (IFAD1998a). In order to sell goods, items must be transported to a market, this behavior is often repeated many times before the goods are sold. During the dry period were agricultural productivity in the northern regions is at a minimum, women, men, and children migrate to urban areas in search of wage labor to subsidize income during the hungry season.

Shea trees are distributed over almost the entire area of northern Ghana, covering approximately 77,700 square km in Western Dagomba, Southern Mamprusi, Western Gonja, Lawra, Tumu, Wa and Nanumba, with Eastern Gonja having the highest tree densities (Fobil 2002). Shea butter has emerged as a promising economic commodity that has gained international recognition due to the products beneficial properties. Accordingly, there has been increased demand for shea butter in recent years by the food and cosmetic industries locally and internationally (Esinam 2010). It takes approximately 20 years for a shea tree to bear fruit and produce nuts, maturing on average at 45 years. Most trees will continue to produce nuts for up to 200 years after reaching maturity (Reynolds 2010). She trees begin flowering by early November, with collection lasting typically from April to August every year. When the shea fruits ripen, they fall under their own weight and are collected by hand (Fobil 2002). Shea nuts serve as the main source of economic livelihood for the rural women and children who are engaged in shea nut gathering in northern Ghana. The importance of the shea tree in Ghana's economy became even more significant with the need to find substitutes for cocoa in the confectionery and cocoa butter industry in the early 1970s (Fobil 2002). Shea butter is also the main edible oil for the people of northern Ghana, being the most important source of fatty acids and glycerol in their diet (Fobil 2002). Families also consume the fruit that surrounds the nut, which is an important part of the local diet especially during the collection months that coincide with the hungry season (Maranz et al. 2004). However, the most important role played by shea in northern Ghana is the fact that shea nuts picked by farmers are primarily sold to raise funds for the purchase of food (Esinam 2010).

Shea is the primary source of income for Dagomba women and processing shea is deeply rooted in Dagomba tradition and the areas inhabited by the Dagomba people have some of the highest densities of shea trees in Africa. The Dagomba women in Ghana were among the first in West Africa to initiate the mechanization of the butter extraction process; adapting a corn mill to grind roasted shea nuts (Fobil 2002). If a mill is not accessible, the women grind the kernels by hand with stones or travel to mills to avoid this manual labor even if the distance is far (up to 70-km round trip as observed in this study). The processing of shea butter in northern Ghana is still dominated by traditional business, both the production process and management. Currently, personal and business capacities of traditional shea butter processors are not fully developed (Aniah et al. 2014). Furthermore, shea processors in Ghana have the option to considerably improve kernel quality with subsequent benefits to the extraction rates obtained by locally based mechanical processes (Lovett 2004).

In 2014, Shea Network Ghana (SNG), a platform of shea sector businesses, stakeholders, and value chain actors in Ghana (formed in 2010) launched a quality campaign. With support from the Global Shea Alliance (GSA) and Interchurch Organization for Development Cooperation (ICCO), SNG set a goal to train 10,000 female processors on shea nut and butter quality. The toolkits and training materials created by the GSA are now utilized to teach shea processors how to increase the quality of their product as well as reduce labor and fuel usage. For example, substituting the use of open fires through use of energy-efficient technology or sustainably sourced biofuels in the post-harvest processing of shea nuts and extraction of butter has been identified as a priority (Glew et al. 2014). This is important because over 2 billion people use biofuels such as wood, dung, and crop residue as their primary means of cooking and heating. Furthermore, biofuel combustion affects human health and the environment on a wide variety of scales (Roden et al. 2008).

Throughout poor, rural areas of sub-Saharan Africa, biomass is the dominant fuel, and cooking is usually performed using a simple 3-stone fire or "open fire" (Mihelcic et al. 2009; Adkins et al. 2010). During shea butter processing open fires are used to boil shea nuts, roast shea kernels, and boil the resulting fat. Thus, the amount of firewood used to extract shea butter can be potentially reduced through the use of improved stoves and roasters. Available data also indicate that Ghana's forests are rapidly disappearing. Between 1990 and 2010, Ghana underwent an average loss of 125,400 ha (1.96%) per year of forest cover, with the highest percent (2.24%) occurring between 2005 and 2010. However, over the 20-year period (1990–2010) only 530,000 ha were reforested (UNDP 2010). Furthermore, the Northern Region offers a great perspective for clean cook stove adoption due to the relatively large upper and middle income rural populations, and the density of biomass suggests that there is less wood available for collection in this region. This creates a higher incentive to adopt more efficient cooking technologies, promoting the use of alternative fuels (Pascaud 2014), and develop methods to process shea that use fewer biomass resources.

2.2 Gender Roles and Shea Butter Processing in Ghana

In Ghana, women are underrepresented in wage employment and political decision making which undermines the effort of achieving gender equality and women's empowerment (UNDP 2010). Women's time burden in Ghana is estimated to be about 20-25% greater than that of men (IFAD 1998c). Rural women also supply 80% of the labor force for cultivating, harvesting, storing, processing, and marketing of staple crops. In addition women are expected to provide the vegetables and additional staple food ingredients, collect fuel wood (often with children's help), engage in income-generating activities during the dry season, and assume responsibility for household and childcare tasks (IFAD 1998c). Furthermore, in the Northern Region the populations are extremely poor and women are particularly afflicted because they are responsible for provision of the domestic protein supply (Fobil 2002).

Women's access to wage employment in non-agricultural sectors has also remained weak, undermining the country's quest to promote gender equality and women's empowerment (UNDP 2010). Women in rural Ghana have been found to cope with their heavy workload and overwhelming obligations in various ways, including: engaging in less productive economic activities, changing to less labor intensive crop cultivation, reducing social and public participation, and requiring their children to assist them with tasks that often diminish school attendance (IFAD 1998c). In countries where shea butter is produced, it is an economic activity of great importance that many women depend on for their livelihoods (Collins 2014). Currently, it is rare for men to participate in shea nut gathering as it is regarded as the job of women and children. NGOs that engage in the shea industry, for instance, emphasize the potential of the industry to reduce poverty levels, particularly among women (Esinam 2010). Shea butter production in Ghana thus has the potential of increasing employment availability to the economically vulnerable population, especially women.

The shea butter business is mostly a hereditary business and the motivation of female processors is not only about income but a way of life in northern Ghana. Women must also preserve the social and cultural values of shea butter (e.g. traditional uses, gathering of women, preservation of knowledge, skills training, community and family bonding) (Aniah et al. 2014). The majority of shea butter is still made traditionally by women who learned the methods from their elders. Participation in this traditional activity provides women a chance to engage with other women, thus fostering solidarity and expanded social networks among female participants (Collins 2014).

As previously mentioned, collecting shea coincides with the hungry season in northern Ghana and, therefore, shea kernel processors sell their commodity immediately to purchase much needed food (Esinam 2010). These collectors thus lose out on higher earnings that could come from processing the collected nuts into shea butter, particularly later in the year, when prices for shea nuts and butter escalate. In this area of Ghana, the remaining non-agricultural income of women usually comes from processing and selling small quantities of crops, petty trading, and handicrafts. In recent years, more women are also entering seasonal or long-term migration to earn income from wage labor in the southern regions (IFAD 1998c). This phenomenon has been attributed to the growth of high-risk populations living in poor conditions in urban areas of Ghana. Overall, women process and sell their agricultural produce to intermediaries at low prices in order to raise money to pay for food and basic necessities. These intermediaries pay for the transport and storage of the product and sell it at higher prices later in the year. It is estimated that some intermediaries make profit margins up to 300-500% (SNV 2010).

As the market for shea expands it thus becomes important to increase the capacity of women as shea butter processors so they can produce innovative and value-added shea products. Increased capacity should enable them to expand the scale of their business enterprises (Aniah et al. 2014). The domestic responsibilities of females are often very time-consuming because of the need to travel to water sources, fields, stores, schools, and health centers, and the lack of energy-saving technology that is available to them (IFAD 1998c). In conclusion, women in the shea industry play an important role by providing for their family's basic needs. As women in the shea industry grow more powerful economically and socially the benefits will transfer directly to their families and aid in poverty eradication.

2.3 Processing Shea Butter

Figure 3 shows the basic steps followed during the processing of shea butter. The shea butter processing procedure is considered very tedious and time consuming (Fobil 2002). The processing of shea starts with par-boiling, which occurs soon after collecting the ripened wild fruits from fields. The process of producing shea butter from the kernel may rely on a manual system, or it may be partly mechanized with diesel or electric mills, crushers, or kneaders (Addaquay 2004).

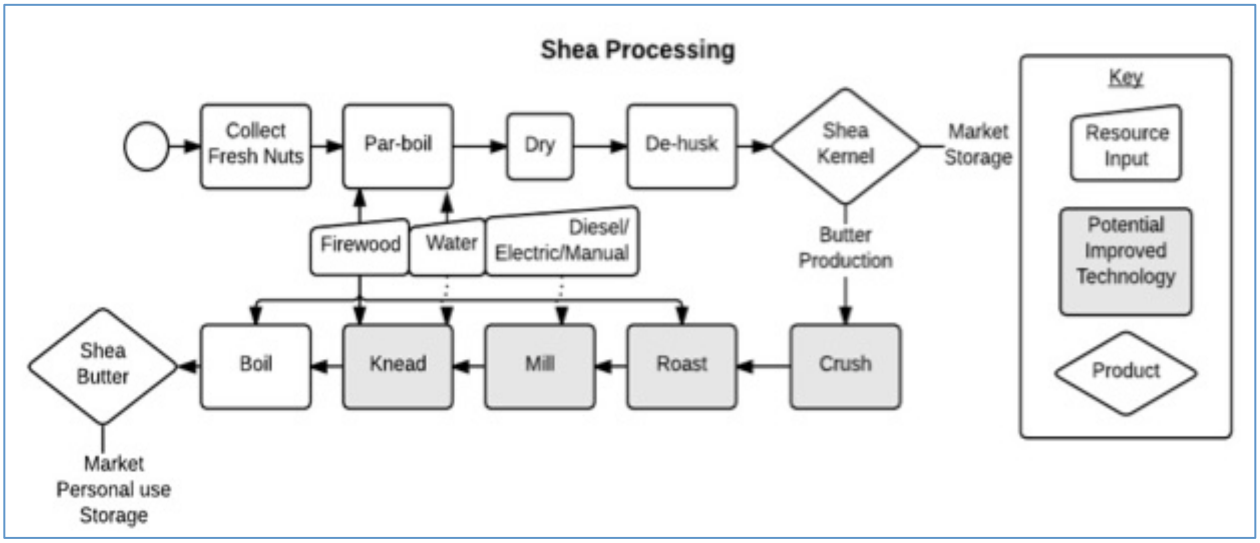

Figure 3. Basic shea processing activities showing resource inputs and potential improved technology in area of study (adapted from Addaquay 2004).

Shea nut production is referred to as an "opportunistic business" because there are no ownership rights over the trees and gathering is equally open to all (Fobil 2002). The women collect the fallen nuts in the morning and sometimes collect more than once a day in the study area. The green shea fruit is eaten by families throughout the season. Excess fruit that is spoiled or not eaten is removed and the nuts are then par-boiled (see Figure 3). Par-boiling is done to stop germination. The boiling also deactivates kernel lipases, which are responsible for the free fatty acid content, FFA levels and this process may denature a proportion of the unwanted components (e.g. latexes and waxes) that can be found in the unheated kernel. The boiling ensures high oil content in the kernels and improves the taste of the extracted oil. This step is important and must be done properly to create marketable shea butter (Fobil 2002). The nuts are then spread out to dry under the sun. After the nuts have dried, the women use wooden mallets to crack the shell exposing the shea kernel (referred to as dehusking in Figure 3). The kernels are removed from the shell and left in the sun to continue drying. As shown in Figure 3, these kernels can now be stored for later use or sold in the market. In the process of making butter the next step is to crush the nuts into small pieces. Women use a mallet or rock to pound the kernels individually when a crushing machine is not available. The crushed kernels are then ready to be roasted. In Ghana, traditional roasting is a common practice and most women do not have access to an improved roaster. When improved roasters are not accessible producers utilize the same cauldron and 3-stone fire used during the par-boiling process. The kernels are manually stirred with a stick in an effort to keep them from burning. The improved roaster is cylindrical container used to rotate crushed shea kernels (see Figure 4). SNV (2013) describes the roasters used by producers in a study as 97 liter containers that are mounted on steel boxes and manufactured by local welders. During the author's field study it was observed that the roaster had an average capacity of 45 kg of crushed kernels. The metal box holding the roaster over the fire is closed on 3 sides and open on the top, bottom, and front. Firewood is fed through the front of the roaster to combust and heat the cylinder as it is manually spun over the flame. The enclosed fire helps to protect the human processor from exposure to excessive heat. Additionally, heat is evenly distributed as the equipment is rolled continuously which prevents burning the crushed nuts (Esinam 2010). The purpose of the roasting process is to concentrate the oil in the kernel. The roasting process must be controlled in such a way as to prevent charring of the kernel, a condition that reduces the fat content (Fobil 2002). After the kernels have been roasted they are ground into a paste. The traditional method using stones requires women to hand mill the kernels into a paste. Grinding is a common practice of food processing in Ghana and is also employed in shea butter manufacturing. Staple foods in the Northern Region that depend on grinding include a corn porridge often ate in the morning and a fermented corn dough also made from corn flour and eaten with stew throughout the day. To prepare these dishes, families harvest corn and use a grinding mill (Figure 4) to produce the starchy staple ingredients for their meals.

Improved (spinning roaster)

Grinding mill

Figure 4. Photos of improved "spinning" roaster (top) and photos of mill used typically for grinding corn for staple foods grinding shea kernels into paste after being roasted (bottom). Taken by the author during field study (August 2014).

Mills are typically privately owned and require a fee to use. Women who live in communities without access to a mill must walk carrying the load on their heads or travel by motorcycle taxi and pay the mill operator to grind their food. It is similar for the grinding of shea kernels due to the observation that women prefer to travel to a mill than to partake in the traditional hand milling method. Although mills are accessible due to the need for milling corn, many mill operators refuse to mill shea because of the residue it leaves, and increased maintenance it can require. Many women must thus travel 5-70 km round-trip as observed during the field study to mill their shea kernels even if their community has a functioning mill.[2] The paste that results from milling is then mixed by the forearm of a women sitting next to a basin of shea paste and water. The woman uses her hand to create an emulsification of shea paste and

[2]A large metal basin commonly used throughout the Northern region holds approximately 30 kg of shea nuts and costs GH¢ 5.00 to mill. According the Ghana Statistical Service 2008 living standards survey, workers in the agriculture industry on average receive GH¢ 3.30 for an 8-hour work day (USD$ 1.00= GH¢ 3.64).

water (a processing step referred to as kneading in Figure 3). Gradually as more water is added, the women begin to "whip" the mixture more rapidly with both their hands, which aerates the mixture. During this process, the fat can be detected as the mixture turns from a deep brown paste to a grey foamy consistency. After extensive whipping and the women's intrinsic knowledge that the fat has been separated, cold water is then added as the mixture is stirred slowly to bring the fat to the surface of the mixture. The fat is then removed from the top of the basin in handfuls to be boiled. The water boils out, lifting impurities to the top of the pot. A spoon or calabash is used to remove impurities as the mixture boils. When the women see that the oil is pure and free of water, they transfer the oil to a clean container slowly to ensure any remaining impurities stay settled at the bottom of the cooking pot. A cloth is sometime used by women when transferring the oil to filter out any fine impurities. As the butter cools, it solidifies and can be stored for personal use or packaged into standard local sizes (individual hand formed balls or large bowls) to be sold in the community or at market.

2.4 Requirements for Improved Shea Butter Production

Improved shea butter processing requires the use of inputs in the form of mechanized technology such as grinding mill, oil filters, and special storage bins. These inputs are costly and in most cases exceed the budget of most individual producers, as they do not have adequate capital to purchase this equipment (Collins 2014). This shortage of working capital is another constraint that makes it difficult for women to buy and store raw materials, as well as invest in labor saving technology. Women primarily rely on informal sources such as family, friends and traditional moneylenders. These sources can have high interest rates, or they may not always have the funds available for making loans (IFAD1998a). As a result, women producers are not realizing the full benefits of participating in the shea sector and they are compelled to sell off their produce to intermediaries at low prices during the harvest season. A solution to assist women to obtain greater value from their labor is to stockpile their produce until market prices rise (SNV 2012). In fact, Mohammed (2013) found that full adopters of improved technologies registered a maximum income of GH¢ 160 (USD$48 US dollars) before adoption and GH¢ 360 (USD$108) after adoption of the technology. The mean income rose from GH¢ 23 (USD$7) to GH¢ 145 (USD$44) after adoption.

Access to an improved technology can be difficult for individuals. Forming women's groups and cooperatives in communities can help to alleviate individual economic hardships. Groups of woman are easier to train and can enforce quality standards among members. SNV (2006) defines a cooperative as an autonomous association of persons united voluntarily to meet their common economic, social and cultural needs and aspirations through a jointly owned enterprise that is democratic and accountable to its members. In many francophone countries in West Africa, most producers have formed women's groups; however, the Ghanaian and Nigerian women are not as well organized (GSA 2012). Accordingly, for effective implementation of improved processing practices, NGOs and organizations in Ghana can assist in formation of shea producer women's groups and cooperatives. Cooperatives provide services to its members which otherwise could not be afforded by individual producers. Some of the cooperatives in the study area now arrange for the purchase of fertilizers, tractor services, and other farming necessities for their members. They also negotiate and sell shea kernels and butter in bulk to buyers (SNV 2012). Organizations have been striving to assist cooperatives with market linkages and improved technologies. Village savings and loan associations (VSLA) (also known as "SuSu" by the Dagomba people of Ghana) are a way for women's groups and cooperatives to save money, access loans, and combine income for a social fund. By accessing loans women can alleviate the pressure to sell shea nuts and butter early in the season for little net gain. Individual profits can be invested as a group and in turn invested in shared equipment and facilities for butter producers. As the demand for shea butter grows, investors are interested in sustainable relationships with shea butter producers. Supporting women's groups with education, improved technologies, equipment, and quality training has been a growing trend among members of the shea industry. To ensure sustainability in these investments, the numerous women's shea butter processing cooperatives should also be encouraged to become client suppliers as well as shareholders in any equipment NGO's, buyers, or organizations provide. This will empower and strengthen the women's groups, enhance their commitment to the project, as well as enrich the rural poor (Addaquay 2004).

It has been found that the improved method of shea butter processing has played an important role in the investment abilities of women shea butter processors. Women invest their incomes into their children's education, their shea business or other new businesses ventures (e.g. food sales, convenience stop, textiles, soap making), health care, and household assets (e.g. storage facilities, furniture, clothing, hygiene products, and electronics) (Mohammed 2013). Furthermore, the reality of women's workloads and multiple, often overlapping responsibilities, need to be considered by development projects in order to prevent the creation of unnecessary stress for women and undesired impacts on them and their families (IFAD1998c). Access to improved technology is important for producers that want to make consistent high quality shea products that can be sold for a higher price while using less time and energy.

2.5 Processing Quality Shea Butter

The demand for shea, especially in the international market, continues to increase. However, in order for Ghana to take advantage of this economic opportunity, the industry needs to develop to produce shea that meets required quality standards (Esinam 2010). The quality of shea nuts and butter begins with the collecting of the shea fruit. For example, women should not collect fruits that have already germinated as this will reduce the extraction rate, increase peroxide levels, and introduce a bitter taste to the butter. Additionally, the producer's handling, drying, storage, and extraction practices affect the quality of the final product. Finally, the equipment used and methods employed also determine the quality of the final shea butter. Currently, the quality improvement in shea nuts and butter in Ghana is from continuous training and supervision of butter producers as well as training support from NGO's according to the buyers' demands (Esinam 2010). However, the shea industry is subject to structural issues that can impact quality– reliable electric power, transport, and access to financing. The path to development for shea thus lies in the investment of processing equipment (e.g. grinding mill, mechanized crushers, mechanized kneading, improved cook stoves), skills training, and most important, organizational restructuring of the supply chain (Reynolds 2010).

Three main quality issues are reported to influence shea production (Lovett 2004): (1) the origin of the kernel (i.e. genetic/environmental influences on the oil profile, unsaponifiables[3] content, etc.); (2) the quality of kernels that can be produced by traditional methods (demand for low FFA, low fungal infestation, etc.); and (3) the ability to maintain consistent and high-quality production of shea butter using best practice methods for extraction, storage, and packaging. Shea is very much a self-contained industry, which has potential to expand quickly (Reynolds 2010) by aiming to reduce inputs (i.e., labor, water, firewood) and creating consistent quality through the use of machines such as crushers, roasters, mills, and kneaders. Attempts to improve

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[3] Unsaponifiable constituents are important when selecting oil mixtures for soap production. Unsaponifiables may have beneficial moisturizing and conditioning properties. When the proportion of unsaponifiables is too high and does not provide beneficial properties inferior soap can result.

supply chains through the formation of cooperatives, market linkages, and in-country processing groups have also been made. However, a main problem for women who are unable to supply the required consistent quality is the loss of higher market prices (Chaflin 2005). The comparison of market prices for shea products in this study is difficult to represent due to the economic crisis of 2014 in Ghana where growth fell 4.2% as commodity prices fell and the currency depreciated. Thus, market prices during this study can not be easily compared to past and future market prices due to varying economic fluctuation during the time of the study. A quality-working group was created in 2012 by the GSA to define specifications for quality for shea nuts and butter. The proposal (GSA 2012) establishes shea nut quality grading parameters for moisture content, FFA, impurities, oil content, as well as heavy metal and pesticide residuals. In order to achieve these parameters, the GSA provides proper practices in shea nut processing and trade to produce the highest quality shea kernels and handcrafted shea butter. The methods for each step during village level collection and processing are described step by step in trainings. Resources such as posters (Example can be seen in Appendix A) have been produced to show crucial steps to manufacture the highest quality shea kernels and butter. Furthermore, the GSA has created guidelines for testing the different grades of shea butter. However, moisture content is the only parameter that can be obtained in the field by inserting the moisture meter into a bag of shea kernels. Moisture meters are used by buyers like StarShea to ensure that the kernels meet standards before purchasing from the producers. Unlike the moisture content, FFA and oil content must be tested in a laboratory and only training of practices to meet the FFA and oil content standards are implemented in the field. To achieve these quality standards, shea producers must follow detailed guidelines while processing kernels and butter and use simple visual (color, germination, texture, impurities) or manual (squeezing nuts to evaluate quality and moisture content) tests. Although most shea producers do not have access to a laboratory, they can ensure that buyers are receiving high-grade kernels and butter by following the GSA's training. The buyers can then conduct laboratory tests to confirm the quality and pay a premium to producers providing high-grade kernels and butter. This creates an incentive to producers to follow quality training and engage in improved practices. It should be noted that many producers may already implement improved processes due to the traditional knowledge passed down from generations of producers to create visually appealing and good tasting butter.

GSA has created an illustrated version of quality standards to be used as a training tool (see Appendix A). They are also working to identify trainers in countries as well as major tasks that need to be performed during the implementation of quality standards training to achieve the goal of improving the quality of shea butter and kernels purchased by traders and buyers leading to increased profit for the women (GSA 2012). An example of the importance of quality and implementation of improved technology can be seen in a case study of the social enterprise, SeKaf Ghana Ltd. SeKaf's shea butter processing facility is located 6 km away from Tamale in Kasalgu which is a central point for women from surrounding villages to socialize while processing shea. Nuts are sourced from over 2,500 women, who have received quality training on kernel processing and storage, for the processing center. These women receive a fair trade price for the kernels they process and a premium for their organic kernels. The butter is then extracted from the kernels by the SeKaf Cooperative Women's Group (SCWG). The trained women of SCWG work together in a clean environment to produce quality butter that can be sold for a higher price on the fair trade market. The SCWG are provided not only with access to improved roasters, electric milling, electric crushing, processing equipment, water, and firewood, but also health care access, training in packaging, access to loans, drying platforms, and warehousing. Using these facilities and improved processing methods that shea butter groups in villages find difficult to access, the women are able to process quality shea butter to sell back to SeKaf. The SeKaf processing center also referred to as the shea butter village is used as a resource for teaching the best practices for processing shea butter. SeKaf is active in the GSA quality-working group and provides consultancies for quality improvement as they strive to implement sustainable solutions for shea processing.

Studies and other research commissioned with United States Agency for International Development Program (USAID) funding (USAID 2014) and assistance from West African Trade Hub (WATH), as well as the ICCO, demonstrate that the major issues of consistent quality and quantity keep emerging in the shea marketing. From subsequent discussions with the private sector, including buyers and sellers of shea butter products, clear demands (i.e., moisture content, oil content, FFA levels) are present (Lovett 2004). The western markets of the United States (US) and European Union (EU) call for quality assurance (QA) and product traceability (Chaflin 2005). Ghana is currently the largest exporter of raw shea products (Addaquay 2004) and although quality shea products are time and labor intensive to produce, the growth and demand from food and cosmetic industries create a profitable market for women with access to shea.

2.6 Material Energy

Though often identified as a natural product, shea butter consumes a lot of material energy, mostly in the form of firewood. In Ghana, much of the fuel used for shea processing is obtained by individual gathering of wood for consumption and not sold. According to Glew et al. (2014), post-harvest processing and extraction of shea butter in Ghana causes over 75% of the entire CO_2 supply chain emissions associated with shea butter manufacturing. Moreover, emissions from burning wood to heat water to par-boil the nuts or during butter extraction are responsible for almost all of these emissions (Glew et al. 2014). The use of fuel wood by shea butter processors also contributes to the degradation of forest resources that are depleting at an alarming rate (UNDP 2010) that was discussed previously. Forest resources largely serve as a carbon sink and fuel source for the population in the Northern Region of Ghana (Jibreel 2013). Thus, improving upon open fire use in the processing of shea through use of a more energy-efficient technology or sustainably sourced biofuels in the post-harvest processing of shea nuts and extraction of butter is an important priority (Glew et al. 2014).

However, adequate statistics on fuel use during shea kernel and butter processing have not been kept. Research in this area thus requires information on 2 topics: (1) the consumption of biofuels, and (2) the emission of waste constituents per unit quantity of burned fuel (e.g., emissions factors) (Ludwig et al. 2003). The assessment of CO_2 emissions arising from products (goods and services) is also emerging with the use of LCA with an increasing desire from retailers and other supply chain organizations to better understand the environmental impact of products (Sinden 2009). International organizations such as the British Standard Institution (BSI) and International Organization for Standardization (ISO) have developed standards with the purpose of providing the analyst with a simplified methodology for assessing environmental impact of products and processes (Ojeda 2010). PAS 2050 builds on the LCA guidance and requirements articulated in ISO 14040 (2006) and ISO 14044 (2006), adopting a life cycle approach to emissions assessment and the functional unit (PAS 2050 2008) as the basis of any reporting. In addition, PAS 2050 brings together key principles from these documents with other relevant methods and approaches in the field of carbon foot printing, including ISO 14064 (2006), IPCC publications (IPCC 2006) and the GHG Protocol (WRI/WBCSD 2004; (Sinden 2009)). Comparisons across product carbon footprints, or the same product over time, can only be achieved by using consistent data sources, boundary conditions, and other assumptions across products and having the footprint results independently verified (BSI 2008).

According to Sinden (2009), significant clarification and simplification of the existing LCA requirements and guidance was undertaken in developing the PAS 2050 specifications which makes them practical to implement, comparable, and able to assist organizations in understanding the life cycle GHG emissions associated with their products. There are also wide ranges of potential uses for information on the carbon footprint of products (Sinden 2009). Stationary combustion is usually responsible for about 70% of the greenhouse gas emission from the energy sector (IPCC 2006). Considerable cost savings can thus be achieved by decreasing energy use and waste. These should be compared to the investment required and any potential increases to operating costs as a result of emission/cost reduction strategies (BSI 2008). Glew et al. (2014) follows IPCC guidelines for evaluating CO_2 emissions from shea processing. The study calculated the CO_2 emitted per kg shea butter in cosmetics by using the activity data $\left(\frac{Kg\ CO_2}{Kg\ Shea\ Butter}\right)$ produced during each step in the manufacturing process. With this standardization per kg of shea butter, resulting in a fictional unit, results of studies not investigating the entire life cycle can still be compared at each activity of the shea butter process. Ojeda (2010) follows IPCC (2006) guidelines for estimation of national inventories of GHG emissions and determined the activity data $\left(\frac{Kg\ Firewood}{Kg\ Shea\ Butter}\right)$ during each step of the shea butter manufacturing process (Figure 3) in 3 villages located near Tamale in the Northern Region of Ghana that utilize improved roasters and have access to grinding mills. Using the default IPCC (2006) net caloric value (NCV) for firewood and an assumed oxidation rate for the carbon found in the firewood of 100%, the CO_2 emitted during each manufacturing process was evaluated by Ojeda (2010). Glew et al. (2014) utilized these findings and followed PAS 2050 standards to evaluate the GHG emissions produced throughout the life cycle of the shea butter cosmetic supply chain. However, Glew et al. (2014) discusses in their results that there are many problems with making simple comparisons between LCA since different allocation methods, system boundaries and functional units mean that miss interpretations can easily be made.

It is difficult for LCA to provide quantitative assessments and comparison of generalized agro-energy chains, even when aiming at assessing the GHG emissions (or CO_2 equivalent emissions) alone. The goal of obtaining precise quantitative assessments of bioenergy chains through the application of the LCA methodology seems a very ambitious target (Chiaramonte et al. 2010). Although an LCA was completed and it was concluded that the LCA of shea could not be directly compared to that of other vegetable oils, Glew et al. (2014) study is useful as a guide to understanding the scale of emissions of alternative products throughout the processing stages, and it directs the attention of investment in CO_2 emissions savings towards the reduction of traditional wood burning in the manufacturing process of shea butter's supply chain. Glew et al. (2014) recommends further field trials to investigate the efficiencies of stove technologies currently in use, assess any potential efficiency improvements that could be made and to design new prototypes for testing during shea kernel or butter processing. Glew et al. (2014) confirmed that when improved stoves and mechanical extraction are introduced to reduce the consumption of wood, shea butter's carbon footprint is also reduced. By establishing a standard method for assessing GHG emissions within the shea butter process and then transferring this information through the supply chain, the provision of shea butter specific data to a common assessment method is supported in a manner that seeks to minimize overall costs of implementation (Sinden 2009). The main material inputs required to produce shea butter are firewood and water, both, which are becoming increasingly harder to source. To understand the material inputs of the shea butter process the material energy consumed at each step of the shea butter processing methods needs to be assessed by how much energy, resources, and time are required. Traditional and improved technologies can be assessed by the energy and resources expended resulting in which technologies have the greatest positive impact on the environment.

2.7 Human Energy

In addition to material energy, shea butter manufacturing is very labor intensive and requires a great deal of human energy for both the traditional and improved processes. Women in northern Ghana make shea butter utilizing labor-intensive traditional methods that are handed down from mother to child over several generations (Aniah et al. 2014). Shea butter processing is a tedious and energy consuming task, and requires sound financial input in order to achieve maximum results (Collins 2014). To improve traditional shea processing methods, interventions such as improved roasters, mechanized crushing and milling, and improved cook stoves have been implemented by shea producers. However, as mentioned previously in this thesis, most shea producers do not have access to these improved technologies.

Human energy is the caloric expenditure of a person during an activity requiring energy. The traditional process of shea butter production requires excessive amounts of human energy and produces poor quality of butter at low profit margins. New appropriate technologies are now available to mechanize various traditional operations. For example, the time and energy of producers can be reduced with access to a kernel-crushing machine. In Ghana, most of the semi-mechanized equipment used by the women either belongs to another individual and wealthier women who require payment of GH¢ 0.50/bag (USD$0.15) of nuts to mill or other equipment is provided as grant by NGO's (Esinam 2010). Other factors such as family size influences the capacity of women in processing shea butter through the availability of family labor (Aniah et al.

2014). In addition to the energy that goes into an intervention, there is also an element of human energy required to install, use, and maintain the intervention (Held et al. 2013). Traditional processing requires higher inputs of human energy, time, and valuable resources such as water and firewood. It can be assumed that increased use of firewood during traditional processing requires more human energy to collect the firewood used. To visualize human energy expelled during the shea butter process, the basic inputs throughout production and their relationship can be seen in Figure 5. Material energy inputs of firewood are also a function of the time and labor exhausted by shea producers and must also be evaluated when looking into labor saving technology interventions for shea producers in developing areas.

Figure 5. The traditional processing activities required inputs of labor, time, firewood, and water.

The shea butter manufacturing process steps can be improved through interventions of improved technology. Held et al. (2013) explains that human energy calculations he used in Mali to determine the human energy embodied in eight community water supply and household treatment methods were based on information published on human energy requirements by the

Food and Agriculture Organization (FAO). The amount of energy required for an activity can be quantified by the time and frequency of the activity, the physical activity ratio (PAR) often referred to as "energy cost", and the individual's basal metabolic rate, which is determined by sex, age and weight (FAO 2001). Each individual intervention can be quantified using Held's et al. (2013) methods and the PAR and BMR data provided by the FAO (2001) to find the amount of human energy saved.

Jibreel et al. (2013) states that the semi-mechanized method of shea processing is the most effective, and requires less use of resources than the traditional practices as discussed earlier, although the mechanize system or method is the best but the cost and higher technology involvement makes acquisition difficult for the processors. When investing in improved technologies it is important for producers, investors, companies, and organizations to understand which investments will have the highest human energy savings at the lowest cost.

Technology required to increase the quality of kernel have been identified, while at the same time reducing the inputs of production (e.g. harvesting with donkey carts as opposed to carrying, means to collect quality water instead of metal-rich surface run-off water, and solar tunnel dryers in place of unprotected sun-drying during the rainy season) (Lovett 2004). Improved manufacturing interventions such as access to improved roasters, crushing machines, and grinding mills can be evaluated by quantifying the human energy savings. To better compare the priority of different improved technologies an economic analysis incorporating the human energy expenditure should be investigated. Different inputs such as time, firewood, and water throughout the shea butter process have been evaluated in previous studies. Table 1 summarizes different studies that have evaluated the amount of time, firewood, and water used to produce a kg of shea butter. For example, in 2013,The Netherlands Development Organization (SNV)

Ghana followed the shea process as a women's processing center with access to improved manufacturing methods such as improved roasters and access to mechanized crushing and milling. They evaluated the amount of time, firewood, and water used in each step. When accounting for the time to produce shea butter, acquiring resources must be accounted for. The more firewood and water expended during production results in more time and energy required by the producer. The amount of resources required during a process is important in understanding the entire amount of resources consumed that initially require human energy to obtain.

Table 1. Comparison of Study's Evaluating Time, Firewood, and Water to Produce 1 kg of Shea Butter.

Study	Time (hours) to produce 1 kg shea butter	Firewood (kg) to produce 1 kg shea butter	Water (L)/1 kg shea butter	Comments
SNV 2013	2.9	1.7	12	1 data set taken over 4 days with processing group in Ghana. Does not include firewood to par-boil nuts.
Hall 1996	20-30	8.5-10		Methods to estimate this time are not available.
Addaquay et al. 2004		7.9	11	Assuming manual traditional processing.
Esinam 2010	0.56-1.8			Based on focus group discussion with shea butter processors. Author assuming 8 hours of time per production day.
Jibreel et al. 2013	0.41-0.98	2.9-3.3	6.9-9.1	Based on 2011 field study data of both traditional and semi-mechanized do not account for wood used to par-boil.

Table 1 indicates significant variations across these studies. Each study made different assumptions and varying processing methods for shea butter processing were observed. In order to compare the results of these studies, each processing step and intervention need to be compared directly. Jibreel et al. (2013) conducted a study that compared traditional processing time and inputs to the semi-mechanized manufacturing process. The results of that study can be seen in and are compared to assumptions made in earlier literature. Table 2 also displays the results of different studies at each processing step (improved and traditional) that data was collected. The results of each study have been converted to $\frac{Minutes}{Kg\ Shea\ Butter}$ in order for comparison.

Table 2. Comparison of Data from Multiple Studies at Each Step of the Production of Shea Butter in Terms of Human Time (Minutes) Required to Produce One kg of Shea Butter. Adapted from Jibreel et al. (2013), SNV (2013), and StarShea ltd (2012).

	Processing Steps	*StarShea ltd (2012)*	*Jibreel et al. (2013)*	*SNV (2013)*
[1]	**Collecting nuts**	61.5	-	-
[2]	**Par-boiling**	20.8	-	-
[3]	**Sorting**	30.8	-	4.7
[4]	**Drying**	15.4	-	5.4
[5]	**Dehusking**	29.2	-	-
[6]	**Traditional crushing**	-	7.3	-
[7]	**Improved crushing**	-	0.2	.78
[8]	**Traditional Roasting**	-	6.1	-
[9]	**Improved Roasting**	-	3.6	6.4
[10]	**Milling**	-	3.0	1.4
[11]	**Kneading**	-	25.5	28.6
[12]	**Boiling**	-	13.3	4.8

A human energy analysis can be used to compare the time expenditure results in terms of caloric expenditure to identify which steps of the shea butter process expend the most time and energy of the shea producer. Because the shea season coincides with the rainy season when agricultural production is of the most importance as well as labor intensive, a woman's time and energy is of great importance to food security. During these critical months in the northern regions of Ghana, time and energy are invaluable to women working in the agriculture and shea industry. To compare the different manufacturing processes each individual step of the traditional and improved methods can be looked at as a function of time and energy expended. The total time to process butter can be correlated to the price received for the butter produced. Thus each processing step's time and energy requirements can be seen as economic losses, and time and energy savings can be seen as economic gains. Collins (2014) found while surveying shea producers in Tamale, that the high cost of inputs such as equipment, mill fees, time, water, and firewood are costly and take time and energy to obtain. Other challenges identified included lack of local market (women must travel by foot or motorcycle taxi for market and mill access), inadequate water and resources such as firewood and water, which require time and energy to obtain, as well as the tedious nature of processing. It can be concluded that the additional labor required to collect these resources expends more time and energy than required during the shea butter process.

To reduce the human energy required by shea producers programs will need to take women's multiple responsibilities and time constraints into account (IFAD 1998a). Looking at each intervention to improve the shea butter process, it is important to understand which intervention will have the most time and energy savings for the women producers.

Previous studies have evaluated the time expenditure for shea butter production (Tables 1 and 2). The labor required during the process can be evaluated by completion of a human energy analysis following Held's et al. (2013) methods. There are many variables when evaluating the shea butter process. Firewood and water inputs also play a part in the time and labor required by the shea producer per kg of butter produced (see diagram in Figure 5). The SNV (2013) study accounted for only the cost of purchasing resources and not the energy required by the producer, which is a more common occurrence, as most producers are individuals producing from their homes. Telmo (2002) completed a study in Mali that collected data on the distance to water sources for community members. Forty-six data sets were taken to conclude that the average distance to a water source was 44 meters, the closest being 3 meters and the furthest being 260 meters. Jibreel et al. (2013) evaluated the time to collect water and firewood (not including par-boiling). The majority of shea producers, as discussed earlier, are not a part of a cooperative or women's group and produce shea butter from their households. These producers process their own kernels before processing butter as well as expend time and energy to provide firewood and water instead of purchasing resources.

Figure 3 displaying the processing steps to extract shea butter (presented previously in Section 2.3) displays which processing steps require additional $\frac{Minutes}{Kg\ Shea\ Butter}$ due to firewood and water collection required in the traditional process. Thus, the total energy (human and material) for each manufacturing step of the improved and traditional process should be evaluated to fully understand the effect of an intervention. Mohammed (2013) explains that the adoption rate of new labor-saving technologies are low in northern Ghana. Al Hassan (2011) estimated that about 35% of women use the modern method of processing shea butter while the reaming 65% still rely on the traditional method in Ghana's Northern Region. As the shea industry grows and investors as well as organizations aim to improve livelihoods of shea producers through different interventions, it is important to understand what affect the intervention will have in regards to time and energy savings for the shea producer. The intervention should also be evaluated by the economic benefits it provides the recipients. By assessing energy inputs from the producers as well as the environment during traditional and improved roasting and milling methods of shea butter production; culturally, economically, and socially appropriate recommendations for manufacturing methods of the shea butter process in northern Ghana can be determined. The poor not only benefit from growth in their nominal income, but also from technologies that make the goods they consume less expensive in the marketplace, thus increasing their purchasing power (Angelsen et al. 2003). In Ghana, shea is an economic natural resource that could be adequately developed to become a vessel for substantial poverty reduction and socio-economic improvement, particularly in northern Ghana (Esinam 2010). Improved technologies can be chosen appropriately to help producers become more competitive. By viewing each step of the shea butter process in terms of human and material energy, the effect of improved technologies on the processors as well as the environment can be identified.

CHAPTER 3: METHODOLOGY

3.1 Study Location

Data collection was completed in the communities of Dipale and Tigla, as well as the SeKaf shea butter processing center from May 2014 to November 2014. Tigla and Dipale are located approximately 1 hour north of the regional capital, Tamale, as well as near the main road known as the Bolgatanga road (see Figure 2 in Section 2.1). To meet research objectives, data was collected on material and human energy throughout 3 different shea processing methods. Surveys were conducted regarding the improved and traditional roasting methods. The carbon emissions are quantified as CO_2 emissions per kg of shea butter and material energy is quantified as MJ expended per kg shea butter. All research methods described received Institutional Review Board (IRB) approval from the University of South Florida under IRB# Pro00013497 beginning July 29th, 2013 where Emily Adams is the secondary study coordinator under the primary study coordinator, Colleen Naughton. The IRB underwent continual review and was approved on July 2nd, 2014 IRB# CR1_Pr00013497. See Appendix B for all IRB documentation for this study.

The shea producers in Tigla and Dipale follow similar processing methods that use open fires to par-boil fresh nuts, roast kernels, and boil butter. There are organized women's groups in Tigla and Dipale that have undergone Global Shea Alliance quality training in nut and butter processing. Dipale shea producers underwent training in 2012 by StarShea ltd field workers and subsequently began selling some of their products to StarShea ltd. Tigla shea producers underwent training in 2014 and also began selling their shea products to StarShea ltd. The shea producers of Tigla have access to 3 improved roasters that are shared between 16 households. The producers of Dipale do not have improved roasters and practice traditional roasting methods. Tigla does not have access to electricity and Dipale acquired grid access during fall of 2014. Data sets were collected in both communities. Table 3 summarizes the similarities and differences between the shea processing methods and variations in Tigla, Dipale, and the SeKaf shea processing village.

Table 3. Methods of Shea Production Implemented in Areas of Study in 2 Communities and a Processing Center where Data in this Study was Collected. (Improved Technologies are Italicized)

	Dipale Community	Tigla Community	SeKaf Processing Center
[1]	Par-boiling with open fire.	Par-boiling with open fire.	N/A * kernels bought from shea nut producers who use open fire.
[2]	Crushing kernels manually.	Crushing kernels manually.	*Crushing kernels mechanically.*
[3]	Roasting kernels traditionally.	*Roasting kernels with improved roasters.*	*Roasting kernels with improved roasters.*
[4]	*Milling mechanically with diesel engine.*	*Milling mechanically with diesel engine.*	*Milling mechanically with electric motor.*
[5]	Traditional Kneading.	Traditional Kneading.	Traditional Kneading.
[6]	Boiling with open fire.	Boiling with open fire.	Boiling with open fire.

Traditional roasting emissions data was collected in Dipale and compared with emissions data from the improved roasting methods in Tigla and the SeKaf shea processing village. Data sets in the rural villages ranged from producers beginning with 19-46 kg of raw or processed nuts. Due to the larger scale of the SeKaf processing center, these data sets ranged from women's groups processing 902 -1,910 kg of nuts. Each data set during the processing of shea kernels into shea butter took approximately 3 days to 1 week. The first step of the shea butter process (par-boiling) was evaluated separately from the other shea processing activities. Par-boiling data was obtained separately and typically took approximately1 hour to collect one data set.

3.2 CO_2 Emissions

3.2.1 Carbon Emissions Due to Open Fire

Fuel combustion can be defined as the intentional oxidation of materials within an apparatus that is designed to provide heat or mechanical work to a process (IPCC 2006). The Intergovernmental Panel on Climate Change (IPCC) provides guidelines to evaluate the carbon emissions produced through energy combustion. Figure 6 shows the steps during shea butter production that will be used to evaluate CO_2 emissions of traditional and improved manufacturing processes practiced in the study area. The traditional method of shea butter processing involves burning open fires to par-boil, roast, and boil shea butter. Women with access to a mechanized mill or crusher will use energy produced by an electric motor or diesel engine in the processing steps of crushing and milling shown in Figure 6. In Ghana both diesel and electric motors are used to power machinery in urban and rural areas. When an improved roaster is used for the roasting processing step, a 3-stone open fire is no longer required; instead wood is placed under the improved roaster as shown in Figure 4 in Section 2.3.

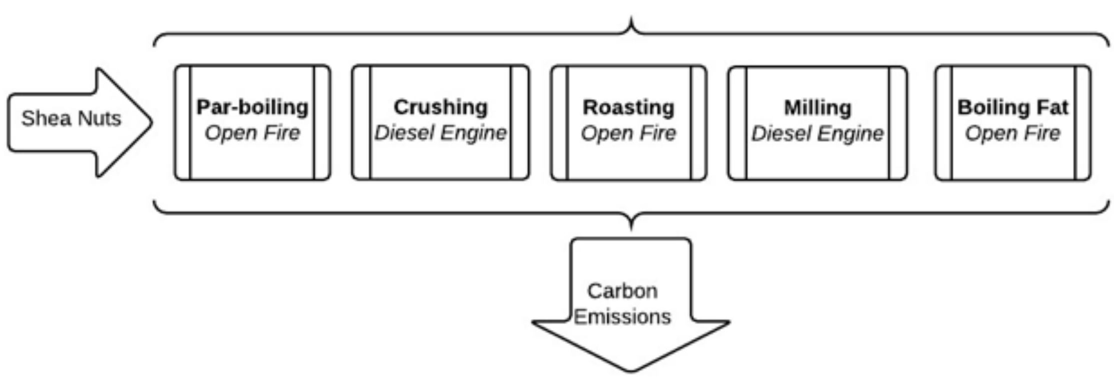

Figure 6. Shea butter processing steps that utilize material energy inputs that require wood or diesel fuels.

The methodology applied in this study for the estimation of CO_2 emissions produced by an open fire at each step of the shea butter process is similar to that of Ojeda (2009). In the research for this thesis, firewood data collection is required for the calculation of carbon emissions during the activities in Figure 6. The estimations use equations and assumptions recommended by the IPCC Guidelines for International Greenhouse Gas Inventories and are provided in Table 4.

Table 4. IPCC Equations and Default Values Used for Estimation of CO_2 Emissions from Energy Activities (Taken from Volume 2 of the 2006 Guidelines, IPCC (2006)).

	Equation	Default Values
[3.1]	$Emissions\ (CO_2) = Activity\ data \times Emissions\ factor\ (EF)$	$Net\ Caloric\ Value\ (NCV)_{firewood} = 15.6\ \frac{Tj}{Gg}$
[3.2]	$Emission\ factor\ (EF) = Oxidation\ rate \times Carbon\ Content_{firewood}$	$Carbon\ Content_{wood} = 30.5\frac{kg}{GJ}$
[3.3]	$EF = 1 \times 30.5\frac{kg}{GJ} \times \frac{44}{12} \times 1{,}000\frac{Gj}{Tj} = 1 \times 111{,}833.33\ \frac{CO_2\ (kg)}{Tj}$	$\frac{44}{12} = \frac{CO_2\ molecular\ weight}{C\ molecular\ weight}$
[3.4]	$Emissions\ (CO_2) = Activity\ data\ (kg) \times \left[NCV\left(\frac{TJ}{Gg}\right) \times EF\left(\frac{CO_2\ (kg)}{Tj}\right) \times \left(\frac{1\ Gg}{10^6 kg}\right)\right]$	$Oxidation\ rate\ of\ firewood = 1$

In Equations 3.1 – 3.3 (provided in Table 4), activity data refers to the total fuel consumed during a processing step (biofuel, diesel, etc.). The net caloric value of a fuel (NCV) is the measure of the consumed fuels value for heating purposes. An emissions factor (EF) relates the amount of a pollutant released to the atmosphere during an activity. In this study, the emissions factor accounts for the amount of CO_2 released during each activity. The IPCC guidelines (IPCC 2006) are used to estimate the CO_2 emissions associated with specific process activity data. Activity data can be measured by the amount of fuel combusted during a specific process. For each step of the shea butter process that consumes firewood, the firewood used was weighed before and after the shea producer completed the open fire activities. Wood was removed immediately from the fire and separated to assist in stopping combustion. Flaming wood was quenched before weighing by sprinkling a small amount of water on any flame that would inhibit weighing the wood. The firewood was weighed with 2 identical luggage scales (Tigla and Dipale) and 1 stationary scale (SeKaf processing center) (see Figure 7). Rubber bike tires commonly used to tie loads for transport of googs in Ghana were employed to quickly wrap firewood and weigh with the appropriate scale.

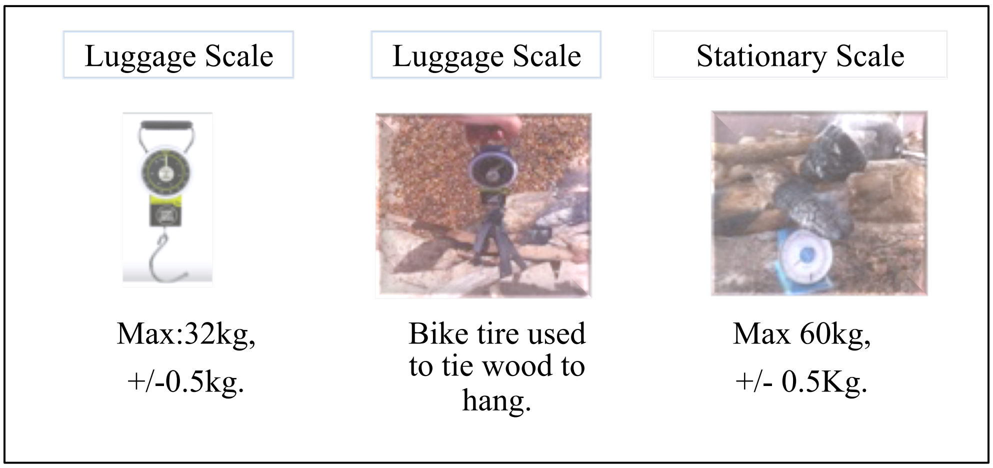

Figure 7. Measurement tools used in weighing wood before and after the shea processing.

As seen in Equation 3.1, both the firewood activity data and the emissions factor are required to estimate CO_2 emissions. The emissions factor can be determined using Equation 3.3 and the default values listed next to Equations 3.2, 3.3, and 3.4. The Net Caloric Value (NCV) for wood and wood waste was assumed to 15.6 TJ/Gg (IPCC 2006). The lower and upper limits of the 95% confidence level for this value are stated by the IPCC to be 7.90 - 31.0 TJ/Gg. According to IPCC (2006), the carbon content of firewood is 30.5 kg/GJ with lower and upper limits stated as 25.9 - 36.0 TJ/GJ. The oxidation rate is assumed to be 1, which means that complete combustion is taking place (100% of carbon in the burning wood is emitted to CO_2)

(IPCC 2006). After activity data is collected in the field, the CO_2 emissions from the burning of firewood can then be determined. These measurements were used to relate the amount of fuel used for different amounts of shea kernels and butter. Large plastic bags were used to weigh the kernels and it was assumed the weight of the plastic was negligible. When kernels or butter were weighed in basins or buckets, the weight of the container was measured and subtracted from the recorded weight. The weight of the nuts was used to calculate the extraction rates for the different methods. Thus, it was important to monitor the kernels being processed throughout the roasting, milling, kneading, and boiling/filtration processes closely so that no kernels or butter were added or removed throughout the entire process.

Explaining the purpose or the study and the basic methods to the community at a meeting arranged and approved by the elders was critical to ensure cooperation and accurate data collection. Thus, the shea producers who agreed to participate in the study were educated to fully understand the importance of keeping the shea kernels, butter, and firewood separate and organized throughout the process. Table 5 describes the data collected in the field and the equations and values used to acquire the desired $\frac{CO_2(kg)}{Shea\ butter(kg)}$ at each processing step involving wood combustion. Table 6 shows CO_2 emissions results were estimated for 6 individual steps for both traditional and improved processing methods.

Each data set was obtained by following a measured amount of nuts through the entire process. The process was monitored closely to ensure nuts, butter, and firewood were not added or subtracted throughout the days of data collection. A local translator was always used to assist the author with complex conversations and questions with shea producers. Although previously explanations were given at a community meeting, the translator assisted in reminding research participants of the importance of not adding wood without weighing first, as well as not mixing/adding/removing shea nuts, kernels, or butter throughout the process. The translator also assisted the researcher in monitoring the participants.

Table 5. Field Data Collection and Estimation of CO_2 Emissions.

Specific data measured in the field	**Comment**
$Nuts_{initial}\ (kg)$	Weight of fresh nuts before par-boiling. Weight of kernels before shea butter extraction.
$Firewood_{initial}\ (kg)$	Weight of wood in fire during par-boiling, roasting, and boiling butter.
$Firewood_{final}\ kg)$	Weight of firewood after nuts, kernels, or butter are removed from fire.
$Firewood_{total}\ (kg)$	$Firewood_{initial}\ (kg) - Firewood_{final}\ (kg)$ Total firewood is measured separately for each activity.
Shea butter (kg)	Final weight of shea butter extracted during the process.
$Activity\ data = \frac{Firewood_{total}\ (kg)}{\text{Shea butter (kg)}}$	Found by multiplying $\frac{Firewood_{total}\ (kg)}{Nuts_{initial}\ (kg)}$ by the conversion factor $\frac{Nuts_{initial}\ (kg)}{\text{Butter (kg)}}$ where, for example, the weight of butter taken after firewood is weighed during the boiling process of the initial nuts.
$Emissions\ \frac{CO_2\ (kg)}{Shea\ butter\ (kg)}$	Emissions are calculated using Equation 3.4 from Table 4 and activity data from row directly above. The values found in Table 6 are determined by averaging the emissions results of the data sets of each activity.

Table 6. Final CO_2 Emission Values Obtained From Study for Shea Manufacturing Processes.

Average Emissions $\frac{CO_2\ (kg)}{Shea\ butter\ (kg)}$
Traditional Roasting
Improved Roasting
Traditional Boiling Water/Butter
Improved Boiling Water/Butter
Par-boiling
Milling

Overall, 31 data sets were obtained over a 6-month period beginning with sorted kernels through the final amount of butter produced. Five data sets were collected using improved roasters in the village of Tigla and 6 data sets were recorded at the SeKaf processing center that also used improved roasters. The 20 data sets collected in Dipale used the traditional roasting methods. Because large quantities of firewood were consumed during the SeKaf study, the author chose to weigh approximately 500 kg of wood in the morning before the production process began. The wood was then weighed again when each activity was finished to ensure women did not go to the wood storage or other group's woodpile for additional wood.

The women's group leader called the Magazea (Dogbani name given to a female leader of a women's group) and male assistants at SeKaf were well versed in the data collection methods discussed in this section and were key in assisting with monitoring of the firewood throughout the process. The male assistants also weighed the kernels and final butter and these weights were recorded and compared to the authors to ensure accuracy. At the SeKaf processing center the data collection methods described for roasting and boiling of shea butter were used. The CO_2 emissions from those 2 processes do not include the entire firewood during process because the shea kernels used at the processing center have been per-boiled in shea kernel producer villages before being transported to the processing center in Kasalgu.

The total amount of CO_2 produced per kg of shea butter produced includes the par-boiling of the kernels. For processors purchasing nuts and not partaking in par-boiling the amount of firewood used during par-boiling cannot be neglected when comparing firewood usage throughout different processes. During collection season the women must par-boil the collected nuts every few days to prevent seed germination. The par-boiled nuts are then added to other solar drying nuts or nut storage areas. Accordingly, the weight of the nuts obtained during par-boiling cannot be applied to the final weight of butter during a data set. Assumptions must be made to compare the weight of the par-boiled nuts to the final amount of shea butter they will produce. Twenty-one data sets were collected during par-boiling in Tigla and Dipale. The wood was weighed before and after par-boiling a recorded weight of fresh nuts. The fresh nuts were a mix of nuts with removed shea fruit, spoiled/partial shea fruit, or fresh shea fruit still attached. The average CO_2 emissions of these 21 par-boiling data sets was considered an accurate portrayal to calculate the amount of wood necessary to par-boil a kg of collected shea nuts. The Equations provided in Table 4 are used to evaluate CO_2 emissions per kg butter during the roasting and final boiling and filtering stages. To assess the CO_2 emissions produced during par-boiling fresh nuts, a conversion from the weight of fresh collected nuts to final butter extraction was applied. According to Ojeda (2010), in the process of par-boiling, the conversion rate of fresh nuts to butter is assumed to be 8.9% (that is, 27% of fresh nuts are converted to dry kernels and only 33 % of dry kernels are converted to butter). According to this conversion rate, 11.22 kg of nuts are required to obtain 1kg of butter. This conversion factor was thus used in this study to convert the measured kg of firewood per kg of nuts during the par-boiling process to the desired activity data (kg of firewood per kg butter).

The initial weight before par-boiling includes fruit, nuts without fruit, germinated nuts, rotten nuts, and soil. Therefore it was necessary to use the conversion rate of $11.22\,\frac{Fresh\ nuts\ (kg)}{Shea\ butter\ (kg)}$ to convert the weight of the nuts before par-boiling measured in the field to the amount of butter produced in order to calculate the value average emissions $\left(\frac{CO_2\ (kg)}{Shea\ butter\ (kg)}\right)$ due to par-boiling found in Table 5. Thus, the actual weight of the nuts used to process shea are the final sorted kernels that will continue through the process of becoming marketable nuts or butter. This weight was taken before crushing the nuts to be roasted. Each of the 21 data sets to assess the CO_2 emissions from par-boiling followed the process of:

1. Weighing the nuts entering the cauldron ($Nuts_{initial}\ (kg)$).
2. Weighing the wood used to make a fire. This includes all initial wood and any wood added to the fire during the boiling of the nuts weighed in step 1 ($Firewood_{initial}\ (kg)$).
3. Weighing the wood after the nuts are removed from the cauldron ($Firewood_{final}\ (kg)$)
4. Calculating the total firewood used $\left(Firewood_{initial}\ (kg) - Firewood_{final}\ (kg)\right)$.
5. Calculate the activity data ($Activity\ data = \frac{Firewood_{total}\ (kg)}{\text{Fresh nuts (kg)}}$)
6. Multiply activity data by conversion factor of $11.22 \frac{fresh\ nuts\ (kg)}{Shea\ butter\ (kg)}$ to obtain the $final\ Activity\ data = \frac{Firewood_{total}\ (kg)}{\text{Shea butter (kg)}}$
7. Use Equation 3.4 from Table 4 and default values in Table 4 to estimate the CO_2 Emissions ($\frac{CO_2 (kg)}{\text{Shea butter (kg)}}$) during par-boiling.

The average emissions ($\frac{CO_2 (kg)}{\text{Shea butter (kg)}}$) of these 21 par-boiling data sets was assumed to represent the emissions produced during par-boiling for all butter produced using open fire 3-stone cook stoves. Data sets were obtained over multiple days for the process of extracting butter from the kernels because of the time and labor involved in tracking the kernels and firewood, unlike par-boiling where a data set could be collected in an hour. Due to the difficulty of monitoring the kernels and butter throughout the entire process, the SeKaf processing village was used to study improved roasting and milling methods. The manufacturing of shea butter at SeKaf processing village begins with 40 bags of nuts and a group of women. The women complete each step of the shea butter process and package their butter at the end. The kernel weight, firewood used, and final butter produced are easy to track at the processing center where women follow an organized system that is monitored by SeKaf employees. The women have access to improved manufacturing technologies in a controlled work environment. Although weighing the high quantities of fuel wood used through each process was labor intensive, the women and production process were more organized and easier to monitor than individual household producers in Tigla and Dipale. The data sets obtained after par-boiling began with first determining the weight of the kernels to be crushed. The women in the study area of Tigla boil all the nuts they have collected and after boiling, de-fruit the nuts, remove germinated nuts, and remove low quality nuts until they are left with high quality nuts for drying. The wood was weighed before roasting and after roasting the kernels. The same kernels were then milled into paste and kneaded. Firewood was again weighed before and after boiling the butter into its final stage. The final weight of butter produced was then measured and recorded. The following steps were used to obtain the amount of $\frac{CO_2\ (kg)}{Shea\ butter\ (kg)}$ during the roasting, and boiling (of shea butter) steps:

1. Weigh kernels ($Nuts_{initial}\ (kg)$) when women are prepared to begin the production process of shea butter. It is important to weigh the kernels after the shea kernels have been sorted to ensure no kernels were removed during the process.
2. Weigh the amount of wood to be used in the fire ($Firewood_{initial}\ (kg)$) and any wood that is added during the process of roasting the nuts. Data collected during the traditional process will involve weighing the wood for a 3-stone fire whereas improved roasting firewood weight will be taken for the wood under a spinning roaster.
3. Weigh the amount of firewood ($Firewood_{final}\ (kg)$) remaining after roasting is complete and kernels (or roaster) are removed from the flame. The $Firewood_{total}\ (kg) = \left(Firewood_{initial}\ (kg) - Firewood_{final}\ (kg)\right)$ can then be determined.

4. When the producer returns with the milled paste, repeat steps 2 and 3 for the 3-stone fire used to boil the butter. At this time, women will begin boiling water to use during the kneading process. Weigh the firewood used to heat the water and additional firewood added as the women switch to boiling the extracted butter. When the butter is finished and removed from the fire, the wood is weighed immediately.
5. The container of finished shea butter can be weighed using the standing scale depicted in Figure 7 or using the luggage scale. In order to use the luggage scale to weigh the basin of shea butter in the field, the basin was placed on a cloth, and the corners of the cloth were tied above the basin at a central point for the luggage scale hook. The basin was then lifted and the weight recorded. The weight of the container and apparatus used to lift the container is weighed and subtracted to find the total shea butter (kg).
6. Calculate the $Activity\ data\ \left(\frac{Firewood_{total}\,(kg)}{\text{Shea butter (kg)}}\right)$ for both the roasting and boiling steps.
7. Use Equation 3.4 and the default values provided in Table 4 to calculate the final $\frac{CO_2\ (kg)}{\text{Shea butter (kg)}}$ from the roasting of shea kernels as well as the $\frac{CO_2\ (kg)}{\text{Shea butter (kg)}}$ from the boiling of shea butter.

During the boiling process it should be noted that women often boil the butter throughout the kneading process. This is a long process where wood is continually added to the fire. It is beneficial to weigh all the wood collected for boiling to ensure no wood is added to the fire un-weighed. For most of the data sets collected, the women knead the shea kernel paste and water in groups and it is a social event where children often help with adding firewood. By weighing all the firewood collected and then weighing the firewood remaining, the author ensured all the firewood was accounted for during the long process where constant supervision was difficult. In the community of Dipale the women often traveled after the roasting process to another community to mill the kernels before returning to knead the paste. The paste was weighed upon return to ensure it was consistent with the initial kernel weight. Verifying this consistency is not always possible due to the practice of adding water to paste for transport purposes. When basins of paste are transported by head, the women find it easier if they add water to the shea paste. This cools and thickens the paste, making it easier to carry and less likely to spill during transport. This makes it difficult to track any loses at this stage if the producer adds water to the paste before returning. According to Lovett (2006), the extraction rate from dry kernel to extracted butter is 0.33-extracted kg of butter per kg of dry kernel. During this study, dry kernels were weighed throughout the butter production process, which accounted for losses during milling and roasting. This provided an extraction rate for the different processes as well as information on what part of the process viable nuts are lost during an activity. The extraction rate from traditional roasting and improved roasting was also examined to determine if there were differences in butter yield between these 2 methods. The extraction rate can be found by dividing the final weight of butter by the initial weight of the kernels being processed.

3.2.2 CO_2 Emissions Due to Diesel Fuel

A diesel engine used to mill the shea kernels will also contribute to the total CO_2 emissions. The emissions produced by diesel engines during shea processing can be evaluated using IPCC (2006) guidelines. In the energy sector the term activity data is used to describe the amounts of fuels combusted. Activity data obtained in the field is sufficient to perform a Tier 1 analysis. IPCC (2006) standards provide: (1) definitions of the different fuels, (2) the units in which to express the activity data, (3) guidance on possible sources of activity data, and (4) guidance on time series consistency. Emissions can be estimated from either knowledge of the fuel consumed or the distance traveled by a vehicle. IPCC (2006) guidelines estimate net CO_2

emissions from fossil fuel combustion from the equations and values seen in Table 7. In order to compare the fuel emissions due to diesel combustion to the emissions produced from firewood in the previous Section (3.2.1), the units must be consistent with the results found in the previous section $\left(\frac{Kg\ CO_2}{Kg\ shea\ butter}\right)$.

Table 7. Default Values and Associated Equations Used for Determining CO_2 Emissions Associated with Diesel Fuel Used During Shea Butter Processing.

	Default Value	**Comment**
[3.5]	E_{FC}	Net CO_2-equivalent emissions of fuel consumption according to US climate registry. Found to be 10.3 – 10.4 $\left(\frac{CO_2(kg)}{Gallon_{Diesel}}\right)$ using default values for diesel fuel in Equations 3.1 and 3.2.
[3.6]	$Fuel_a$=Diesel	Amount of Fuel of type a consumed (L).
[3.7]	EF_a	Emission Factor of Fuel type.
[3.8]	$Density_{diesel} = 0.84\frac{kg}{L}$	IEA (2004).
[3.9]	$NCV_{Fuel\ a} = 43.4\ \frac{TJ}{GJ}$, 95% confidence 41.4- 43.3$\frac{TJ}{GJ}$	IPCC (2006).
[3.10]	EF_{diesel} = Emissions factor diesel= 74,000 - 75,300 $\left(\frac{CO_2(kg)}{TJ}\right)$	IPCC (2006).
	Equation/Conversion	**Comments**
[3.11]	$Fuel_a = Liters_{Fuel\ a} \times Density_{Fuel\ a} \times NCV_{Fuel\ a} \div 10^6$	Using values $0.84\frac{kg}{L}$ and 43.4 $\frac{TJ}{GJ}$ to find $Fuel_{diesel}$ = $0.000138\ \left(\frac{TJ}{Gallon_{Diesel}}\right)$
[3.12]	$E_{FC} = \Sigma(Fuel_a \times EF_a)$	Used to calculate $E_{FC,diesel} = 10.3 - 10.4 \left(\frac{CO_2(kg)}{Gallon_{Diesel}}\right)$
[3.13]	$\frac{Gallon_{Diesel}}{Shea\ butter\ (kg)}$	Conversion factor calculated in field study used to find $Emissions \left(\frac{CO_2(kg)}{Shea\ butter\ (kg)}\right)$

IPCC (2006) default values are provided in Table 7 for all parameters not monitored in this study. The following step describes how to calculate the emissions factor for diesel fuel $\left(\frac{CO_2(kg)}{Gallon_{Diesel}}\right)$ and find the final emissions in terms of the amount of $\left(\frac{CO_2(kg)}{Shea\ butter\ (kg)}\right)$:

1. Diesel is used to power the engine; therefore, values and assumptions associated with Equations 3.7, 3.8, 3.9, and, 3.10 will be used.
2. Using the given density and NCV of diesel fuel (Equations 3.8 and 3.9) and Equation 3.11 form the IPCC guidelines calculate $Fuel_{diesel} = 0.000138\left(\frac{TJ}{Gallon_{Diesel}}\right)$ Assuming 1L of diesel.
3. The result found in Equation 3.1 can be multiplied by the given emissions factor for diesel (3.8), as seen in Equation 3.12 to find $E_{FC,diesel} = 10.3 - 10.4\left(\frac{CO_2(kg)}{Gallon_{Diesel}}\right)$.
4. Finally, $E_{FC,diesel}$ must be multiplied by the conversion factor 3.13 to determine the net CO_2-equivalent emissions of fuel per kg of shea butter. This requires collection of fuel consumption data in the field to calculate the conversion factor (Equation 3.13).
5. The amount of fuel consumed per kg shea butter (Equation 3.13) was calculated in the field and can be multiplied by the result of Equation 3.12 to find the desired result $emissions\left(\frac{Kg\ CO_2}{Kg\ shea\ butter}\right)$ due to diesel fuel.

Two improved mills were identified to use in the study: a new GRATIS mill in Tigla installed during the time of the study as well as the mill in Gushie (see Figure 8). Dipale shea producers in this study often travel 10 km to Gushie to mill their shea kernels due to the mill operator in Dipale often refusing to mill shea kernels. This is because as previously mentioned; milling shea kernels requires extra cleaning and maintenance than for milling corn.

Location: Gushie Capacity: 250 kg/hr
Ownership: Private
Origin: India (Adico brand but purchased second hand)
Cost: ≈ GH¢ 2,000 (USD$ 601)
Age: >10 years
Motor: 11 kwh diesel

Location: Tigla Capacity: 250 kg/hr
Ownership: Community
Origin: GRATIS (Tamale, locally made)
Cost: GH¢ 4,200 (USD$ 1,262)
Age: 2 months
Motor: 11 kwh diesel

Figure 8. Mills with specifications used to calculate CO_2 emissions due to diesel combustion during shea butter processing.

A range of CO_2 emissions estimated from diesel emissions associated with the mills available to producers in northern Ghana was analyzed by testing a new locally fabricated mill as well as an aged imported mill that has undergone maintenance. The amount of fuel used to mill shea kernels in Gushie was measured using a 0.75-L bottle marked by adding 7 Tablespoons of water in increments (equal to 0.10 L); the amount of fuel was measured with an accuracy of $\pm 0.05\ L$ before and after milling. In Tigla the fuel cannot be removed from the tank. The volume of the tank was measured using a ruler $(l \times w \times h)$. To find the amount of fuel the depth of the fuel in the tank was measured before and after milling the shea kernels to find the change in volume of the tank. In addition to the fuel, the shea kernels were also weighed before milling. The paste produced by the mill was then kneaded into shea butter by the women and the final weight of the shea butter produced was recorded. Thus, with the amount of fuel used and shea butter produced, the conversion factor 3.3 ($\frac{Gallon_{Diesel}}{Kg_{shea\ butter}}$) was determined. Finally, multiplying the calculated conversion factor (3.3) by the result in Equation 3.1 provided a value for CO_2 emissions with units $\frac{CO_2\ (kg)}{Shea\ butter\ (kg)}$ that is comparable to the firewood emissions at each stage of the process.

This method has uncertainties considering the fuel tank in Tigla could not be emptied making it difficult to measure the amount of fuel. Often in Ghana the diesel is purchased in small quantities from roadside suppliers who source from petrol stations and often dilute the fuel before sales. It was observed during the author's study that if fuel was not purchased from a certified source it often did not provide appropriate power. According to the Climate Registry (CR 2012) Table 13.1 in the US default CO_2 emission factors for transport fuels 2012, default emission factors assume that diesel fuel can emit 10.2 Kg CO_2/Gallon diesel consumed. This value varies slightly from the IPCC default value range of 10.3 - 10.4 Kg CO_2/Gallon diesel consumed. This implies that uncertainties exist with default values.

SeKaf provides women with electric mills and a crushing machine to process shea butter. Photographs and specifications of the mill and crusher can be found in Figure 9. The 11-kwh electric motors are also a part of the carbon footprint but are often deemed negligible. To compare electric motors to diesel engines, the EIA (2007) study reported that Ghana's electricity emissions factor is 0.15 MT CO_2/ MWh. During the study at SeKaf, data sets were collected to find the capacities of the equipment in order to calculate the associated CO_2 emissions.

The manufacturer capacities were unknown, in order to find the true working capacities the following steps were taken:

1. During the use of the crusher the weight of the kernels are weighed on the standing scale and placed by the crushing machine (seen in Figure 9).
2. Time was recorded at the beginning of the crushing with a stopwatch and stopped when the motor is turned off and all the kernels are crushed.
3. The amount of kg kernels/hr was calculated to find the machines capacity,
4. The capacity is converted to kg shea butter/hr.
5. Using the motor specification of 11 kwh and the emissions factor of 0.15 $MTCO_2$/ MWh= 0.15 (kg CO_2/kwh) the equivalent CO_2 emissions can be determined ($\frac{CO_2\ (kg)}{Shea\ butter\ (kg)}$ from an electric mill or electric crusher).

The same steps were followed for calculating the capacities of the 2 mills with a different method of weighing. The mills were often observed to run at the same time for one women's group and it was also observed they do not run at the same capacity. Separate times are recorded for each mills start and finish, when a basin (as seen in Figure 9) is full it is placed on the standing scale and recorded. The weights of paste from each mill were kept separate in order to find the varying capacities. This data can be compared to the emissions estimated from diesel powered mills and also be used to predict the $\frac{CO_2\ (kg)}{Shea\ butter\ (kg)}$ emissions from a diesel powered crusher (diesel crusher not available for field testing during this study).

Diagram of SeKaf crushing and milling facility. 2 electric grinding mills with one set up in series with crusher	Grinding mill 1 and shea kernel paste. Grinding mill 1 has its own motor	Crusher and sorted kernels to be crushed. Crushing machine is run in series with mill 2 off of electric motor 2

Figure 9. Specifications and photos of SeKaf mills and crushers as set up in processing facility.

The Ghana Regional Appropriate Technology International Development Service (GRATIS) produces both mills and crushers that process shea nuts. Mills are commonly seen throughout northern Ghana, while crushing machines are rarely accessible by shea producers. Gratis mills and crushers can be evaluated based on the given manufacturing capacity (mill= 250 kg/hr, crusher = 1,500 kg/hr). Using the conversion of 3.03 kg kernels/kg shea butter and the electrical CO_2 emissions factor provided by the EIA for Ghana, the emissions related to electric shea processing emissions can be found. Although a crusher with a diesel engine was not accessible during the study, observations show that crushers may eventually be available for shea producers to utilize. Collected data from the diesel mill (diesel use per kg butter) can be correlated to the potential emissions of a diesel crushing machine at SeKaf as well as GRATIS. Thus, the diesel consumed by the mill per hour can be compared to the capacity of shea butter production per hour of the crushing machine. Ghana experiences frequent power outages.

Moreover, many communities in northern Ghana are still without access to electricity, and diesel powered machines are also commonly used in electrified areas despite access to the electricity grid. Both electric and diesel improved crushing and milling technology are in demand by shea processors.

3.3 Wood Moisture Content

The default values for wood properties assumed to calculate the emissions due to open fires during shea butter extraction vary depending on available wood, rainfall, and wood storage practices. The NCV and carbon content of wood vary based on wood type, moisture content, as well as size (Ludwig et al. 2003). The oxidation rate was assumed to be 100% because it was outside of the study scope to collect the data necessary to calculate the actual value. The Environmental Protection Agency (EPA 2013) explains that when smoke is visible, incomplete combustion is taking place. This would cause fewer CO_2 emissions and increased emissions of pollutants such as particular matter, carbon monoxide (CO), and hydrocarbons. However, determining emissions of other pollutants due to incomplete combustion was considered outside the scope of this study. Additionally, the IPCC (2006) guidelines assume the default NCV of wood is based on 20% moisture content. BSI standards (Appendix C) were followed for calculating the moisture content of wood in the SeKaf chemical laboratory to compare to the IPCC (2006) value.

The SeKaf processing center is at the same location TAMA shea cosmetic products are produced. A chemical laboratory is on site for testing chemical properties of soaps and other emulsifications. The author was granted access to this lab to complete moisture content testing of the firewood supply. The following steps were followed to measure the wood moisture content (BSI 2011):

1. Preheat the laboratory test oven to 200°C, then reduce the temperature to 105°C.
2. Select producers at SeKaf processing center to choose what they consider "good quality" and "poor quality" firewood.
3. When the wood samples are identified, the center of the wood sample is cut to remove a square piece of wood from the core approximately 2 in × 1 in × 25 in.
4. Samples are immediately placed in a plastic sample bag and labeled based on the identification as "poor quality" or "good quality".
5. The samples are measured on a tarred scale accurate to 100^{th} of a gram.
6. The samples are placed in the oven for 2 hr with temperature kept constant at 105°C. The samples are weighed again after 2 hr time and placed back into the oven. After an additional 2 hr, the samples are removed and weighed again. This is repeated until the 2 final weights of a sample are constant and the sample is considered completely dry.
7. The moisture content can be then calculated using Equation 3.14:

$$\%\, Moisture\ content_{wood} = \frac{Weight\ wood_{initial\,(kg)} - Weight\ wood_{final\,(kg)}}{Weight\ wood_{initial\,(kg)}} \times 100 \qquad [3.14]$$

The change in weight during the drying process accounts for the entire moisture content in the wood sample. This procedure was completed for 3 samples of "poor quality" wood and 3 samples of "good quality" wood identified by the producers. Each sample was taken from a different wood storage pile at the facility. A second study was completed where 9 samples were taken of wood chosen by the women for use that day and a moisture content calculation was completed. The producers sort through 3 large wood piles each day to choose desired wood and create piles for their work stations. A variety of woods were chosen from the piles created by the producers by choosing 9 types of wood that were different in thickness as well as texture. This was done to see how a variety of preferred wood types varied in moisture content compared to the wood labeled as “poor quality.” Shea processing season takes place during the rainy season. Therefore, although shea is still continuously processed during the drier months, par-boiling has to be completed during the rainy season to stop germination. The difference in the woods moisture content from the assumed 20% would increase the uncertainty of the IPCC (2006) default values and their corresponding emissions results. Another factor of uncertainty is the moisture content of wood in rural areas that do not have access to wood storage and the wood collected is exposed to rainfall, which may increase the moisture content.

3.4 Human Energy Analysis

Human energy quantifies the caloric expenditure associated with a process that is calculated using the physical activity ratios (PARs) and basic metabolic rates (BMRs) (Held et al. 2013). PAR is the energy cost of an activity, and range from less than 1 up to around 8 for very strenuous activities. Shea processing has been described as an arduous task, consuming both time and energy (Jibreel et al. 2013). Different interventions such as improved technologies and practices have been implemented to reduce labor and save time throughout the shea butter process. To verify these statements and quantify the actual energy savings of an intervention (e.g. improved roaster, mechanized crushing, and mill access) a human energy analysis was completed. This study looked at the human energy expenditure during different shea processing methods. The original objective of this study was to calculate the human energy expended during firewood collection. Finding the average energy expended per kg of firewood collected can be correlated to the amount of firewood used to produce 1 kg of shea butter found in the material energy portion of this study. The human energy expended per kg of firewood collected was calculated using the PAR values for firewood collection from the FAO (2001) and measuring the time to collect firewood as well as the weight of the wood collected. By reducing the material inputs throughout the shea butter process, the human energy can also be reduced. The human energy expelled was calculated using the methods provided in Held et al. (2013). Table 8 describes the calculations used to determine the human energy expended for an activity. The BMR is calculated using FAO-provided predictive equations based on sex, age and weight. Women shea producers in this study ranged in age from 18-71 years.

Table 8. Human Energy Expenditure Calculations. Adapted from Held et al. (2013).

	Equation	Comments
[3.14]	$BMR\left(\frac{MJ}{hr}\right) = 0.062 * Weight\ (kg) + 2.036$	FAO (2001) predictive equation for an 18-30 year old women.
[3.15]	$BMR\left(\frac{MJ}{hr}\right) = 0.034 * Weight\ (kg) + 3.538$	FAO (2001) predictive equation for a 30-60 year old women.
[3.16]	$Human\ energy\left(\frac{MJ}{Shea\ butter\ (kg)}\right) = (PAR - 1) * (BMR) * \frac{Activity\ time\ (hr)}{Shea\ butter\ (kg)}$	Expended energy performing a given activity per a kg of shea butter.

To further compare the human energy expenditure throughout the improved and traditional processes, 3 variables are needed at each processing step: (1) time to complete the activity (2) weight of nuts, kernels, or butter being processed in the activity and (3) the given PAR value (energy cost) for the activity. During observations in the field the author found other activities of the shea butter process expending human energy. Accordingly, additional time data was collected during the field study (e.g. traditional crushing, milling, improved crushing, improved roasting, and distance to accessible market/mills). Throughout the literature review studies also assessed time for different shea processing activities and different technologies. The main objective of these human energy calculations is to compare field and observational data from past studies to each other as well as this study. Data is taken to evaluate the time taken to collect or process a fixed weight of material (e.g. nuts or firewood) throughout the improved and traditional shea butter processing methods can be described with common units (MJ/kg shea butter) by utilizing the FAO-reported PARs. Table 9 shows the PAR of all shea processing activities reported by the FAO (2001) when possible. The FAO describes three different ranges of PAR values, I, being light activity, II, being moderate activity, and III being vigorous activity. A PAR value in the III range was chosen to describe the kneading activity due to the high intensity of the activity as well as work required by the women to manually knead the paste to extract shea butter.

Table 9. PAR Values for Shea Butter Activities Demonstrated Throughout the Improved and Traditional Shea Butter Processing Methods (FAO 2001).

Activity	Labor	Activity Analogue	PAR Value
[1]	Collecting shea nuts	Picking fruit	3.3
[2]	Par-boiling	Cooking	1.8
[3]	Sorting	Shelling	1.6
[4]	Dehusking (shell removal)	Shelling	1.6
[5]	Traditional crushing	Pounding grain	5.6
[6]	Improved crushing	Standing	0
[7]	Roasting	Cooking	1.8
[8]	Travel to mill	Walking with 25-30 kg load	3.9
[9]	Manual traditional grinding	Grinding grain with mill stone	4.6
[10]	Collecting firewood	Collecting wood (for fuel)	3.3
[11]	Collecting water	Collecting water	4.5
[12]	Kneading	III	4.81

The time spent during the processing of shea is needed to complete the human energy analysis for each activity. Table 1 and Table 2 in the literature review (Section 2.7) showed previous studies that calculated the minutes spent on different activities throughout the shea butter processes as well as the amount of firewood and water necessary per kg of shea butter. Table 10 describes the values needed to complete the energy analysis as well as the means of obtaining them. Each activity in Table 10 must be converted to the unit $\left(\frac{Activity\ time\ (hr)}{Shea\ butter\ (kg)}\right)$ to utilize in the human energy calculations. Time measurements obtained in the field for this study used a stop watch and recorded with the time with an uncertainty of ± 1 minute, the weight of shea kernels and butter were recorded with the scales pictured in Figure 7.

Table 10. Activity Time Expenditure Throughout the Shea Butter Process and Method of Obtaining the Final Value of $\left(\frac{Activity\ time\ (hr)}{Shea\ butter\ (kg)}\right)$.

Activity	Activity description	Activity Measurement	Comments
[1]	Collecting shea nuts	Measured time and weight of nuts collected by Tigla community members (n=3).	$11.22\ \frac{Fresh\ nuts\ (kg)}{Shea\ butter\ (kg)}$ Assumption used to convert weight of fresh nuts collected to final butter produced.
[2]	Par-boiling	Measured weight of nuts undergoing par-boiling in each data set and observe amount of time to par-boil these amounts (n=21).	Same conversion from activity 1 to convert fresh nuts (kg) to shea butter (kg).
[3]	Sorting	Value obtained from SNV (2013) study (n= 1).	Results based on a single data set.
[4]	Dehusking (shell removal)	Value obtained from StarShea (2012) study (n=2).	Results from timing activities to produce shea kernels in two villages producing shea and weighing final shea kernels processed.
[5]	Traditional crushing	Recorded kernel weight and time taken to crush (n=9).	Assumed conversion rate of 3.03 (kg) crushed kernels per 1 (kg) shea butter.
[6]	Improved crushing	Recorded capacity of crushing machine (kg kernels per hour) (n=3).	Data sets collected at SeKaf processing center.
[7]	Improved roasting	Recorded weight of kernels and time taken to complete roasting at SeKaf processing center (n=14).	Assumed all improved roasters of the same size contain 45 kg of kernels (2 roaster contents were weighed and all roasters in study were filled with the same method at SeKaf).
[8]	Travel to mill	Observed distance traveled by women to mill and weight of kernels carried (n=6).	Assuming a walking speed of 5 km/hr to find round-trip time (TranSafety 1997).
[9]	Manual grinding	No studies available.	Not observed in this study.
[10]	Collecting firewood	Measured round-trip time to collect firewood and its weight (n=8). Amount of firewood used during the traditional (n=20), improved (n=5), and improved centralized processing center (n=6) were recorded in the field.	Assuming the majority of firewood is collected by foot only 6 of 8 data sets will be used, 2 data sets utilized bicycle transport.
[11]	Collecting water	Values obtained from Telmo (2002) (n= 46).	Assuming a walking speed of 5 km/hr to find round-trip time. 11 L of water is required to produce 1kg shea butter (Table 1).
[12]	Kneading	Value obtained from SNV (2013) study (n= 1).	Results based on a single data set.

The human energy $\left(\frac{MJ}{Shea\ butter\ (kg)}\right)$ for each activity can be calculated with Equation 3.16 (see Table 8) using the observations, calculations, and assumptions provided in Table 10. The potential for energy savings as well as time can be observed in the results of the human energy calculated during each activity. This study focuses on collecting human energy data related to firewood collection because it directly correlates to the material energy used in the par-boiling, roasting, and boiling steps of the shea butter process. As seen in Table 10 the frequency of data collected varies and thus the uncertainty of the results will very.

A broader picture of what activities have the most potential for energy savings can be obtained by extending this energy analysis beyond just firewood collection and examining past literature and improved technology interventions. This information is valuable to shea producers and the organizations and industries investing in improved technology interventions. The human and material energy data compared and collected during this study is to be used as a platform for further research into the human and material energy saving technology for shea butter processing. A full understanding of the material and human energy of traditional processing methods in relation to improved technologies available to only some producers would provide insight to what interventions affect processing efficiency the most as well as the amount of time, resources, and energy expended by the producer themselves. The results of past studies can be used with these methods to produce values with similar units for comparison in the results and discussion of this study.

3.5 Ethnographic Survey

The human and material energy calculations in this study investigate the actual expenditure of resources and energy; however, they do not take into account the personal perception of how the producers see the effect of improved technologies in terms of social, cultural, and individual aspects. To investigate the perception of this new technology a survey was designed based on an ethnographic interview for field use in Mali by Ms. Colleen Naughton (PhD Student, Civil & Environmental Engineering, University of South Florida). The survey utilized qualitative methods, as well as anthropological methods in ethnographic interviews, focus groups, and participant observation. Naughton describes in her dissertation research proposal the importance to explore the cultural implications and importance of shea particularly during the shea or hungry season. The ethnographic survey was developed by Naughton using Spradley's methods of asking a mixture of questions (description, structural, etc.) that can lead to a deeper understanding of shea (Spradley 1979). Collaborating with the Peace Corps Ghana Shea Committee, the author of this thesis, Naughton developed a similar survey with changes to incorporate the different practices and issues in Ghana. Based on field observations from the original Naughton survey adaptation, additional ethnographic surveys were created to investigate firewood usage and other identified issues related to traditional and improved roasting practices.

To investigate the benefits of this technology and user's perceptions, the improved and traditional roasting surveys adapted from Naughton were conducted between the months of August and November 2014. Appendix D contains the 34 survey questions administered to investigate shea producer's feelings toward improved roasting, traditional roasting, as well as the general question regarding the importance of shea composed by Naughton and the Peace Corps Ghana Shea Committee. The goal for the survey was to quantify the adoption rate of the improved technology as well as learn how the shea producers perceived improved and traditional roasting. The improved roasting surveys were conducted in Tigla, 18 shea producers were interviewed with the assistance from a community translator. Twenty-eight traditional roasting surveys were conducted in Dipale with the help of a translator. These communities were chosen because of their history of working with the author. The women shea producers have a relationship with the author and the translator in both Tigla (where the author lived and conducted research) and Dipale (where the author managed a school nutrition program and the community had a history of working with Peace Corps volunteers). The community of Tigla received access to improved roaster for the shea season of 2014. The improved roasters were obtained after an extensive community needs assessment and a FTF grant submission. The survey focused the roasting step of the shea butter process and how frequently different roasting methods were practiced and any improvements and issues they encountered. Producers were asked if they used the new roaster and why, and what differences are experience with the new technology. Although the survey focused on traditional and improved roasting methods, through the participant interactions and interviews, other issues were addressed by the women regarding shea butter processing and lack of access to improved technologies.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Material Energy and CO_2 Emissions

Material energy results were obtained through quantifying the amount of firewood combusted and the correlating CO_2 emissions for traditional and improved processing stages of shea butter. This section discusses the results of field data collection and observations regarding material inputs (e.g. firewood and diesel fuel) throughout the traditional and improved shea butter processes while Section 4.2 will discuss the human energy involved. Furthermore, the results related to the second objective of this research to determine the CO_2 emissions from the material inputs for traditional and improved shea butter processing technologies are also discussed. Finally, the results from this field study are compared to past studies (Jibreel et al. 2013, SNV 2013, Ojeda 2010, Glew et al. 2014, StarShea 2012) to provide an overview of CO_2 emissions related to activities during shea butter processing practiced in the northern regions of Ghana.

4.1.1 CO_2 Emissions Emitted from Firewood Combustion

CO_2 emissions during the shea butter process can be calculated from the firewood usage throughout the process. The firewood usage (also known as the firewood activity data) from the author's field study as well as previous studies (SNV 2013; Jibreel et al. 2013) are compared in Table 11. The firewood activity data refers to the total amount of firewood used per kg of shea butter produced during each processing activity.

Table 11. Firewood Activity Data (Firewood (kg)/ Shea Butter (kg)). Adapted from the Author and Previous Studies.

Study	Par-boiling	Roasting	Boiling	Total	Comments
Adams (2015) Traditional	7.7	1.1	1.3	10.1	roasting (n=20), boiling (n=20).
Adams (2015) Improved	7.7	0.95	1.2	9.9	roasting (n=5), boiling (n=5).
Adams (2015) SeKaf Processing Center	7.7	0.45	0.49	8.6	roasting (n=6), boiling (n=6).
Jibreel et al. (2013) Improved	7.7	1.1	1.8	10.6	(n=1) (one data set throughout one process).
Jibreel et al. (2013) Traditional	7.7	1.5	1.8	11.0	(n=1).
Glew et al. (2014); Ojeda (2010) Improved	8.3	0.86	1.9	11.1	(n=12).
SNV (2013) Improved	7.7	0.49	0.63	8.8	(n=1).

** Par-boiling (n=19). For all studies assuming 7.7 firewood (kg)/shea butter (kg) from Adams 2015 field study results.*

The firewood expended during the roasting and boiling stages of the shea butter process were used in the equations and methods given in Section 3.2 to find the associated CO_2 emissions. The data collected in the field to produce the emissions results in Table 12 for the three study areas (SeKaf, Dipale, and Tigla) can be found in the Appendix F as Tables F.1-F.4. The Jibreel et al. (2013) and SNV (2013) studies did not record the firewood used for par-boiling shea nuts; therefore, the author used the 2015 study results from par-boiling nuts in Tigla and Dipale (12.6 $\frac{CO_2\,(kg)}{Shea\ butter\ (kg)}$, n=19). CO_2 emissions results of Adams (2015) field study and other previous literature following the same calculation methods are found in Table 12.

Table 12. Comparison of CO_2 Emissions Results $\left(\frac{CO_2\ (kg)}{Shea\ butter\ (kg)}\right)$ and Extraction Rates for Traditional and Improved Shea Butter Processing Methods.

Study	*n**	*Method*	*Par-boil*	*Roast*	*Boil*	*% Extraction*	*Total*	Comments
SeKaf (Adams 2015)	6	*Imp.*	13.4	0.846	0.852	38.7	15.3	Calculations use amount of sorted nuts and not the initial weight of nuts issued to processors (34% extraction rate before sorting).
Tigla (Adams 2015)	5	*Imp.*	13.4	1.50	2.12	34.9	17.1	Only improved technology implemented during process is improved roasting.
Dipale (Adams 2015)	20	*Trad.*	13.4	1.90	2.43	32.6	17.8	Dipale processors use traditional methods with the exception of traveling 1- 60 km to mill shea kernels.
Glew et al. (2014), Ojeda (2010)	12	*Imp.*	14.5	1.50	3.40	33.0	19.4	Calculations based upon assumed 33% extraction rate of shea butter from kernels. All data sets collected separately as done with par boiling in this study.
Jibreel et al. (2013)	1	*Imp.*	13.4	0.837	1.05	-	15.3	Initial amount of kernels to produce 25 kg of shea butter is not mentioned in study, thus no extraction rate.
Jibreel et al. (2013)	1	*Trad.*	13.4	0.628	1.05	-	15.1	Only roasting is a variable of traditional and improved. Boiling and par-boiling data all utilize 3-stone fire method.
SNV (2013)	1	*Imp.*	13.4	0.851 -1.22	1.11	32.5	15.8	13.8 kg-19.8 kg firewood to fuel the roasting process (study includes shea waste as biofuel and has been converted to firewood for calculations).

The total CO_2 emissions found using IPCC (2006) guidelines range from 15.1 $\frac{CO_2\ (kg)}{Shea\ butter\ (kg)}$ (Jibreel et al. 2013 improved study) to 19.4 $\frac{CO_2\ (kg)}{Shea\ butter\ (kg)}$ (Glew et al. 2014). The Glew et al. (2014) study was based on firewood data from Ojeda (2010) and is the only study which included par-boiling data and the other studies were assumed to have the same emissions due to par-boiling as observed in the authors 19 field data sets. The Jibreel et al. (2013) study calculated firewood use by the amount of basins used for each study

($\pm 1\ headloads$) with each head load assumed to weight 30 kg. There was a slight reduction of CO_2 emissions when improved roasters were implemented (23.5% difference) at households in shea processing villages in the authors study. Jibreel et al. observed a similar difference, 28.5%, from the improved and traditional roasting methods. Overall, the improved roaster effected the total CO_2emissions by 2.27% and 1.32% respectively for improved and traditional shea butter processing.

The total emissions associated with the improved processing of Tigla and the traditional processing of Dipale resulted in a 4.01% difference. The different studies, utilizing all different levels of improved technology, all have similar total carbon emissions. This is because of the large role par-boiling plays in the total emissions produced during the shea butter process. All shea kernels produced, independent of what technologies and methods are used, must undergo par-boiling shortly after being collected. In all of the studies examined women utilize the same method of a three-stone fire to par-boil. Par-boiling has been identified by both Glew at al. (2014) and Ojeda (2010) as the shea processing activity responsible for over 75% of CO_2emissions throughout the shea butter process.

These previous studies discuss the importance of improved cook stove implementation to alleviate the emissions produced during par-boiling. Thus, shea quality training has focused on reducing the amount of firewood used during par-boiling as well as promoting improved cook stoves for shea processors in northern Ghana. Figure 10 displays the final results of all firewood activity data collected in the field during the author's 2015 field study, as well as the final CO_2 emissions, and extraction rate calculated for each of the three processing methods observed during the study. The material inputs and resulting emissions can be compared at each processing step throughout this process diagram.

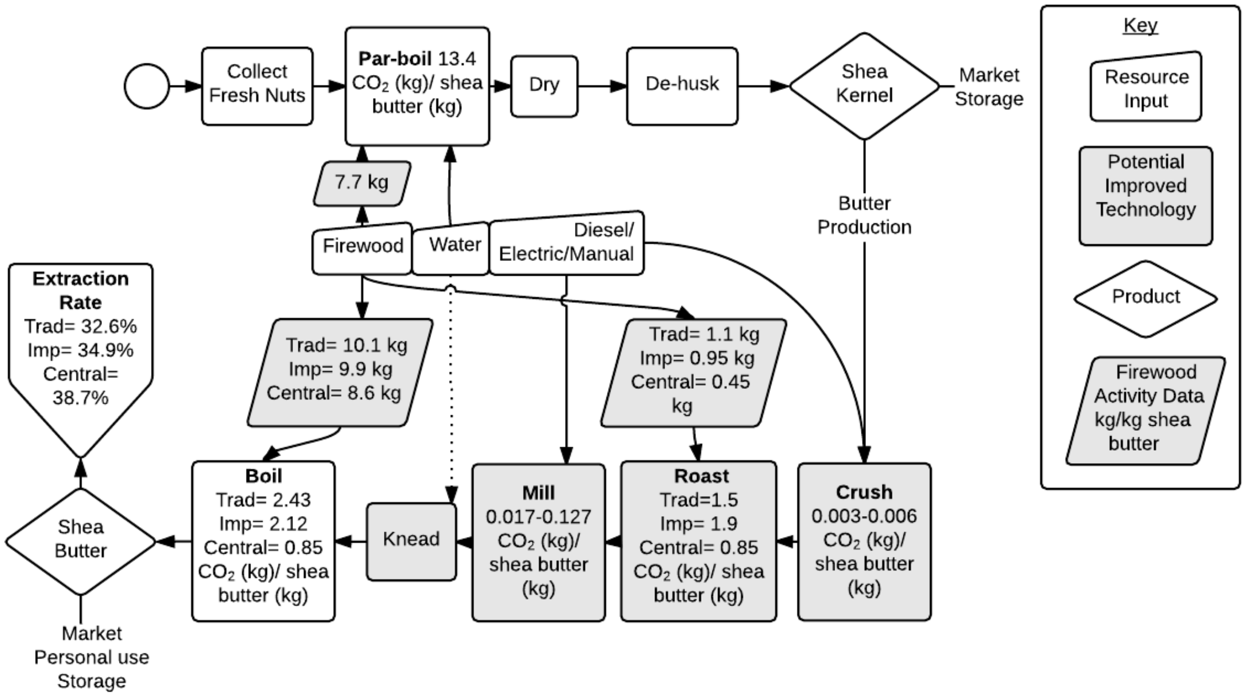

Figure 10. Basic shea processing activities showing results of firewood usage, final CO_2 emissions, as well as extraction rates of the traditional, improved, and centralized processing unit methods of shea butter production.

Figure 10 displays the results found in Table 12 as a process diagram showing the data and results found from the beginning of the shea butter process to the end during the 3 field studies. This data demonstrates that improved roasters utilized instead of traditional cauldrons can influence the total CO_2 emissions by between 1-3%. This is not as significant as the affect that improved cook stoves could have on the initial par-boiling firewood activity as described in Glew's et al. (2014) study seen in Figure 11. Glew et al. views emission reductions as a function of improved cook stoves and improved technologies. The results display that the replacement of 3-stone fires with to replace 3-stone with improved cook stoves can reduce emissions during the boiling processes have a potentially larger impact than the implementation of mechanical processes.

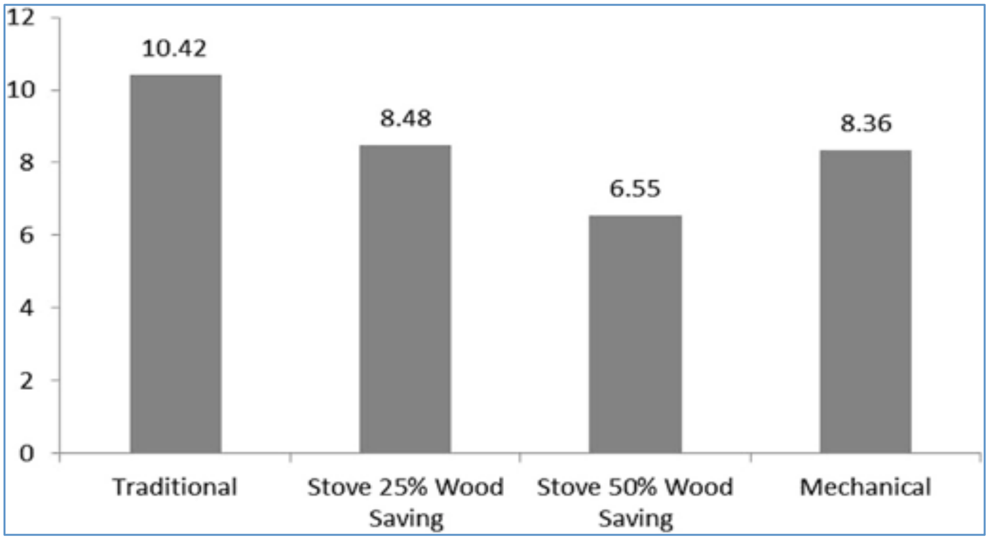

Figure 11. Comparison of the CO_2 equivalent emissions of 1 kg shea butter production for different extraction scenarios. Adapted with permission from Glew et al. (2014).

As evident in Table 12, there are differences in the CO_2 emissions from the roasting and 3-stone boiling methods found in Jibreel et al. and at the SeKaf processing center, as well as CO_2emissions from the improved roasting and 3-stone boiling methods in Tigla and the study conducted by Glew et al. (2014). The training underwent by the shea producers in the study conducted by Ojeda (2010) was not reported; however, the producers involved in Adams (2015) field study all underwent the same quality training developed by the GSA sustainability committee and implemented by StarShea ltd field workers. At the SeKaf processing center, typically a women's group was using 6-9 roasters. When they finish roasting, the kernels are emptied onto a cooling platform then the roaster is filled with crushed shea nuts and roasting continues until the kernels issued to their group are finished. The women in Tigla were observed to roast individually (although neighbors, friends, and family were present and assisted with tasks sporadically) and fill a roaster 1-3 times before completing the roasting of their crushed kernels. The emissions results from improved roasting in the village of Tigla and the SeKaf processing center that are provided in Table 12 resulted in a 56.4% difference in emissions during the improved and traditional roasting methods. It was observed during roasting in the village of Tigla that pieces of wood with smaller diameters were used for fuel combustion while the women at SeKaf chose the larger logs buried in the wood storage pile, or split very large logs with an axe into pieces sized to fit under the roasting apparatus. Both Tigla and SeKaf producers completed the same training and have access to the same roaster and utilize the 3-stone fire for boiling yet there is a significant (56.4%) difference in carbon emissions during roasting where SeKaf had lower fuel usage. Table 12 also shows that during the boiling process an 85.3% difference in carbon emissions was observed. Again both producer groups have had the same training and are using the same equipment. The reasons for this difference could be because typically at the SeKaf processing center the larger pieces of wood take women longer to ignite than smaller pieces; therefore, the fire does not need to be replenished often.

When questioned, the women roasting kernels at SeKaf stated that the larger and lighter the wood, the hotter the fire. Women would sort through the available wood storage piles to select particular pieces of wood to use in their fire. The wood was often taken from the middle of the pile where it was protected from rain and not touching the ground. If large logs and smaller branches of firewood are collected at the same time the smaller branches will dry out more quickly than large wood pieces and become properly seasoned for combustion faster. The larger logs will also have a higher moisture content causing them to burn slowly at a lower heat if combusted before becoming properly seasoned. This potentially could cause heating to take longer but also generate secondary emissions (discussed later in Section 4.1.2); smaller pieces of wood when dry will combust more rapidly at a higher heat. Figure 12 displays the typical wood used by women during the roasting of shea kernels in Tigla compared to the producer's choice of wood at the SeKaf processing center.

Figure 12. Photographs of wood taken during 2014 field study of wood used for roasting in Tigla and at the SeKaf processing center. Wood photographed is a representation of the wood typically used by producers in each study location.

Large amounts of smoke were witnessed during roasting at the SeKaf processing center. During the study a company project was in progression to replace 3-stone fires with improved cook stoves as well as improving roasters by adding chimneys, this was considered a need due to not only the amount of firewood being consumed but also the amount of smoke enveloping the butter producers, smoke being a byproduct of secondary combustion (Curkeet 2011). Potentially SeKaf could have lower primary emissions (CO_2) due to slow combustion of the wood (possibly wet) being used, leaving a higher weight of wood at the end. Whereas in Tigla the smaller branches are combusting faster and leaving less wood to be weighed at the end of the activity.

Other observations lead to varying conclusions. The SeKaf processing center is run very efficiently, workers are highly motivated and are not distracted by other activities like women in

Tigla who are processing shea while doing other household and daily tasks simultaneously. The processors at SeKaf also have more experience with quality production than the producers of Tigla who received training the same year as the study. Quality training and efficiency/focus on the activity could potentially be a reason less wood is consumed during the roasting and boiling process at the SeKaf processing center.

During the boiling of butter it was observed by the author that the butter is being boiled throughout the entire kneading process at all three study areas. This is done for convenience as well as to output quality shea butter. The fat separated during the kneading process should be heated and filtered the same day and never left sitting for long periods according to the GSA quality training. At SeKaf up to 12 women are kneading butter while others assisted them with providing warm/cold water as well as attending to the heated butter. In Tigla the women also knead in a group supporting each other. Typically a group of 4 to 5 women were kneading a single women's butter together. This rotation continues throughout the season as women continued to help each other knead, and in return receive assistance when their paste is ready to be kneaded. The more women assisting, it can be assumed the faster the continuously heated cauldron of shea butter is filled and filtered. Alternatively in Dipale women often kneaded on their own, with the help of a family member, or less than 3 other women was commonly observed. In addition, in Dipale only 1 or 2 women were observed kneading butter and placing it into the continuously boiling cauldron during the process before filtering. The community of Dipale has a shea producers group that markets their nuts and butter. The author observed that women participating in the selling of shea kernels and butter to outside markets participated in this group (approximately 30 members) and were seen often working together in groups while processing shea butter (similar to the women sharing kneading labor in Tigla). The women processing butter alone or with a small amount of family help were typically not participating in the women's group and were producing butter for personal use or intention to sell to the local market only.

The highest CO_2 emissions during the boiling process were observed in Dipale, 13.6% more than their neighbors in Tigla, and 96.2% more than the processors of SeKaf (see Table 12). Although an exact answer cannot be given to why this increase in emissions is occurring, observations lead the author to believe that a women working independently without assistance will use more firewood to boil their shea butter during the kneading process than those who work together in groups to knead a single women's shea butter in a much shorter period of time. These issues discussed are interesting variables that can also affect the material energy consumed during shea butter process. The influence of wood diameter, skill level of producer, individual and processing group dynamic, and the difference of village versus processing center settings on the CO_2 emissions produced during the boiling and roasting activities have the potential to affect the amount of material inputs shea producers must provide. Quantifying these variables is important to understand the potential to reduce material energy used in shea butter processing but is outside the scope of this study.

4.1.2 Firewood Moisture Content

During the field study, a moisture content evaluation was conducted at the SeKaf processing center to better understand the firewood utilized by women compared to default values assumed by IPCC (2006) guidelines. The EPA (2013) states that wood that has not been properly dried (seasoned) will not burn efficiently and will emit more harmful pollutants. Wood is purchased by SeKaf Ghana ltd and provided to the producer groups. The wood is transported by a truck to the processing center and left in large piles for use in shea butter and black soap production. The firewood is not covered unless moved to the roasting area that provides rain shelter. The women collect this wood when their assigned processing group is either roasting kernels or boiling water/butter during work hours that particular day. The results from this study investigate the moisture content of the "preferred quality" wood selected by the women for use, as well as the "poor quality wood" identified as undesired by the producers. These results calculated according to the methods in Section 3.2 are included in Table 13. Additional moisture content data of wood identified as "good quality" by the producers on a later date is also included in Table 13. The BSI standards followed in these experiments are included in Appendix C and the individual sample results collected at the SeKaf chemical lab can are in the Appendix Table F.4.

Table 13. Moisture Content (Following BSI 2011 Standards) of SeKaf Processors Preferred "Good Quality" and "Bad Quality" Firewood Identified in Firewood Storage.

Estimated Quality of SeKaf Firewood	**Measured Moisture Content**	**Sample Size (n)**
Good	16.2%	12
Bad	29.9%	3
Range min	9.27%	-
Range max	34.0%	-
Total average	18.9%	15

**Three samples tested in the 9%-10% range.*

The firewood data for evaluating the moisture content were collected in September 2014 during the rainy season. Rain was observed approximately twice a week. The author observed that the "good quality" wood was selected from the center of the piles where the wood was less likely to be exposed to moisture. The results show that the SeKaf processors were typically using wood of approximately 16% moisture content which 22% less than the default moisture content of 20% provided by IPCC (2006). In addition, firewood with up to 34% moisture was measured in the wood storage pile (a 52% difference from the 20% moisture content assumed by IPCC (2006)). In the villages of Tigla and Dipale the author observed that women stored their firewood in individual piles outside of each compound. During the dry season (December-April), when the demand for agricultural labor is at a minimum, women spend the day collecting firewood to stockpile for the rainy season (May-November) when time to collect firewood is limited due to agricultural productivity. Curkeet (2011) considers wood with moisture content of 20-25% to be properly seasoned to maximize heating efficiency and minimize poor combustion. To properly season firewood, proper storage and time is required. The IPCC (2006) guidelines for the calculation of GHG emissions due to combustion of wood/wood waste assumes an oxidation rate of 100%, which assumes full combustion and the production of CO_2 and water (H_2O) only. Incomplete combustion can be seen by smoke production (Curkeet 2011) that is an indicator of emissions of particulate matter, CO, and hydrocarbon emissions. In the field study, wood used to process shea butter was observed to undergo not only primary combustion but secondary as well.

4.1.3 CO_2 Emissions Due to Improved Mills and Crushers

In addition to CO_2 emissions from direct burning of firewood throughout the shea butter process, there are also emissions from fuel or electricity use with improved mills and crushers. Mechanized mills used for grinding agricultural products are also used by shea producers for milling kernels into the paste used to extract the butter. The manual process of shea butter production requires manual crushing of shea kernels grinding roasted shea kernels into a fine paste and does not have associated CO_2 emissions. During this study the practice of manually milling roasted nuts into paste was not observed. Women use a community or nearby grinding mill to avoid the manual labor, crushing machines also exist to alleviate the time consuming task of crushing individual shea kernels manually. The crushing machines are rarely accessible in northern Ghana and only producers in urban areas or supported by a COOP or NGO have access to improved crushing technology. Mechanized mills and crushers utilize diesel or electric engines for power. Combusted diesel fuel as well as consumed electricity of the semi-mechanized processes contributes to the overall CO_2 equivalent emissions throughout the shea butter process. The results of the estimation of CO_2 equivalent emissions associated with use of diesel and electric powered mills and crushing machines is provided in Table 14.

Table 14. CO_2 Equivalent Emissions due to the Processing of 1 kg of Shea Butter.

	Motor Type	Kg CO_2 −equivalent	Comments
Tigla Grinding Mill	Diesel	0.078	-
Gushie Grinding Mill	Diesel	0.127	-
SeKaf Grinding Mill #1	Electric	0.017	Newest addition to milling/crushing equipment.
SeKaf Grinding Mill #2	Electric	0.025	Motor connected in series to crusher.
SeKaf Crushing Machine	Electric	0.003	-
Theoretical Crushing Machine	Diesel	0.006	Assuming average kg diesel/kg butter = 0.038 and mill/crusher capacity ratio of 250/1500.

The data collected to find CO_2 equivalent emissions are provided in Appendix F, Table F.5. Table 14 shows that the crushing machines were found to have minimal CO_2 equivalent emissions (0.003 – 0.006 Kg CO_{2e}) compared to the grinding mills that is because of their high operating capacity and minimal fuel usage. The electric motors also have lessened CO_2 emissions especially because Ghana utilizes a good percent of hydropower for their electricity production. The grinding mills were found to have a higher range of CO_2 emissions, 0.025 – 0.127 Kg CO_{2e}.

4.1.4 Comparison of Methods

Figure 13 displays the results found during the study of material energy expended in the shea butter process in terms of $\frac{CO_2\,(kg)}{Shea\ butter\ (kg)}$ emissions during each shea butter processing activity. The amount of firewood combusted in terms of CO_2 emissions can be compared to the CO_2 emissions found for diesel and electric powered equipment utilized during the process of improved milling and crushing of shea kernels. The results in Figure 13 show that the oldest of the SeKaf grinding mills account for less than 0.2% of CO_2 equivalent emissions throughout the process. In regards to material energy, this figure shows that mechanized mills and crushing machines were found to have much less environmental impact compared to firewood usage.

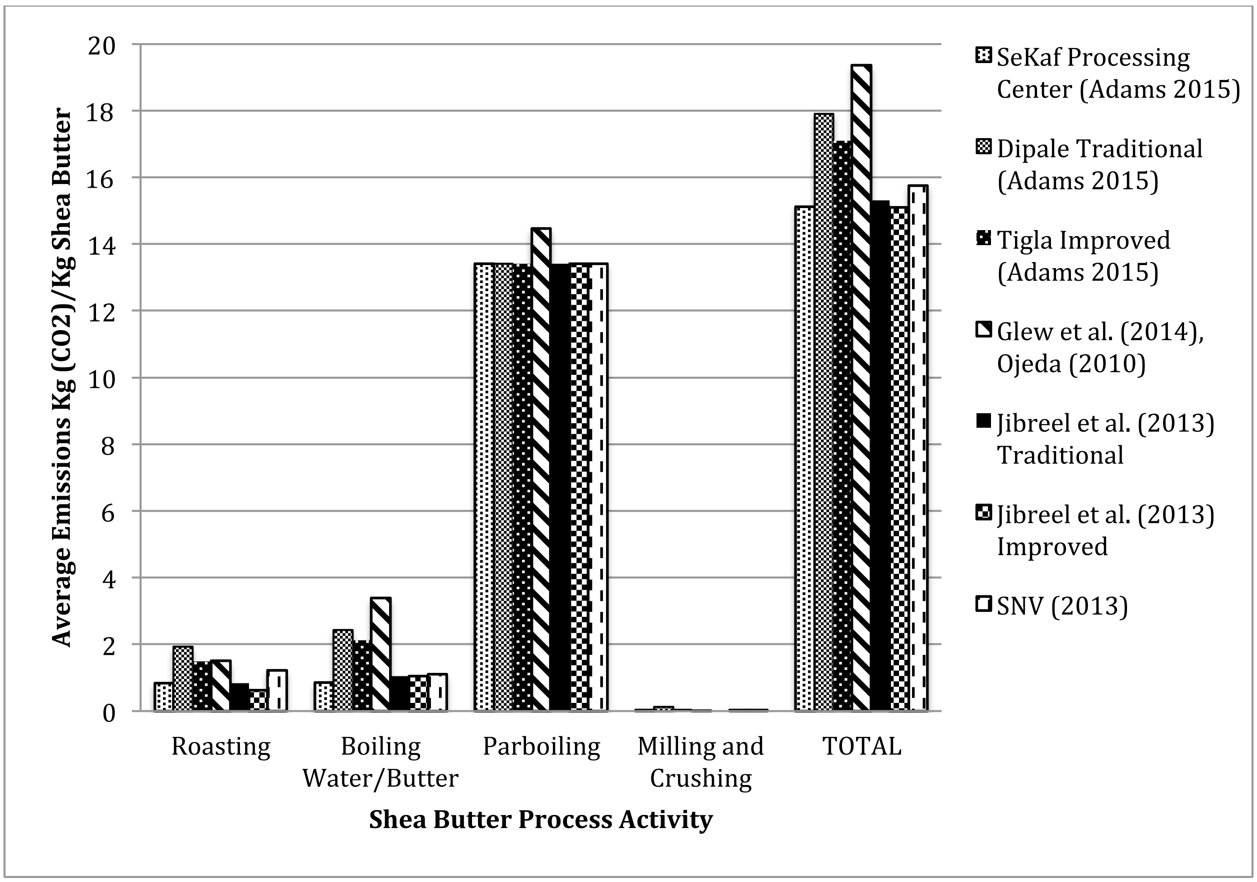

Figure 13. Average emissions $\frac{CO_2\,(kg)}{Shea\ butter\ (kg)}$ produced from traditional and improved methods of shea butter production.

Figure 13 shows that the traditional roasting method had greater CO_2 emissions than processors utilizing the improved roaster, without including mill/crusher emissions the traditional process was found to produce 17.8 kg CO_2/kg shea butter whereas 17.1 and 15.3 kg CO_2/kg shea were calculated at the village of Tigla and the SeKaf processing center respectively. The traditional processing method in Dipale was found to have fewer emissions than that of the Glew et al. (2014), and Ojeda (2010) which found a total of 19.4 kg CO_2/kg shea butter in the improved processing center study results. Although the same IPCC (2006) guidelines were followed, many variables could cause this variation in results (e.g. firewood type, season, precision of data collected, producer practices, etc.).

The Glew et al. (2014) and Ojeda (2010) studies calculated emissions based on an assumed 33% extraction rate, whereas this study (Adams 2015) used the actual extraction rate of each data set (found to range from 22-44%) to determine the firewood activity data in term of shea butter (kg). As seen in Table 12 the extraction rates used in this study were generally higher than 33%, which would decrease the amount of resulting emissions. If the actual extraction rate was greater than 33% but the conversion factor of 3.03 nuts per kg shea butter was used in calculations (as in Glew et al. (2014); Ojeda (2010)), the final emissions result would be higher than the emissions calculated using the actual extracted amount of shea butter.

The results of this study verify that as the extraction rate increases the firewood use and overall emissions decreases. Overall the same patterns in primary combustion emissions can be seen in the examined shea butter processing studies of different methods in the Northern Region of Ghana. In regards to material energy, improved cook stoves for boiling would have the largest positive environmental impact of the improved technologies discussed (improved roaster, mill, mechanized crushing).

4.2 Human Energy

The human energy expended throughout the traditional, improved, and centralized shea butter production processes are evaluated using the FAO's standard PARs and correlating processing steps in Table 15. These PAR values were based on field data, observations, and the author's personal experience of shea processing. These standard PAR values are considered an accurate comparison to each labor step experienced during the shea butter process.

Table 15. PAR Values and Activity Analogues from FAO (2001) Chosen for the Shea Butter Processing Human Energy Analysis.

	Labor	Activity Analogue	PAR
[1]	*Collecting shea nuts*	Picking fruit	3.3
[2]	*Depulping*	Shelling	1.6
[3]	*Par-boiling*	Cooking	1.8
[4]	*Sorting*	Shelling	1.6
[5]	*Dehusking*	Shelling	1.6
[6]	*Crushing (traditional)*	Pounding Grain	5.6
[7]	*Mechanized crushing (improved with 10 km travel)*	Walking with 25-30 kg load	3.9
[8]	*Processing center/local crushing and milling*	Standing (Negligible)	0.0
[9]	*Roasting (improved and traditional)*	Cooking	1.8
[10]	*Mechanized milling (10km travel)*	Walking with 25-30 kg load	3.9
[11]	*Kneading*	III	4.8
[12]	*Boiling*	Cooking	1.8
[13]	*Collecting Firewood*	Collecting wood for fuel	3.3
[14]	*Collecting Water*	Collecting water	4.5

Human energy was quantified into (MJ/ kg shea butter) using the energy cost given by the FAO (PAR) as well as the time spent during each activity during the shea butter production process. Table 16 outlines the data collected in this study as well as alternative study results regarding time spent to complete a shea processing activity. The values collected from the field and alternative studies are converted to the similar units (min of time / kg shea butter). This value is a function of the time spent during the activity, the weight of shea nuts or butter involved in the activity, and conversion factors.

To find the amount of time spent during an activity of the shea butter process, values found in Table 1 in section 2.9 as well as the firewood activity data in Table 11 was used to convert the data collected in this Study into common units in order for comparison. The following assumptions were chosen to complete human energy expenditure calculations:

1. 11 L of water is required to produce 1 kg shea butter (Table 1 Section 2.9)
2. Firewood required per kg shea butter was derived from the firewood activity data for each process in Table 11.
3. The average human walking speed assumed during travel is equal to 5 km/hr (TranSafety 1997).
4. Average distance to grinding mill for communities without access is 10 km round trip.
5. 25 L of water (1 jerry can) collected per trip to a water source.
6. Time to mechanically mill or crush the kernels needed per 1 kg of shea butter is based on the GRATIS manufacturing capacities (Grinding mill= 250 kg/hr, Crushing machine=1,500 kg/hr).
7. 2.72 minutes is required to collect 1 kg firewood (Adams (2015), n=9), 0.55 minutes is required to collect 1 L of water (based on distance from Tigla town center to borehole).

The value selected in the energy calculation can be seen in bold in Table 16. The values were chosen based on the method of obtaining the data as well as the values accuracy to describe the processing steps observed in the field. The average pedestrian walking speeds found in TranSafety (1997) are equal to 5km/ hr, which is a common value used for human walking speed calculations. In Table 16 the values given for collecting nuts provided by StarShea (2012) study required 44.9 min to collect enough nuts to produce 1 kg shea butter based on 2 data sets completed in Burkina Faso.

Reducing time it takes to gather nuts is difficult due to the unique properties of the shea tree and nut. Planting shea in accessible groves for collection would not benefit collectors for over a decade due to the time required for a shea tree to mature and begin to fruit. According to Esinam (2010). Access to donkey carts or bicycles for shea nut collection could be beneficial in only certain areas were fruiting trees are accessible by these forms of transport. Shea trees grow sporadically and are often only accessible by foot. Shea nut pickers indicated that output levels in a year depend on the yield from the shea tree. This varies from two to seven (2-7) bags per year per person. During this study, the author observed that shea collectors were unable to collect the entire amount of shea fruit available. Shea trees were densely populated in the study area but women were pressed for time to complete the demanding agricultural work required during the rainy season. The majority of the population depends on subsistence farming for survival.

Although research is being conducted on quickening shea fruit production, increasing yield for trees, as well as promoting conservation/management/planting and grafting of shea trees, no successful technology interventions have been identified. Reducing the amount of time of shea production activities such as crushing and firewood collection, could provide the producer with more time and energy to collect the available shea fruit Shea nuts collection varies by month, time, location, tree density, as well as that season particular shea fruit production. The average value of 124 min/ 1 kg shea butter was found for the amount of time to collect shea nuts. This value is found by the author's average observations in the field and was chosen due to the methods used to obtain the data as well as the fact that the data is consistent with the location and season of the majority of data being analyzed and compared in this study.

Shea nut collection time is difficult to generalize due to the many variables involved that change throughout different communities and cultures found in the shea belt. The human energy analysis in this study is an accurate portrayal of the studies included at the specific study locations and must be reevaluated or expanded to be applied to shea butter production within different conditions. Results such as boiling, sorting, and roasting time have fewer variables and can more easily be compared across different studies. The time to travel to a mill also varies greatly for every community; the value of 10 km was based on the distance between communities sharing the market town of Diare (market town of Tigla and Dipale). This distance is not accurate for the majority of shea producers outside of this area and therefore would need to be modified to evaluate other specific shea production processes.

Collecting water is another variable that cannot be standardized; a much more extensive data collection regarding time to collect water would be needed to derive a value suitable for communities in the study area. The distanced to the main borehole in the community of Tigla and the average amount of water carried in the author's place of stay was used for this study. Water collection is another variable that should be evaluated on a case-by-case basis as water scarcity and access is community specific. For example the borehole in Tigla does not produce water during the dry season creating months throughout the dry season where the distance to collect water increases from a 1.45-km round trip to greater than a 4-km round trip.

Table 16. Time (min) per Shea Butter (1 kg) Produced during Improved and Traditional Shea Butter Processing Activities.

	Study Results $\frac{Time\ (min)}{Shea\ butter\ (kg)}$				Chosen Values for analysis		
Shea Processing Activities	***Adams (2015)***	***Jibreel et al. (2013)***	***SNV (2013)***	***StarShea ltd (2012)***	***Min/ kg shea butter***	***n****	***Comments***
Collecting nuts	**124**			44.9	124	3	Assuming conversion rate of 11.22 fresh nuts per kg shea butter.
Depulping	**11.3**			22.4	11.3	2	Shea nuts often depulped with help of family member and children eating the fruit.
Par-boiling	**21.9**			15.1	21.9	19	Calculated from average of all par-boiling data sets observed.
Dehusking				**21.3**	21.3	2	Activity not monitored, thus utilizing the data collected by StarShea ltd (2012).
Sorting	**6.82**		4.60		6.82	4	Data collected at SeKaf processing center and in Tigla households.
Crushing (trad.)	**31.7**	7.27			31.7	9	Data collected in Dipale.
Crushing (imp.)	**0.121**	.240	2.00		.121	1	Data collected at SeKaf processing center.
Roasting (trad.)		**6.06**			6.06	1	Data collected in Dipale.
Roasting (imp.)	**5.24**	3.64	6.36		5.24	14	Data collected at SeKaf processing center and in Tigla.
Milling (travel)	**9.09**				9.09	N/A	Appendix F.
Milling (mechanized)	**0.727**	3.03	3.45		0.76	N/A	Data collected at SeKaf processing center.
Kneading		**25.5**	**33.30**		29.4	3	Average of earlier field studies.
Boiling		**13.3**	**5.30**		9.30	3	Average of earlier field studies.
Collecting firewood (trad.)	**26.2**	8.91			26.3	8	Data collected in Dipale and Tigla.
Collecting water (trad.)	**5.20**	5.02			5.20	N/A	Data based on Tigla water supply.
Collecting firewood (imp.)	**25.6**	7.92	4.73		25.6	8	Amount of time to collect firewood correlates to amount of firewood consumed in different processing methods requiring different input amounts.
Collecting water (Imp.)		**3.81**	**6.44**		5.13	N/A	Data based on Tigla water supply.

**Frequency (n) correlates to chosen values (bold) to represent activities in energy calculation of* $\frac{Time\ (min)}{Shea\ butter\ (kg)}$.

For activities not evaluated in the field by the author in this study (e.g. kneading and dehusking time) a value from an earlier study was chosen or an average of the values provided by prior studies to evaluate the entire human energy expenditure of the shea butter process. An average value was taken when multiple studies evaluated an activity with similar methods and conditions to that of the author's area of study and one value could not be determined more accurate than the other. To evaluate the different methods of shea processing in regards to human energy, 6 different examples of different processes (Table 18) are described by the $\frac{Time\ (min)}{Shea\ butter\ (kg)}$ required at each step based on the field calculations and assumptions shown in Table 16. Five of the 6 processes were commonly observed in northern Ghana, The process evaluating improved roasting with access to a mill and crushing machine through travel was added to evaluate the impact of producers having the same access to a crusher as they do a mill. The mill access and potential crushing machine access was based on the area of study pictured in Figure 14. To find the energy expended by producers to travel to a mill the distance traveled is required.

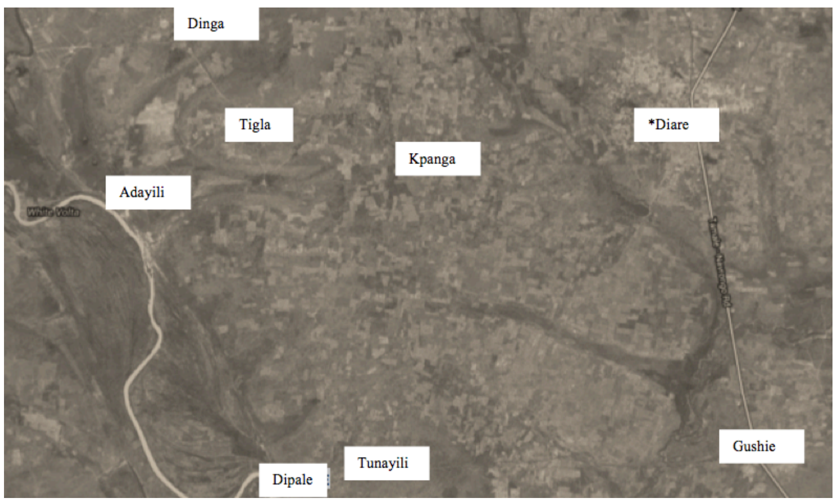

Figure 14. Map of Diare market town and surrounding communities. Created by the author using Google maps (2015).

To find this value seen in Table 17 for walking to a mill the average distance traveled by community members to mill their kernels was evaluated. Table 17 displays the community mills frequented by neighboring community producers as well as the distances mapped during the authors 2015 field study. By taking the average distance women from the different communities were traveling to mill their shea kernels, a value of 10 km was found to be the average distance producers were traveling when there was no access to a mill in their community.

For this area of study it cannot be assumed that all shea producers have access to a mill, as commonly observed throughout the authors peace corps service. To evaluate the impact of a mill and/or crushing machine in the area of study, traveling a distance of 10 km to access this equipment is assumed considering improved technologies do not only impact the communities they are located but also the nearby communities within traveling distance. For example, when Tigla received a grinding mill in Spring 2014, the community members of Adayili now require less human energy to mill shea kernels due to the 24-km trip to Diare's grinding mill being reduced to a little over 4 km per trip to mill shea kernels in Tigla.

Table 17. Distance Traveled by Community Members without Mill Access to Mill Shea Butter.

Community	Mill Locations Frequented	Average Round Trip Distance (km)
Adayili	Tigla	4
Kpanga	Tigla, Diare	8
Tunayili	Gushie	10
Dipale	Gushie	18
	Total Average:	**10**

The final 6 processes chosen to represent current and potential shea processing methods in the area of northern Ghana are organized in Table 18. The production of only shea kernels is also evaluated to consider the producers selling only kernels for profit and not partaking in shea butter production. The shea processing center without the energy expended by those producing the kernels used in the facility is also accounted for to evaluate the energy required to produce shea butter in an improved facility such as SeKaf's shea butter village.

Table 18. Comparison of $\frac{Time\ (min)}{Shea\ butter\ (kg)}$ Expended Throughout the Traditional and Improved Shea Butter Processes Observed in the Northern Region of Ghana.

	Traditional process (with travel to mill)	Improved process (with community mill)	Improved Process (with travel to mill and crushing machine)	Centralized processing center	Shea kernel processing	Processing center including kernel processing
Collecting	124	124	124	-	124	124
Depulping	11.3	11.3	11.3	-	11.3	11.3
Par-boiling	21.9	21.9	21.9	-	21.9	21.9
Dehusking	21.3	21.3	21.3	-	21.3	21.3
Sorting	6.82	6.82	6.82	6.82	6.82	6.82
Crushing trad.	31.7	31.7	-	-	-	-
Crushing imp.			9.09	0.12	-	0.12
Roasting trad.	6.06	-	-	-	-	-
Roasting imp.		5.24	5.24	5.24	-	5.24
Walking 10 km to mill	9.09	-	9.09	-	-	-
Milling	0.76	0.76	0.76	0.76	-	0.76
Kneading	29.4	29.4	29.4	29.4	-	29.4
Boiling	9.30	9.30	9.30	9.30	-	9.30
Firewood collection trad.	26.2	-	-	-	-	-
Water collection trad.	6.07	-	-		-	-
Firewood collection imp.	-	25.6	25.6	-	19.6	19.6
Water collection imp.	-	5.13	5.13	-	4.14	4.14
TOTAL	301	269	73.5	56.2	209	253

The 6 processes were chosen based on the authors observations of common processing methods implemented in northern Ghana over 2 years/shea seasons. To visualize the human energy expenditure, the total time spent per kg shea butter value in Table 16 was multiplied by the energy cost (PAR) in Table 9 of Section 3.4. The result was then multiplied by 25 (kg) to find the time spent during each shea processing activity per 25 kg of shea butter production (See

Appendix F). The human energy expended can then be evaluated in terms of MJ per 25 kg of shea butter production (typical value used in studies as well as a weight of butter that can be produced by about 1 jute sack). As seen in Table 18 each processing method has different total energy expenditures. By calculating the percent of energy (MJ) expended during each activity of the entire process, the different interventions (e.g. crushing machine, mill access, roaster) can be evaluated in terms of human energy savings. Different activities have a varying level of importance to shea producers depending on their processing methods as well as access to improved technologies. For example the traditional method of crushing requires over a half hour of labor to crush enough nuts to produce 1 kg of butter. This large amount of time and labor makes other interventions such as improved roasters less important for energy savings. In contrast at a processing center where women have access to mechanized mills and crushers the majority of the women's time is spent kneading the paste. This creates incentive for processing centers to explore new technologies to assist in kneading the butter to increase production speed and reduce labor required by workers.

The total human energy expended for different processes are compared in Figure 15. The most significant difference is seen between the energy expended a butter processing facility comparative to the other process. The kernel processing method by itself requires 49.6 MJ of energy, it accounts for 56% of the energy expended over the entire traditional process of butter production practiced in Dipale, and examining the process of fresh shea nuts to the final butter produced at the SeKaf processing center 72% of the total energy spent is processing the shea nuts in the village, where only 32% of the total energy is spent to process handcrafted shea butter from the processed kernels.

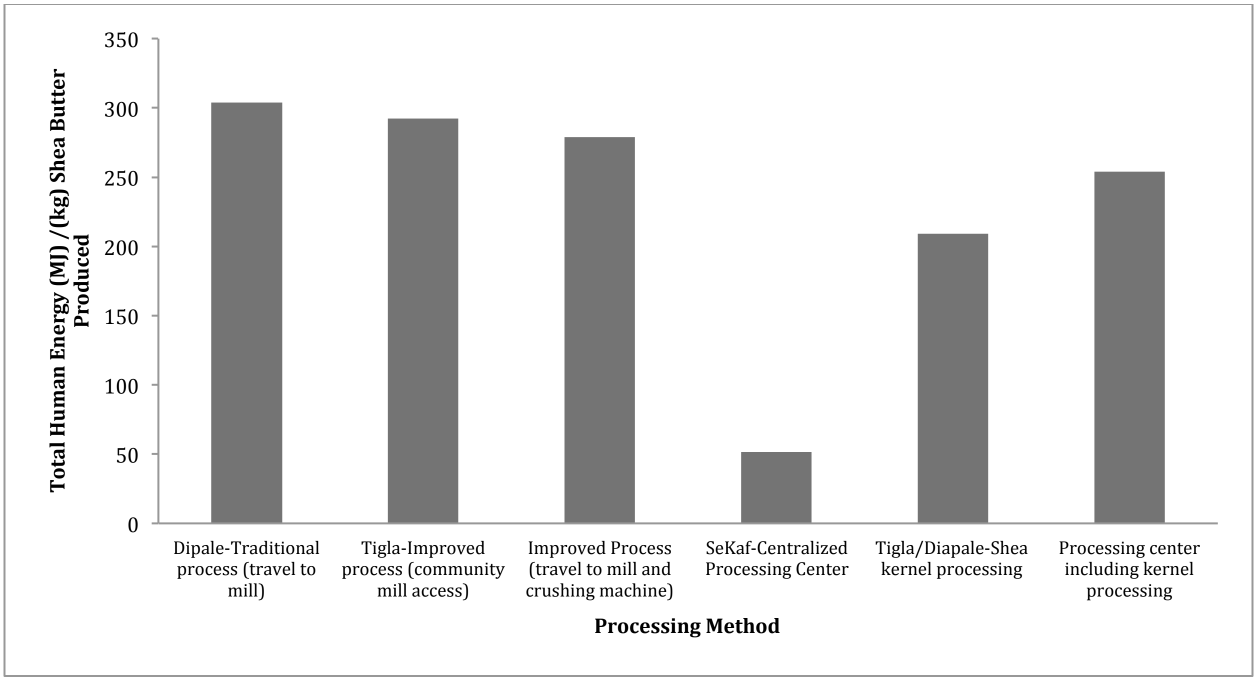

Figure 15. Total MJ of human energy expended for the production of 25 Kg of shea butter for different shea butter processing methods practiced in the Northern Region of Ghana.

Figure 16 compares the activity energy as a percent of the total for the three processing methods examined in the study. The majority of energy is expended through the collection of shea nuts. In the Northern Region near Tamale (study area) the amount of shea nuts collected is dependent on the amount of time women can spare during the day to collect the nuts. In Tigla and Dipale there were no restraints on shea collected. In Tigla because of the large quantities of shea trees as well as available fruits to collect the trees are seen as communal. The shea fruit fallen at farm is allowed to be collected by anyone.

Often community members were observed collecting fruit at farm or near their house to eat and then discarding the nut without the thought of adding it to the family collection of nuts to be processed. During the 2015 study there was more shea fruit than community members could harvest. Thus, it can be assumed if any intervention saving time and energy for shea producers is successful, the producers will have additional time and energy to put towards the limiting factor of their production potential-the collection of the shea nut.

The amount of human energy required for an activity during a shea processing activity is depicted in Figure 15 by the percent of total energy required for each processing activity. For example, kneading accounts for almost 25% of human energy requirements at a shea processing center. This is due to the assumption that producers at the processing center have access to a mechanized mill and crushing machine as well as firewood and water. Thus, the majority of energy expended at a processing center is due to the kneading of shea butter during extraction. Appendix H displays the distribution of energy expended at the SeKAf processing center alone without accounting for the kernel processing. This results in almost 90% of energy expended during the kneading process.

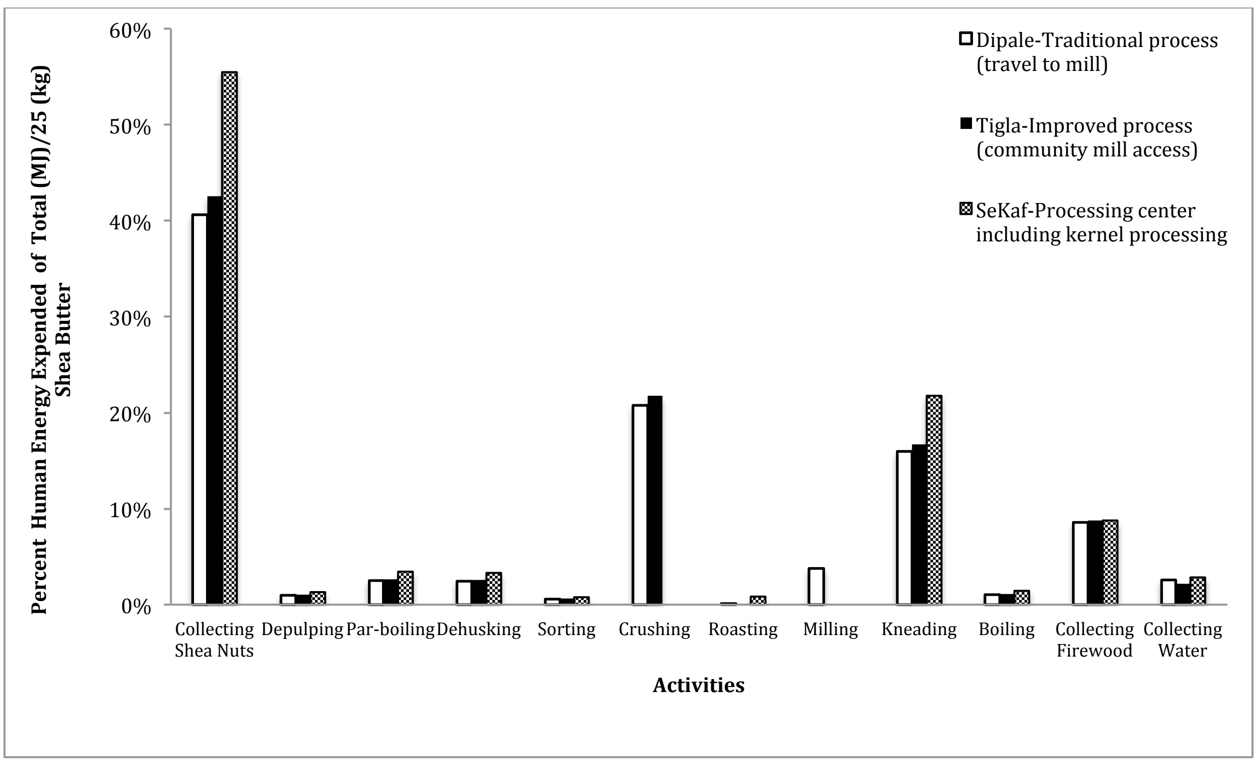

Figure 16. Percent of total human energy (MJ) expended during multiple shea butter processing in Tigla, Dipale, and the SeKaf processing center study locations.

Other energy consuming activities have been quantified such as the energy required for crushing (18.5 MJ per 25 kg of shea butter) and kneading (14.2 MJ per 25 kg of shea butter). The individual activity energy can be found for each process in Appendix Tables G.1 - G.6. Tables G.1 - G.6 display the time required per kg of shea butter, the PAR for the activity, the total MJ of energy required per 25 kg of shea butter, as well as the correlating percent of total energy required per activity. Appendix H uses this data to produce Figures H.1- H.6, which display the human energy, expended during each activity of the shea butter process as a percent of the total energy. Figure 17 shows this data for the traditional process practiced in Dipale.

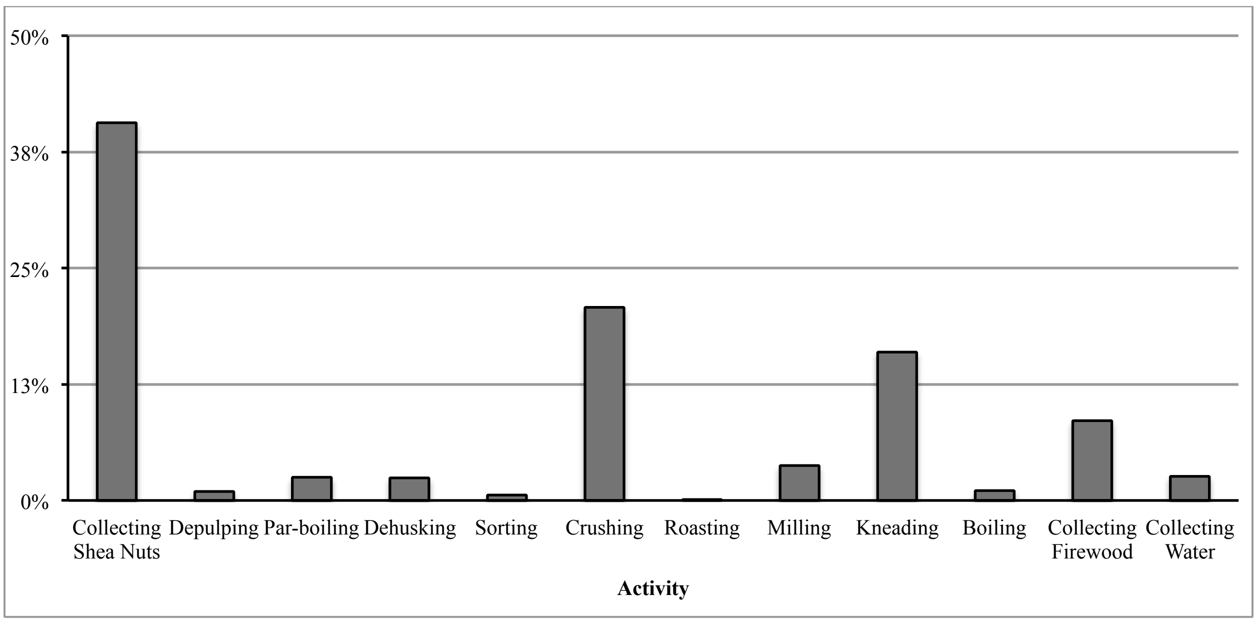

Figure 17. Percent human energy expended during each activity of the traditional shea butter process observed in the village of Dipale.

Figure 17 confirms that collecting shea nuts requires the most time and human energy, the amount of shea nuts collected is the limiting factor on how many kg of kernels or butter a producer will achieve. By saving time and human energy during other intensive steps such as crushing, kneading, or firewood collection, the producer can use additional time and energy to increase production through nut collection. Crushing energy can be alleviated through mechanized machines powered by either electricity or diesel fuel. Crushing mills can be found in larger towns in northern Ghana such as regional capitals. Crushing machines are an expensive investment for an individual, and are not independently owned an operated for a charge in the area of study due to the lack of demand. Milling is needed to grind staple foods but no existing demand for crushing machines other than shea processing exist in rural communities. This makes it difficult for individual operators to make a profit charging individual producers. Organizations and cooperatives have the potential to pool money and invest in technology such as a crushing machine unlike individual producers.

Kneading is also an energy intensive task that can be improved for energy and time savings. Currently industrial kneading processes utilize mixing/kneading machines to extract shea butter. This method is only seen at advanced processing centers or in large organized groups of processors. Kneading machines are produced locally and have been adopted by few processors. SeKaf has identified the energy expended during kneading as a key activity for energy saving potential. During this study new machinery was being adapted to extract butter during the kneading process. These machines are still in the design phase, and while functioning, still require improvements before a cost benefit analysis can encourage investment in locally available, affordable, mechanized kneading. A clear answer to sustainably reducing human energy during the kneading process has not been achieved, the energy expended do to firewood collection, on the other hand, has many opportunities to be alleviated.

Looking closely at the percent human energy expenditure per activity throughout the traditional method (Figure 17) it can be seen that manual crushing as well as firewood collection require a significant amount of the total energy expended during production. Improved crushers are available in northern Ghana and can be attributed to time and energy savings for shea producers with access to this improved technology. The majority of shea producers do not have access to crushing machines in Ghana as well as the capital required to invest and maintain such equipment.

4.3 Human and Material Energy

Material energy was quantified by weighing the material input of firewood during the shea butter process and calculating the corresponding CO_2 emissions from the fuel combustion based on IPCC (2006) guidelines for GHG emissions calculations. The activities in the shea butter process that require the most resources as well as improved technologies to potentially reduce CO_2 emissions were evaluated through the material energy analysis. In rural communities, shea producers collect the firewood and water needed to process their shea kernels, the work required to source the required inputs is a function of human energy and time. The human energy can be calculated from the caloric expenditure required by each activity to evaluate the energy expended from shea butter processing. Processing shea butter not only differs throughout the 21 producing countries, it also varies throughout communities and processing groups throughout the Northern Region of Ghana. Shea butter processing has many variables and is hard to compare directly. By comparing individual activities in similar terms for each process, conclusions were made on which activities are most in need of an intervention. The material energy results reaffirmed that par-boiling has the greatest environmental impact. Through the evaluation of traditional and improved roasting methods, a reduction in firewood was noted in the Adams (2015) and Jebreel et al. (2013) study (23.5% and 28.5%, respectively). However, the overall reductions in CO_2 emissions using the improved process were only 1-3%. During the traditional process, 28% of human energy expelled is due to firewood collection. By reducing material inputs through the intervention of improved cook stoves (up to 75% firewood reduction), both material and human energy could be reduced by a single intervention. The total human energy expended during the traditional process was found to be 3.6 MJ per kg shea butter. Comparing this to the material energy, the total MJ of energy used to produce 1 kg of shea butter through the traditional methods was found to be 158 MJ per kg of shea butter. This concludes that energy (MJ) is not the most effective way to compare human and material energy in regards to shea butter. The heat energy produced by the wood cannot be directly compared to the caloric energy expended by human. The energy of the firewood greatly exceeds any of the energy expended by producers during an activity. The energy of the producer is a function of time and as discussed earlier time is of great importance during the farming season that coincides with shea season. The amount of time spent to produce shea butter can be compared to the profit of the shea butter itself. The market price of firewood purchased for use at a processing center can be compared to the effect it has on the final profits, and the time spent during each shea butter processing activity can be compared to the final profit to see theoretically how much of an economic impact time saving activities could have on a producers profits. Using the data on material and human energy collected during traditional processing in rural villages as well as improved processing methods in a centralized processing center, the impacts of improved technology and different practices can be evaluated by profits. To view the economic differences between rural traditional processing and centralized processing centers the data collected needs to be discussed in terms of economic value. During the study time period (July 2014- September 2014) the local market price was GH¢ 3.00 (USD$ 0.83) per 1 kg of shea butter and GH¢ 0.70 (USD$ 0.18) per 1 kg shea kernels. These market prices fluctuate throughout the year as well as the price of wood and milling fees. For the purpose of this study the market price and input costs were taken from the period and location of the study. Shea butter production depends on the amount of time a woman has to produce it. In Table 19 the amount of time taken during each step of the traditional process is itemized. By taking the percent of the total time each individual step takes to produce a kg of shea butter, each individual percentage of time can be correlated to the percent of the profit for a kg of shea butter (GH¢ 3.00 per kg). Women were found to be producing GH¢ 0.60 of shea butter per hour of time spent on processing activities.

Table 19. Time Calculated for Each Processing Activity to Produce 1 kg of Shea Butter Compared to Market Price of 1 kg of Shea Butter.

Activity	Traditional Processing (with travel to mill) (min)	% of total time	Time cost GH¢ (% of market price)
Collecting nuts	124	0.41	1.23
Depulping	11.3	0.04	0.11
Par-boiling	21.9	0.07	0.22
dehusking	21.3	0.07	0.21
Sorting	6.82	0.02	0.07
Crushing (traditional)	31.7	0.10	0.31
Roasting (traditional)	6.06	0.02	0.06
Walking 10 km to mill	9.09	0.03	0.09
Milling	0.76	0.00	0.01
Kneading	29.4	0.10	0.29
Boiling	9.30	0.03	0.09
Firewood collection	26.2	0.09	0.26
Water collection	5.20	0.02	0.05
Total	**303**		**3.00**

Viewing each activity in terms of how much time is expended per 1 kg of shea butter, the activities in need of time saving interventions can be identified. The traditional method is compared to the improved processing center as well as shea kernels processing to identify what economic impacts centralized processing has on shea producers time and profit. Centralized processing has different effects of shea producers culturally, socially, and economically. The material and human energy data can be used to compare the economic differences between the women producing traditional shea butter, the women selling kernels to be processes elsewhere, and the women at processing centers producing butter from purchased kernels. Table 20 compares these 3 processes using time and cost values calculated in this study using the 2014 field study data.

Table 20. Economic Comparison of Traditional Shea Butter Processing, Centralized Shea Butter Processing, and Individual Shea Kernel Processing Methods.

Comparison	Trad. Process	Units	Village Shea Nut Processing	Units	Processing Center	Units	Assumptions
Time taken to produce 1 kg of shea butter	**304**	min/ kg shea butter	**69**	min/ kg shea kernels	**51.7**	min/ kg shea butter	3.03 kg nuts/kg butter
Production capacity of producer	**34.7**	kg/ month	**153**	kg/ month	**205**	kg/ month	8 hr/day 22 day/month
Value of monthly production	**104**	GH¢ / month	**107**	GH¢ / month	**615**	GH¢ / month	3.00 GH¢ /kg butter. 0.7 GH¢ /kg nuts
Cost Inputs to be deducted from value	Mill fee 5	GH¢ / month	-	-	Firewood 38.3 Electricity 3.1 Shea kernels 435	GH¢ / month	1.7 kg firewood/ kg butter 0.11 GH¢ / kg firewood (SNV 2012) Crush and mill - 0.015 GH¢ /kg shea butter
Total Profit	**99**	GH¢ / month	**107**	GH¢ / month	**139**	GH¢ / month	
Cost of time spent on crushing	0.31	GH¢ / kg shea butter	-	-	0.00	GH¢ / kg shea butter	0.15 min/kg shea butter to crush shea nuts
Total cost of crushing	**11**	GH¢ / month	-	-	-	-	-
Wood	0.25	GH¢ /kg shea butter	0.07	GH¢ / kg nuts	0.11	GH¢ /kg shea butter	-
Total cost of time spent collecting firewood	8.7	GH¢	11	GH¢ / month	38.3	GH¢ / month	-
Cost savings with 75% reduction in firewood	6.5	GH¢ / month	8.25	GH¢ / month	28.7	GH¢ / month	Improved cook stove with 75%firewood reduction
Profits with improved cook stove technology	**106**	GH¢ / month	**115**	GH¢ / month	**168**	GH¢ / month	-
Profits with Improved Crushing Machine	**110**	GH¢ / month	-	-	-	-	-
Total human energy (calorific expenditure)	**193**	MJ/month	**100**	MJ/month	**131**	MJ/month	Traditional= 5.56 MJ/kg Village nut process= .65 MJ/kg kernels SeKaf=.64 KJ/kg shea butter
Total material energy (heat energy)	5,250	MJ	1,650	MJ	3,000	MJ	9.7 kg fire wood/ kg shea butter –traditional 0.69 kg fire wood/kg nuts –par-boil 0.934 kg fire wood/ kg butter- Processing center

Table 20 results are based on the assumption of producers working 8 hours a day, 22 days a month on shea butter production (observed at processing center and equivalent to approximately 4.5 hours of time spent on shea processing a day. The time calculated for each method to produce shea butter or shea kernels was used to find how many kg could be produced in 1 month with the assumed working hours. Thus, the income potential based on the market price was found. It was found that during the traditional processing method the time spent crushing shea kernels account for 11 GH¢ work of time during a month of processing. The total profits for the different producer types was found to be 99, 107, 139 GH¢ per month for traditional butter processors, kernel processors, and processing center producers respectively. All three methods can be improved through the use of improved cook stoves, where the traditional method profits could be increases by improved crushing methods as well. The total energy expended by producers was the highest for those traditionally processing from fresh nut to final shea butter (125 MJ) where nut processors and processing center producers were only 100 MJ and 109 MJ of energy per month respectively while seeing an increased profit as well.

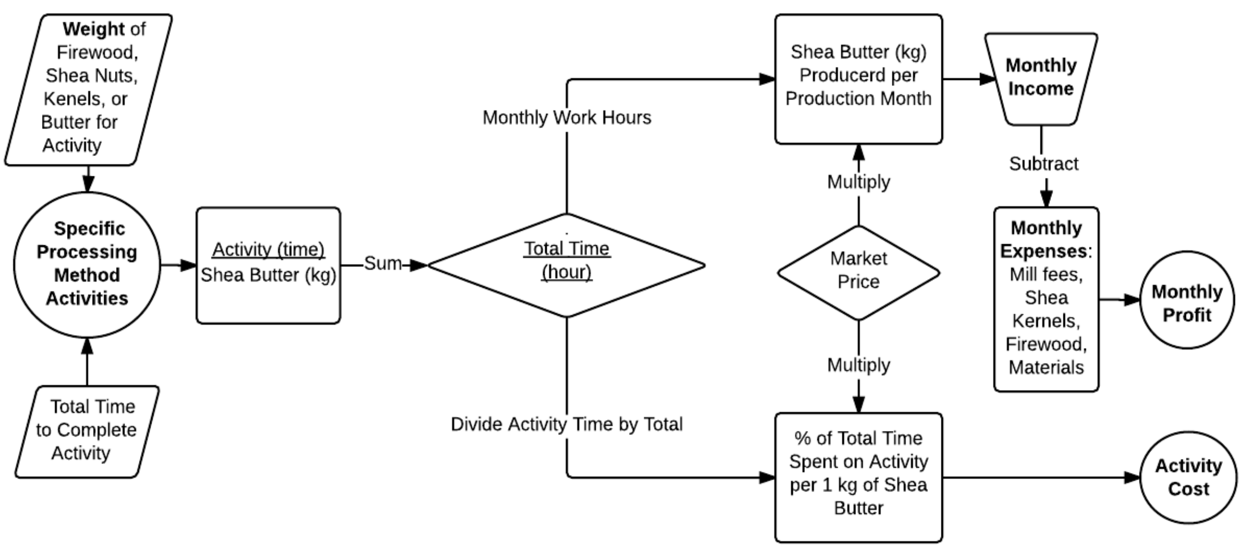

Figure 18. Method used to compare shea butter processing methods in terms of production profits and individual processing activity cost.

Following the methods displayed in Figure 18 the estimated profits and activity costs for shea processing methods can be evaluated. Table 20 displays the results of applying the methods of Figure 18 to the material and human energy data collected during the traditional, improved, and centralized processing methods observed in the authors 2015 study. The results provided in Table 20 demonstrate that women completing the traditional processing of shea butter will not lose profit by scaling down and producing only shea kernels for sell to outside butter processors. Shea is a unique commodity due to the peculiar way it must be harvested and processed. Time is a limiting factor for women in the Northern Region of Ghana who only have so many hours a day to devote to the collection of abundant shea nuts. The results of this study reveal that adding value to their product by processing shea kernels into shea butter requires substantial human energy as well as improved technologies, which in turn is unable to justify completing the entire process from shea nuts to butter extraction as an individual producer. In the Northern Region women can capitalize on time savings by increasing shea nut collection for a higher production rate. The time spent collecting shea nuts is of the highest importance for shea processors to meet buyer's demands and increase personal income. Processors can save time and energy by processing only the fresh nuts to kernels and selling them to nearby processing centers. Processing center workers have access to improved technologies such as crushing machines and mills, processing centers also have a greater potential for adapting improved cook stoves for boiling. It is more economical to invest in improved cook stoves for processing centers than for individual producers, the processing centers will also be using cook stoves solely for processing shea butter making locally made improved cook stoves with chimneys feasible for implementation. Household in the area of study prefer three-stone fires as it is adaptable to the size of pot or container they are heating and can be moved easily from the center of the compound to anywhere outside the compound. This individual cooking behavior is difficult to implement improved cook stoves that are not as adaptable. In a processing center the boiling area stays constant as well as the pots used to process the shea creating an environment for improved cook stove implementation. Shea kernel processors would experience time and energy savings through the use of improved cook stoves during the par-boiling process. The environmental impact of par-boiling is by far the greatest during shea butter processing as well as one of the most difficult to address. Improved cook stove adoption in rural households is of great importance to reducing emissions in developing countries. Shea kernel processors expend the majority of their energy collecting shea nuts and collecting firewood to par-boil the shea nuts. The most economical way to impact GHG emissions produced by shea kernel processors would be the addition of wood burning education during training. The GSA should include the importance of seasoning and storing wood properly to reduce smoke and secondary combustion. One possible dilemma exists for shea butter processors in northern Ghana. If they only process and sell there nuts, will they be losing the profits of selling shea butter, which has a much higher market price. The results of this study show that the traditional shea butter processing methods require more time and energy. Thus by collecting and processing only shea kernels the same profits (even higher profits) than processing shea butter can be obtained. The cultural and social implications of implementing a centralized processing center for shea butter production and removing shea butter production from individual household requires further examination to determine other impacts outside of time and profitability. If shea butter produced for sale to international buyers is completed in processing centers the household consumption will still exist for communities that rely on shea butter as an edible oil. Women processing and selling kernels to processing centers will still need to supply their own family with shea butter for household consumption. Many factors outside the scope of this study play a role in the final effects centralized processing of shea butter will have on shea producers. The results of this study show an increase in profit and time savings for producers, although other significant variables regarding individual and community social and cultural aspect must also be taken into account when determining what interventions will benefit shea producers.

4.4 Survey Results

In accordance with the third objective of this study to assess users' perceptions of improved roasters for shea kernels, surveys were conducted in the field (see Appendix D). The improved roasting survey consisted of 10 main points. The questions and a description of the responses given are provided in Table 21 for improved roasters and Table 22 for traditional roasting. The participants are kept anonymous and age of ranged from 20 to 72.

Table 21. Improved Roasting Survey for 2015 Study in the Community of Tigla, Northern Region, Ghana.

Question	Results (n=18)
1. *When was the last time you used the new roaster for your shea nuts? How many times have you used it this year?*	• 5 used the roaster in the last 2 weeks. • 5 in the previous month. • 3 over 1-3 months ago.
2. *When is the last time you used the traditional pot and three stone fire to roast? How many times have you used it this year?*	• 15 responded last year. • 1 in the past 2 weeks. • 1 in the past 2 months.
3. *How do you like the new roaster? Which do you prefer, the new roaster or the three stone fire?*	• All participants preferred the improved roaster.
4. *How much firewood does the new roaster use compared to the 3 stone fire? Does it use more or less?*	• 10 believed it used less wood. • 6 were unsure. • 2 replied that is used the same amount of firewood.
5. *How much time does it take to roast nuts with the new roaster compared to the three stone fire? Does the new roaster take more or less time?*	• 10 replied that it used less time • 4 responded unsure. • 3 responded that it used the same amount of time.
6. *Have you had any problems with the new roaster? How could it be improved?*	• 14 had no problems. • 4 were unsure. • 1 replied that the roaster was hard to fill as well as to empty the roasted kernels.

Table 21. (Continued)

7. Does the new roaster affect your final butter in any way? Do you notice if it makes larger amounts of butter from your nuts?	• 11 responded that they were unsure. • 8 believed it did affect the final butter by quality, amount, taste, or smell. • 5 confirmed it increased the amount extracted.
8. Where did you get the new roaster? What was the cost? How did you pay for it? Do you share it with other women? How many?	• The response was a mix of the nearby district and regional capital Savalugu and Tamale where machinists are available. • The women responded with a range of guesses. Some believed the roaster was over GH¢ 100 (Approximately USD$30 during the time of the survey), or GH¢ 30 (which was the amount each household gave towards a FTF grant for mill and improved roasters). • All women explained that either (1) the whole community shared, or (2) all the women shared the roasters.
9. When did you last use the new roaster?	• 6 used it in the last month, • 3 used it over a month ago. • 3 in the past week.
10. When did you last use the pot and 3 stone fire to roast?	• Only 1 used it this season.

The survey confirmed that all shea producers were utilizing the new roasters. Although not every shea producer in the entire village was interviewed at least one women from each house participated. This ensured that all family's opinions were voiced in the results. The producers were excited about the new roasters as well as using them. When questioned if anything negative about them could be found, or if they could be improved, almost all women were certain that the roasters were an enhancement and had no suggestions for further improvements for roasting their kernels. Only a few women noticed the difficulty of filling and emptying the spinning roasters through the small latch and opening, or the fact that the community could use more than shea kernel roasters to share. This was the first season that the women producers of Tigla formed a women's group and signed contracts with buyer (StarShea ltd). The women underwent quality training and were given the option to sell their nuts to StarShea in the jute bags StarShea ltd provided them. The women stored their nuts in the community warehouse and sold their nuts to StarShea ltd during the season. Many women still processed butter for personal consumption and only two women processed to sell in the community and at the Diare market. Five women were noted for their behavior change, the previous year they had produced shea butter, they focused only on producing nuts to sell to StarShea ltd. With the high price offered for nuts and the fact that StarShea ltd transported the kernels and did not require the women to travel with them to sell motivated the women to collect only nuts. The women believed they were making more money through this practice. One women also noted how she didn't have the time or energy to produce shea butter, and it was easier for her to just sell shea kernels instead to make money which she would use to buy any oil the family needed as well as other important family needs such as school fees, clothing, and cooking ingredients. The improved roasters were not only happily received by the community but they were utilized. More importantly the management of the equipment was easily organized by community leaders and proved successful as all women utilized roasters and acknowledged effective sharing practices during the survey.

The roasters were purchased using FTF grant money as well as funds raised by the community and their labor donated towards setting up the new grinding mill. The roasters were presented to the community leaders during a community meeting where the community leaders agreed the Magazea (women's leader) would be in charge of them. It was observed that the roasters were stored at the Magazea's compound until shea season began and the roasters were stored in multiple houses as they rotated throughout the community. The women had no problem sharing the roasters, no communication issues or ownership issues arose during the 2014 shea season. Tigla is considered a very small community (16 households) and family values are of great importance to them. The entire community considers each other family, this idea even expands into the surrounding communities were families are tied through marriages and extended lineage. Although the community has a hierarchy the ability to share equipment came easily to the people of Tigla. Their willingness to share peacefully was observed many times throughout the author's stay as a peace corps volunteer. These values and attitudes have had an effect on the adoption of technology. Many communities in the northern regions of Ghana encounter problems with new technology ownership when implemented by an outside party. In larger communities a similar new technology would be difficult to monitor, when a community contains more identifiable groups sharing among each other does not come as easily.

When implementing improved technologies such as improved roasters these cultural values and attitudes must be evaluated. Tigla has shown that 3 roasters was sufficient for 16 households to share, would a community not as organized or with different community relationships be able to adopt and properly implement this technology must be discussed before assuming improved roasters would be a sustainable intervention for shea producers in a community. Even after 5 community meetings regarding the equipment, funds, donations, voting, and contract discussion with community members those being interviewed were unsure were the roasters came from and what they cost. Most participants knew that they donated money and that they came with the mill but the exact terms of the contract were known full by only two survey participants. During the author's time in the Northern Region, improved roasters were only witnessed in communities were they were provided by an outside source such as a company or NGO. On one occasion in the nearby village of Pong Tamale a peace corps volunteer identified a community shea producer owning her own roaster. The women reported purchasing it over a decade before and could not recall what she paid. She bought it in Tamale (regional capital) and had been using it for over a decade to process her shea butter.

Table 22. Traditional Roasting Survey for 2015 Study in the Community of Dipale, Northern Region, Ghana.

QUESTION	Results (n=28)
1. Are there any new (spinning) roasters in your village?	• All participants responded that there was no access to improved roasters in the community.
2. Would you like a new shea nut roaster? Why?	• All participants responded yes and believed they it would enable them to either roast nuts faster, make higher quality shea butter, help with their work, or help the women of the community.
3. Would you use a new shea nut roaster?	• All participants agreed they would use an improved roaster over the traditional method.
4. How much firewood does roasting take? Is this a lot?	• 3 participants mentioned that par-boiling takes the most wood and the majority of the participants expressed that the roasting process consumed a large amount of firewood. • Participants commented that they use less wood during the harmattan (dry season). • A common issue mentioned was using too much wood and over-roasting the kernels. Most agreed that it requires a lot of firewood to roast their shea kernels.
5. When you roast the nuts do they sometimes burn?	• 11 participants do not have problems with burning their shea nuts. • The remaining 17 have problems with burning their nuts because they utilize too much wood or do not pay proper attention during the activity and the kernels at the bottom of the cauldron burn. This creates undesirable kernels and reduced the amount of butter able to be extracted.
6. How long do you roast your nuts for?	• Participants responded in a range of 30 min to 1 hr spent on roasting a pot of shea kernels. • 1 participant believed over an hour, and 1 responded 20 minutes.
7. Where can you buy a new spinning roaster?	• All participants responded either the district capital/market town Savalugu (30 km) or the regional capital Tamale (60 km).
8. How much do the new roasters cost?	• All participants were unsure. All 28 participants were unable to guess a price.

The surveys assess the perspectives of producers in Dipale and Tigla regarding roasting methods. The community with improved roasting access adopted the technology and expressed excitement towards and utilized the new equipment. The entire group of shea producers adopted the new technology and only one producer mentioned also using the traditional fire in series with the improved roaster. It is difficult to know if the producers truly adopted the technology or were fearful of voicing a negative opinion about technology since the surveyor was involved with acquiring the improved roaster. Improved roasters are a cheaper intervention compared to electric and diesel equipment such as crushing machines, but roasters are still a large investment for producers, and producers also are unsure about where an improved roster can be obtained and at what cost. The surveys revealed that women are interested in adopting this technology but do not have the means of investing in or obtaining it as an individual. The survey also revealed that despite their interested they had yet to investigate where to source an improved roaster and at what cost. A heightened interest was observed when considering improved crushing machines as well as mill access. The community mill operator often refused to mill shea kernels unless business was slow. Women from Dipale often traveled to mill their shea kernels. They also recognized the time and labor associated with crushing, and was eager to discuss a solution to this arduous processing activity. The survey conducted in Dipale confirmed shea processors interest in improved roasters and were verbally prepared to adopt the technology. The dialogue created through this survey revealed the women's interest in alleviating the time and energy consumed during the manual crushing of shea kernels. These discussions inspired the collection of human energy data regarding crushing as well as further investigation discussed earlier in this study regarding the impacts of improved roasters. Although the majority of study participants were unsure about how the improved roasters affect quality, extraction rate, time, and fuel usage; many women believed that they would save energy through work, time, and fuel reduction by adapting the improved roaster. Although 3 roasters were available, only a single roaster was seen being used by a woman even if she had 2-3 iterations to complete. It can also be noted in Dipale women were selling Shea nuts to an external buyer, StarShea ltd. During the 2014 season women voiced their interest in also selling shea butter. In Fall 2014 the women of Dipale also sold shea butter in addition to nuts to StarShea ltd. When visiting local shea butter producers partaking in butter processing the women expressed how they enjoyed producing butter and also how they received a higher price for butter than for the kernels. The women producing shea butter did not seem concerned with the extra time or energy put into the processing; they were highly motivated by the increased profit.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS FOR SHEA PRODUCTION AND FUTURE RESEARCH

5.1 Conclusions and Recommendations for Shea Production

This study has four objectives, the first objective being to quantify human energy and material inputs for traditional and improved processing stages of the shea butter process. Human energy was quantified through the calculation of the MJ of energy expended by shea processors during processing activities, the second objective of this research (calculate CO_2 emissions for traditional and improved processing technologies) determined the material energy which was evaluated using IPCC (2006) standards to find the kg CO_2/kg shea butter released based on the amount of firewood used at each stage of shea processing. The equivalent CO_2 emissions due to mechanized crushing and milling was found to be negligible compared to the use of wood fuel, while par-boiling was found to have the most significant amount of heat energy released (76.2-89.5% of total traditional and improved processes). The heat energy (MJ) is based on the net calorific value and the total amount of firewood combusted. The material energy can be attributed to negative environmental impacts such as pollution and deforestation.

The material input of firewood also directly affects shea processors through the amount of time, energy, or money spent to obtain firewood, as well as smoke inhalation and health issues related to use of open fires. Calorific expenditure was evaluated using FAO standards of energy required from different activities and the field data collected of time spent preforming each activity. The amount of firewood required for shea butter processing was highest during par-boiling (7.7 kg firewood / kg shea butter) and is constant for the improved and traditional methods evaluated. In the 3 methods evaluated, the traditional method expended the most firewood (10.1 kg firewood / kg shea butter), followed by the method incorporating improved roasters (9.9 kg firewood / kg shea butter), and finally the least amount of firewood was needed during the central processing center where improved roasters were used (8.6 kg firewood / shea butter). Smoke inhalation by women and children is a common issue in the developing world due to use of open fires. By educating women on the health effects of smoke on their health as well as their families, the adoption of improved cook stoves will become more obtainable as women see it as an economic and health benefit for their families. Wood storage structures can also be a potential investment for organizations and NGOs to assist women with their personal as well as material energy use.

The main processing difference identified between the improved village processing method and the improved centralized processing center method can be seen in the wood combusted by the producers, as well as the amount of women kneading while the butter is undergoing the final boiling process. A group as large as 12 women would knead an average of 623 kg of shea butter during the final boiling process at the SeKaf centralized processing center. However in the village based studies of Tigla and Dipale 1 to 5 women were observed to assist a women in the kneading of her shea butter. During the study the amount of shea butter kneaded in Tigla and Dipale averaged to be 28 kg of shea kernel paste. 28 kg of shea butter extracted from the paste fills a 60-L cauldron approximately halfway, thus women in villages were often observed using smaller cauldrons over open fires. The use of less firewood could be attributed to the observation of a single fire heating approximately 60 kg of shea butter compared to household processors using a single fire to heat only 28 kg during the kneading process. The practice followed by women to heat shea butter and filter during the kneading process can also be correlated to use of more firewood the longer the kneading process takes. At the processing center women are not distracted by household tasks and other chores like household producers experience. It was also observed that at the processing center women in other groups who were experiencing a waiting period before they could continue their work would often assist the group kneading with their task decreasing the overall kneading time. This leads to the conclusion that larger quantities of shea butter produced with little distraction in a group effort use less firewood during the final boiling stage of the shea butter process in terms of the total shea butter extracted.

The results from this study support results of Glew et al. (2014), as well as the Ojeda (2010) study. That is, par-boiling has the largest effect on the environment sustainability of this process in terms of CO_2 emissions and uses the most material resources of all the manufacturing activities. Regarding material energy, a decrease in CO_2 emissions was observed with access to improved roasters making the improved technology desired to decrease environmental degradation due to shea processing, although, the evidence suggests that improved cook stoves have a much higher potential for emissions reduction due to firewood combustion throughout shea production. Electric mills and crushing machines have less of an environmental impact than diesel machines due to material energy, in terms of human energy the savings provided by these technologies during the shea butter process have the potential to increase the producer's profitability.

The material and human energy expended in a processing center is much less than for women completing the entire traditional shea butter process from their household. One issue is what impact the promotion of centralized processing centers will have on the economic and social well being of household shea producers. This study concluded that shea kernel processing has the same economic profit and used less human and material energy then processing the butter traditionally for household shea producers. This study also recognized that women also wanted to continue processing and selling shea butter from their household even when they had access to a market for processing only the shea kernels. The social and cultural issues of removing butter processing from households and investing in centralized processing needs to be addressed in specific communities and location before assuming the cost and energy savings are the most sustainable and positive impact available to the shea producers.

Improved roasters have been shown to reduce CO_2 emissions, although, it is not seen as significant in regards to emissions reduction due to the greater impact improved roasters would have during the boiling processing. The survey suggested that shea producers perceived the improved roasters to reduce the amount of firewood used as well as work required. The results of this research found traditional roasting required 10.1 kg firewood / kg shea butter and improved roasting in Tigla required 9.9 kg firewood / kg shea butter and SeKaf improved roasting required only 8.6 kg firewood / kg shea butter. This study demonstrated that traditional roasting increases the amount of firewood used, the significant difference between the firewood used by the improved roasters in Tigla compared to those at the SeKaf processing center lead to questions of uncertainty due to the large variation in firewood expended. The results of the moisture content experiments show that firewood used has the potential to be in the range of (9.27-34.0%), a moisture content greater or less than the recommended 20% which can increase the likelihood incomplete fuel combustion. If incomplete combustion is taking place during the roasting process, greater amounts of particular matter, carbon monoxide, and hydrocarbons not accounted for in this study will be released into the atmosphere. The moisture content also affects the heating value of the wood. This can cause a longer roasting time with greater environmental degradation. The time difference observed between improved and traditional roasting is inconclusive due to the fact the wood used in the villages contained unknown moisture content. The roasting time could be longer or shorter based on the ability of the wood to properly roast the kernels, and therefore cannot be confirmed if the roaster itself has a direct effect on time savings.

The third objective of assessed users' perceptions using improved roasters to process shea kernels. Ethnographic surveys conducted in the villages of Tigla and Dipale revealed successful adoption by the women of Tigla who received improved roasters to share. Furthermore, the surveys demonstrated a desire for improved roasters by the women of Dipale who do not have access to the improved shea kernel roasters. The Tigla survey results showed successful adoption of the new technology by the women interviewed and it was affirmed that 3 roasters were easily shared between the women of Tigla. The Magazea was given control of the improved roasters and plays an important role in the high adoption rate. The women using the shea nut roasters relate to each other as community members, women's group participants, as well as mutually respectful of their women's community leader (Magazea). These relationships foster mutual respect among community members and their ability to work together for reciprocated benefit. As the women found solace in working in groups to knead shea butter, they also encountered positive benefits from equally sharing the shea kernel roasters. Through associations as well as elected hierarchy, where participants are involved in the organization, and respectful of leadership new technologies and practices can be implemented smoothly as well as sustainably. As new technologies and practices are made available to shea processors, the existence of community groups and leadership involved in managing these technologies is of great importance. Shea processors being impacted by these interventions must be consulted and made a stakeholder before investments in improved technologies or changed practices are permitted. Ownership and solidity of producers involved in the intervention will play a role in the overall adoption and success of the investment. Access to improved roasters is perceived differently by producers than that of an improved crusher. The management, maintenance, and ownership of an improved crushing machine is also very different from that of a spinning roaster. To ensure successful adoption and sustainability of an intervention the perception of the receiving producers must be fully understood based on their individual group or community organization, needs, behavior, location, and practices.

5.2 Future Research

The final objective of this study was to compare traditional and improved processing methods of shea butter production; and make culturally, economically, and socially appropriate recommendations for shea butter processing methods. The evaluation of material energy expended during multiple shea butter processing methods revealed many variables involved in firewood usage that have not been properly investigated. These variables, especially the secondary air emissions discussed previously, are important when assessing the total emissions and environmental impact of shea processing. These factors should not be overlooked when evaluating improved technologies for producers. It is important to understand how working in groups, adapting quality training, and properties of the wood selected can change the amount of material inputs required throughout shea butter processing. This study in turn concludes that further research regarding wood moisture contents impact on shea butter production time is important to better understand the impact of properly drying/seasoning wood can have on the human and material energy expenditures.

Emissions of other air pollutants because of incomplete combustion as well as the effect of quality of wood used (based on moisture content) needs to be addressed. In the future it is also recommended that quality training for shea producers include information on proper wood storage as well as the importance of seasoning collected wood before burning. This is not only an environmental concern, but also a health concern for producers. Improved cook stoves have been recommended for material energy savings as well as air quality, but education on proper wood burning is not common or emphasized in current shea quality processing training in northern Ghana. Affordable wood storage shelters made from local materials should be investigated for producers using the open-fire method. By forming COOPs, women's groups, and investing in centralized processing centers there is a potential to also centralize improved technologies. Implementing improved technologies such as improved cook stoves, mechanized crushing/milling, and improved roasters is much more feasible in centralized areas used by an organized group. The majority of shea producers in northern Ghana do not have access to mechanized crushers to save time and energy during shea butter processing. Crushing machines are locally available in the larger towns of northern Ghana and fabricated in the regional capitals. Manual crushing consumes valuable time and is recognized by producers as a difficult task that needs to be improved. During surveys, producers noted this need and voiced that the time it takes to crush shea kernels affects the time and energy they have to complete other important tasks such as farming and caring for their family. This study identified the need for shea producers to have access to crushing machines for shea processors, but did not assess the interventions impacts beyond time and energy savings. When implementing improved technologies, it is important to consider the entire life cycle of the investment, ownership, maintenance, as well as its social, and cultural aspects.

The potential of shea production in northern Ghana has yet to be reached. Through adoption of improved technologies, women have the opportunity to save time and human energy, which in turn can be used to produce an even greater amount of shea kernels and butter. Shea butter has been identified as a key income for women of the northern regions and energy savings increases productivity and provides producers the chance to grow their shea production and increase their earnings. The profits derived from shea are used to subsidize family costs of food, household items, and children's school fees. Increased shea productions correlates directly to a family's ability to alleviate poverty, support women's empowerment, fund education, and provide proper nutrition. These are all key areas stakeholders and development agencies target, monitor, and evaluate. Thus, government agencies and development workers can use increased shea productivity to alleviate key issues in communities. Development workers, organizations, and the government in northern Ghana can utilize the results of human and material energy savings discussed in this study to complete a more thorough needs assessment with a better understanding of the impacts of the different improved shea processing technologies. To ensure that processing continues to be done in Ghana that provides employment for women of all ages, women must produce quality shea products that meet the standards of local and global consumers. Stakeholders must also focus on organizing cooperatives and women's groups, creation of VSLA groups and micro financing, quality control training, and providing access to improved technologies to empower the women to produce the quantity of quality shea butter in demand. The higher price for quality shea butter has the potential to alleviate poverty amongst rural women producers living in the shea belt. By instructing women on the proper storage, drying, and fire wood selection methods, women can alleviate environmental degradation while producing high quality shea butter. These educational points regarding firewood can be easily adapted to the current shea quality training resources available. By quantifying a shea butter processing methods in terms of human energy as well as material energy the most important interventions can be identified for individual producers. Individual perceptions regarding prospective adoption of the technology as well as it's social and cultural impact must also be evaluated before determining the most sustainable action regarding improved technology to be implemented with a target group.

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APPENDICES

Appendix A. Best Practices For Quality Shea Nut Production Training Poster

Figure AA.1. Best practices for quality shea nut production training poster.

Appendix B. IRB Certification Documentation

UNIVERSITY OF SOUTH FLORIDA

RESEARCH INTEGRITY AND COMPLIANCE
Institutional Review Boards, FWA No. 00001669
12901 Bruce B. Downs Blvd., MDC035 • Tampa, FL 33612-4799
(813) 974-5638 • FAX (813) 974-7091

7/2/2014

Colleen Naughton
USF Civil and Environmental Engineering [redacted]

RE: **Expedited Approval for Continuing Review**

IRB#: CR1_Pro00013497

Title: Mixed Methods Analysis to Quantify the Impacts of Shea Butter Production on the Livelihoods of Sub-Saharan, African Women Producers

Study Approval Period: 7/26/2014 to 7/26/2015

Dear Ms. Naughton:

On 7/2/2014, the Institutional Review Board (IRB) reviewed and **APPROVED** the above application and all documents outlined below.

Approved Item(s):

Protocol Document(s):

Shea Butter Research Proposal ver.2 4.2.14

The waiver of documentation of consent has been renewed.

The IRB determined that your study qualified for expedited review based on federal expedited category number(s):

Research involving materials (data, documents, records, or specimens) that have been collected, or will be collected solely for nonresearch purposes (such as medical treatment or diagnosis).

Collection of data from voice, video, digital, or image recordings made for research purposes.

Research on individual or group characteristics or behavior (including, but not limited to, research on perception, cognition, motivation, identity, language, communication, cultural beliefs or practices, and social behavior) or research employing survey, interview, oral history, focus group, program evaluation, human factors evaluation, or quality assurance methodologies.

As the principal investigator of this study, it is your responsibility to conduct this study in accordance with IRB policies and procedures and as approved by the IRB. Any changes to the approved research must be submitted to the IRB for review and approval by an amendment.

We appreciate your dedication to the ethical conduct of human subject research at the University of South Florida and your continued commitment to human research protections. If you have any questions regarding this matter, please call 813-974-5638.

Sincerely,

[redacted]

USF
UNIVERSITY OF SOUTH FLORIDA

RESEARCH INTEGRITY AND COMPLIANCE
Institutional Review Boards, FWA No. 00001669
12901 Bruce B. Downs Blvd., MDC035 • Tampa, FL 33612-4799
(813) 974-5638 • FAX (813) 974-7091

July 29, 2013

Colleen Naughton
Civil and Environmental Engineering
[redacted]

RE: **Expedited Approval for Initial Review**

IRB#: Pro00013497

Title: Mixed Methods Analysis to Quantify the Impacts of Shea Butter Production on the Livelihoods of Sub-Saharan, African Women Producers

Study Approval Period: 7/26/2013 to 7/26/2014

Dear Ms. Naughton:

On 7/26/2013, the Institutional Review Board (IRB) reviewed and **APPROVED** the above application and all documents outlined below.

Approved Item(s):

Protocol

Document(s):

Shea Butter Research Proposal ver.1 3.1.12

Consent/Assent Document(s)*:

Shea Butter Verbal Description vers. 2 7.18.13 (granted a waiver)

*Please use only the official IRB stamped informed consent/assent document(s) found under the "Attachments" tab. Please note, these consent/assent document(s) are only valid during the approval period indicated at the top of the form(s). (Waivers are not stamped).

It was the determination of the IRB that your study qualified for expedited review which includes activities that (1) present no more than minimal risk to human subjects, and (2) involve only procedures listed in one or more of the categories outlined below. The IRB may review research through the expedited review procedure authorized by 45CFR46.110 and 21 CFR

56.110. The research proposed Research involving materials (data, documents, records, or specimens) that have been collected, or will be collected solely for nonresearch purposes (such as medical treatment or diagnosis).

(5) Collection of data from voice, video, digital, or image recordings made for research purposes.

(6) Research on individual or group characteristics or behavior (including, but not limited to, research on perception, cognition, motivation, identity, language, communication, cultural beliefs or practices, and social behavior) or research employing survey, interview, oral history, focus group, program evaluation, human factors evaluation, or quality assurance methodologies.

Your study qualifies for a waiver of the requirements for the documentation of informed consent as outlined in the federal regulations at 45CFR46.117(c) which states that an IRB may waive the requirement for the investigator to obtain a signed consent form for some or all subjects.

As the principal investigator of this study, it is your responsibility to conduct this study in accordance with IRB policies and procedures and as approved by the IRB. Any changes to the approved research must be submitted to the IRB for review and approval by an amendment.

We appreciate your dedication to the ethical conduct of human subject research at the University of South Florida and your continued commitment to human research protections. If you have any questions regarding this matter, please call 813-974-5638.

Appendix C. Testing Moisture Content (BSI) Methods

Testing moisture content (simple method)

This is a simplified version of the drying and analysis method found in the draft standard for woodfuel moisture content analysis published in the UK by the British Standards Institution[1] (BSI). The methodology contained here is designed to give an approximate figure for personal use using the minimum of specialist equipment and should not be used for marketing purposes or as a substitute for a complete analysis conducted by an approved test centre. Further details of the detailed methodology and testing laboratories are available from the Biomass Energy Centre website at www.biomassenergycentre.org.uk

Setting up Equipment

You will need the following equipment:

Sample containers	These must be airtight sealable containers appropriate to the type of fuel. Plastic food containers are appropriate for chip but for logs sealable airtight plastic bags may be used. You should weigh all containers before use.
Oven	An electric oven will work best. You need to check the oven's specifications for the maximum length of time that it can be run continuously. Fan ovens may not be appropriate for testing chip as the air circulation may blow fine particles out of the sample container.
Containers (for chip)	Should be corrosion resistant, non-combustible, and large enough to contain a complete sample (eg clean metal or ceramic roasting tin). You should weigh all containers before use.
Scales	Must be accurate to the nearest 1g, should have a "re-zero" or "tare" button to allow for the weight of containers, and be able to weigh several kg
Oven thermometer	In-oven thermometers are widely available from kitchen stores. Should be accurate to nearest 2°C, adjustable and must have a waterproof sensor for calibration.
Heat proof mat	To provide insulation between hot samples and the scales.
Heat proof gloves	eg oven gloves.

[1] Based on the suite of standards produced by CEN/TC335. A full, detailed methodology is contained in documents: BS EN 14774-2:2009, BS EN 14778-1:2005 BS EN 14778-2:2005 available from BSI or from BEC

Sampling and testing logs

As with chip, you should choose logs to give a representative section of the load. Bear in mind that there is potentially a much greater variability between, and within logs than with other woodfuels. In the case of logs that have been seasoned before cross cutting, you should remember that logs cut from the end of the length will be significantly drier than those cut from the middle.

Moisture content is likely to vary between logs with different: size, species, number of split faces, and cracks, as well as where they occur in the stack.

You should pick a minimum of two logs to test per cubic metre. The logs should be chosen from the middle of the stack and not have been in contact with the ground.

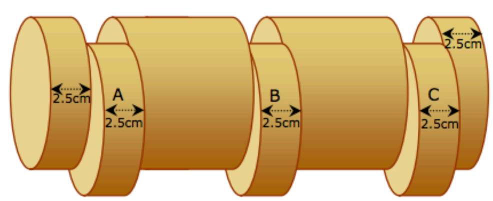

Figure 3

Remove all bark from the logs and cut one 2.5cm thick slice 2.5cm in from each end and one from the centre of the log (see figure 3). Make sure that your sample is representative as any areas that have been split or have been stored with the bark already stripped will be drier than logs which still have bark on.

When you have cut your sample sections from the logs, you should place them in an airtight container immediately (eg sealable plastic bags)

Testing the log samples

- Preheat the oven to the point marked during calibration for an internal temperature of 105°C. You should use the thermometer used during calibration to double check.
- Weigh the samples in the airtight container before opening. This provides an accurate weight of the sample before any material or water is lost from the sample.
- If you are testing more than one sample, remember to label them using a permanent marker so that you know which results apply to each sample.
- Put all of the samples in the oven at the same time (lay them directly on the oven shelves).
- Log each sample weight every two hours (you should make sure that you have a heat proof mat between your samples and the scales.) when the weight of a sample remains unchanged (to within 10g) for two consecutive measurements it can be considered to be oven dry.

Testing Moisture Content (simple method)

Calibration

The process of heating wood removes the water from your sample, but may also release other volatile compounds within the wood. This has been allowed for under the testing methodology, but it does mean that samples must be dried at a standardised temperature to avoid unreliable results. Domestic ovens are not precision instruments and frequently have a wide margin of error in terms of temperature control, so some form of calibration is necessary.

Thermometer calibration

First you need to check the calibration of the oven thermometer. The most straightforward way of doing this is to place it in a large bowl of ice water. When the temperature of the water stops changing adjust the thermometer according to the manufacturers instructions so that it reads 0°C. If the thermometer does not read low enough, then boiling water may be used to calibrate to 100°C, but bear in mind that this is more difficult to do safely.

Oven Calibration

To calibrate the oven, place the calibrated thermometer in the middle of the oven and set to 200°C (using the main oven control) when the oven has reached temperature check the reading on the thermometer against the oven setting. The oven manufacturer should provide instructions on any fine tuning of the temperature calibration possible.

When you have calibrated the oven, turn it down to 105° (the working temperature for moisture testing) and check it against the thermometer. Some oven models only allow calibration in 5° or even 10° increments and it may be that even with calibration you still need to set the oven control higher or lower to achieve an accurate temperature, using the calibrated thermometer as your guide.

Taking a sample

The critical factor in taking a sample is that it should be representative of the whole. You should have the same distribution of particle sizes in your sample as exist in the store, and the sample should have the same moisture content as the surrounding material.

Sampling and testing chip

In a large stack of fuel, there will be variations in the moisture content throughout the stack and you will need to take a sample from more than one place to allow for this. You should take a minimum of 5 samples, taking material from the upper, middle and lower parts of the fuel stack. Ignore any material from the lowest 30cm of the stack as this is likely to pick up additional moisture and other contamination from the ground.

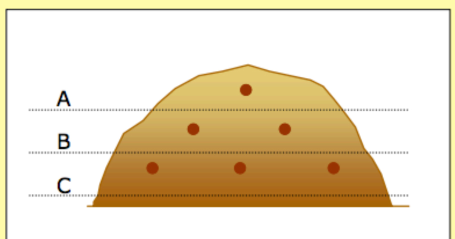

Figure 1

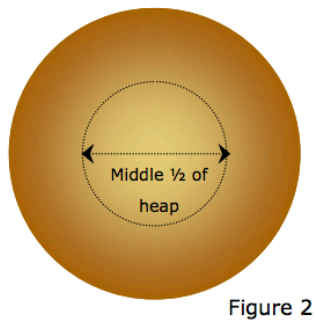

Figure 2

You should dig through the heap and take samples of at least 1 litre each from different points (As shown in figure 1) from the middle ½ of the heap as shown in figure 2. The number of samples required will increase with the amount of fuel to be tested. For batches of over 15 tonnes, increase the number of samples taken from layer C by 1 for every 5 additional tonnes[2]. The samples should all be the same size, and include the same proportions of over and undersized pieces as the area they are taken from. If there is a large amount of observable variation through the stack, then you will need to collect more samples to take account of this. All samples should then be sealed in a pre-weighed airtight containers (eg plastic food containers) as soon as you have collected them. Do not mix the samples.

Testing the chip samples

- Preheat the oven to the point marked during calibration for an internal temperature of 105°C. You should use the thermometer used during calibration to double check.
- Weigh the samples in the airtight container before opening. This provides an accurate weight of the sample before any material or water is lost from the sample.
- Weigh the heatproof container that you will be using to heat the chip.
- If you are testing more than one sample, remember to label the containers so that you know which results apply to each sample.
- Transfer each sample from the airtight container to a labelled heatproof container
- Put all of the samples in the oven at the same time.
- Log each sample weight every two hours (you should make sure that you have a heat proof mat between your samples and the scales.) when the weight of a sample remains unchanged (to within 10g) for two consecutive measurements it can be considered to be oven dry.
- This process can take a long time, so make sure that you do not run the oven for longer than the manufacturers recommend. If the samples take longer than this (or you need to leave the samples) then switch off the oven leaving the samples inside and allow it to cool down and start heating again later.
- Meanwhile thoroughly dry the airtight containers on a radiator or similar and re-weigh (if any material has stuck to the inside)

Remember that it is very easy for heated, dry wood to catch fire. Make sure that you take care while testing and dispose of your sample in an appropriate manner afterwards.

[2] NB this methodology is not suitable for quantities in excess of 30 tonnes

Testing Moisture Content (simple method)

- This process can take a long time, so make sure that you do not run the oven for longer than the manufacturers recommend. If the samples take longer than this (or you need to leave the samples) then switch off the oven leaving the samples inside and allow it to cool down and start heating again later.
- Meanwhile thoroughly dry the airtight containers on a radiator or similar and re-weigh (if any material has stuck to the inside)

Remember that it is very easy for heated, dry wood to catch fire. Make sure that you take care while testing and dispose of your sample in an appropriate manner afterwards.

Determining moisture content

You should now have accurate weights for:

- The airtight container
- The heatproof container (if used)
- The sample before drying
- The sample after drying
- The weight of any moisture left inside the airtight container after transfer to the oven
- The weight of any other material left inside the airtight container after transfer to the oven

You should be able to use these weights to determine the total weight of each sample before and after drying.

The moisture content (MC) of a piece of wood is defined as the weight of water expressed as a percentage of the weight of the wood either the total (wet) sample weight (wet basis) or the dry wood weight (dry basis) All fuel calculations are carried out on a "wet basis" (MC_{wb}) [3]

The wet basis moisture content is a measurement of the proportion of the sample which is water expressed as a percentage of the total sample. For example if the wood in a sample weights 50kg and the water in the sample also weight 50kg, then the total MC of the sample would be 50% as half of the sample is water.

The MC_{wb} = (the weight of water in a sample/ total initial weight of the sample)x100

[3] "Dry basis" is expressed as the percentage of the oven dry weight of the wood. For example, if the wood in a piece of timber weights 50kg and the water also weighs 50kg then the dry basis moisture content is 100%. The main advantage of this method is that the oven dry weight of the wood remains constant. This method is the standard used by many of the organisations doing research on wood, as well as building surveyors and architects. (It is rare to use dry basis measurements when talking about woodfuel)

The MC_{db} = (Weight of water in a sample/ oven dry weight of sample)x100

Analysis

If you have taken samples as shown in the methodology above, you should have a figure for moisture content (in %) for each sample taken. Based on these sampling rates you can then work out a simple average (mean) of all the values to calculate a moisture content figure for the whole volume.

If your sampling regime is different from the one above, you will need to take into account the extent to which your distribution of samples is representative of the whole and if necessary adjust the mathematical weighting of different samples accordingly.

Moisture Meters and testing

If you are using a moisture meter for a quick indication of moisture content you should calibrate it first against wood that has been checked using the methodology above. You should also be sure that you know whether the meter is giving a reading in wet or dry basis.

Correct sampling practice is particularly important when testing logs, especially if has been cross cut recently. If the wood has been seasoned in long (eg 2m) lengths there will be a significant difference between the middle of the length (high MC) and the ends (low MC) this can give rise to significant variation in measured values between logs.

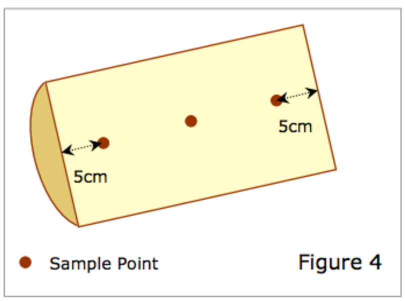

Figure 4

To measure the moisture content of a firewood log using a resistance type hand held moisture meter, it must be freshly split and then three measurements taken on the freshly split surface: 5cm in from each end of the log and in the middle of the split surface with sufficient contact (see figure 4). It is recommended that you test at least 5 logs from each $2m^3$ batch. You should then calculate the average (mean) MC over all of the readings.

The resistance type of moisture meter can give a good indication of the moisture content of logs but they will only ever give an approximate indication. For a more accurate measurement of logs or when assessing wood chip, you should assess moisture content using the methodology contained here. If you wish to conduct an analysis for marketing fuel, or assessment of compliance to standards or specifications you should get a complete analysis conducted by an approved test centre.

A full methodology on how to determine moisture content and other physical properties of woodfuel has been published by the European Standards Committee CEN/TC 335, this is expected to be adopted by the BSI as a BS EN standard in 2011. For further details go to www.bsigroup.co.uk

Appendix D. Roasting Surveys Used for Traditional and Improved Roasting Evaluation

These surveys are copies of Colleen Naughton's (Civil & Environmental Engineering, University of South Florida) traditional and improved roasting surveys used in the villages of Tigla and Dipale were energy analysis of improved and traditional roasters was conducted by the author.

AD.1. Traditional Roasting Survey for Dipale

I want to understand more about roasting shea nuts and how much firewood is used. By understanding we can continue to make better ways to produce shea butter. this survey is optional, you do not have to answer any questions if you do not want to. Do you agree to participate? Yes/no

Name________________________
Approximate Age___________Community____________________

I. QUESTION	ANSWER
9. Are there any new (spinning) roasters in your village?	
10. Would you like a new Shea nut roaster? Why?	
11. Would you use a new Shea nut roaster?	
12. How much firewood does roasting take? Is this a lot?	
13. When you roast the nuts do they sometimes burn?	
14. How long do you roast your nuts for?	
15. Where can you buy a new spinning roaster?	
16. How much do the new roasters cost?	

AD.2. Improved Roasting Survey for Tigla

I want to understand more about roasting shea nuts and how much firewood is used. By understanding we can continue to make better ways to produce shea butter. this survey is optional, you do not have to answer any questions if you do not want to. Do you have any questions? Do you agree to participate? Yes/no

Name________________Approximate Age___________ Community__________________

I. QUESTION	ANSWER
11. When was the last time you used the new Roaster for your Shea nuts? How many times have you used it this year?	
12. When is the last time you used the traditional pot and three stone fire to roast? How many times have you used it this year?	
13. How do you like the new Roaster? Which do you prefer, the new roaster or the three stone fire?	
14. How much firewood does the new roaster use compared to the 3 stone fire? Does it use more or less?	
15. How much time does it take to roast nuts with the new roaster compared to the three stone fire? Does the new roaster take more or less time?	
16. Have you had any problems with the new roaster? How could it be improved?	
17. Does the new roaster affect your final butter in any way? Do you notice if it makes larger amounts of butter from your nuts?	
18. Where did you get the new roaster? What was the Cost? How did you pay for it? Do you share it with other women? How many?	
19. When did you last use the new roaster?	
20. When did you last use the pot and 3 stone fire to roast Shea nuts?	

AD.3. Importance of Shea Survey

I WANT TO UNDERSTAND HOW IMPORTANT SHEA IS TO THE YOU AND THE WOMEN IN YOUR COMMUNITY, IF YOU WANT TO HELP ME LEARN YOU CAN ANSWER THE FOLLOWING QUESTIONS.	
II. QUESTION	ANSWER/COMMENTS
1. How many days a week did you collect Shea nuts?	
2. How many times a day did you go to collect?	
3. Did any children help you? If yes how many?	
4. How much butter did you produce? (Bowls, from a bag of nuts, how do you measure?)	
5. How many bags of nuts did you produce this year?	
6. How many bags of nuts did you produce LAST year?	
7. What do you do with the butter you make?	
8. Is Shea butter important to you during the rainy season? Why?	
9. Is Shea butter important to you during the dry season? Why?	
10. How much butter do you use a day? (Cooking)	
11. Do you use other cooking oils? Which ones do you prefer? How often do you use them?	
12. Do you use Shea butter for anything other than cooking?	
13. Do you have a garden? What do you plant? What do you do with the produce? (sell/eat/combination)	
14. Do you sell your nuts? To who?	
15. Do you sell your butter? To who?	
16. What will you use money from selling nuts and butter for?	
17. Thank you for your time. Do you have any questions or comments?	

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Appendix F. Data Collected for this Thesis's Field Study

This appendix contains data collected to complete a material and human energy analysis of common shea butter processing methods observed in the Northern Region of Ghana, West Africa.

Table AF.1. CO_2 Emissions due to Par-boiling 2014 Field Study.

n	Wood initial (kg)	Nuts initial (kg)	Wood final (kg)	Total wood (kg)	Firewood (activity data) (kg) per 1 kg butter	CO_2(kg)/ shea butter (kg)
1	11.1	68.7	4.20	6.90	6.97	12.2
2	20.0	107	1.00	19.0	10.6	18.6
3	15.0	46.0	8.00	7.00	5.24	9.13
4	47.0	120.0	32.0	15.0	3.58	6.25
5	41.0	182	10.0	31.0	8.48	14.8
6	38.0	113	8.00	30.0	8.86	15.5
7	49.0	112	9.00	40.0	9.16	16.0
8	29.0	181	4.00	25.0	9.67	16.9
9	28.0	220	3.00	25.0	10.0	17.5
10	49.0	197	19.0	30.0	6.87	12.0
11	43.0	175	12.0	31.0	8.09	14.1
12	23.0	124	4.00	19.0	9.27	16.2
13	55.0	175	20.0	35.0	7.14	12.5
14	23.0	136	1.00	22.0	10.7	18.7
15	31.0	144	3.00	28.0	10.1	17.7
16	15.0	36.5	7.00	8.00	5.98	10.4
17	13.0	18.5	6.00	7.00	6.04	10.5
18	29.0	56.5	18.0	11.0	4.26	7.42
19	35.0	54.0	19.0	16.0	5.13	8.95
				Average	**7.70**	**13.4**

Table AF.2. CO_2 Emissions due to SeKaf Processing Center Roasting and Boiling 2014 Field Study.

Sample	Kernels issued (kg)	Kernels sorted (kg)	Wood initial for roasting (kg)	Wood final for roasting (Kg)	Total wood for roasting (kg)	Firewood (activity data) (kg) for roasting per 1 kg butter	Emissions (CO_2) for roasting/kg shea butter
1	914.0	813.5	417.0	227.0	190.0	0.6	1.1
2	1817	1643	-	-	-	-	-
3	902.0	787.0	355.0	309.0	46.0	0.2	0.3
4	931.0	806.5	309.0	192.0	117.0	0.4	0.7
5	1910	1710	442.0	50.0	392.0	0.7	1.2
6	1894	1729	347.0	35.0	312.0	0.6	1.0

Sample (cont.)	Wood initial for boiling(Kg)	Wood final for boiling (Kg)	Total wood for boiling (kg)	Shea Butter (kg)	Packaged Shea Butter (kg)[4]	Firewood (activity data) (kg) for boiling per 1 kg butter	Emissions (CO_2) for boiling/kg shea butter
1	333	207	126	-	312	0.40	0.704
2	-	-	-	622	625	-	-
3	289	86.0	203	346	332	0.61	1.07
4	181	29.0	152	321	332	0.46	0.805
5	466	56.0	410	633	633	0.65	1.13
6	376	179	197	612	612	0.32	0.562

[4] Packaged shea butter refers to weight taken by employees of total butter packaged by women's group. When the butter was moved to the cooling room the author recorded the weight, the following day the employees recorded the weight of the same butter after moved into new containers. This record was obtained to compare to authors results to affirm accuracy.

Table AF.3. CO_2 Emissions due to Traditional Roasting and Boiling Methods in Dipale, 2014 Field Study.

n	Kernels (kg)	Wood initial for roasting (Kg)	Wood final for roasting (Kg)	Total wood for roasting (kg)	Firewood (activity data) (kg) for roasting per 1 (kg) shea butter	Emissions (CO_2) for roasting/kg butter
1	32.0	17.5	9.0	8.5	1.06	1.85
2	15.0	10.0	4.0	6.0	1.33	2.33
3	29.0	12.0	5.0	7.0	0.67	1.16
4	31.5	17.0	6.5	10.5	0.91	1.59
5	42.5	17.0	4.0	13.0	1.37	2.39
6	22.0	15.0	6.0	9.0	1.13	1.96
7	67.0	26.5	6.5	20.0	0.68	1.18
8	31.0	9.0	1.0	8.0	0.80	1.40
9	33.0	18.0	8.0	10.0	0.77	1.34
10	26.0	12.0	4.0	8.0	1.00	1.74
11	12.0	8.0	3.0	5.0	1.25	2.18
12	26.0	20.0	12.0	8.0	0.89	1.55
13	27.5	15.0	5.0	10.0	1.25	2.18
14	15.0	9.0	4.0	5.0	1.00	1.74
15	23.0	12.0	4.0	8.0	1.00	1.74
16	16.0	10.0	2.0	8.0	2.00	3.49
17	18.0	13.0	3.0	10.0	2.00	3.49
18	21.0	8.0	5.0	3.0	0.43	0.75
19	38.0	20.0	2.0	18.0	1.50	2.62

Table AF.3 (Continued)

n	Wood initial for boiling (Kg)	Wood final for boiling (Kg)	Total wood for boiling (kg)	Shea Butter (kg)	Firewood (activity data) (kg) for boiling per 1 (kg) shea butter	Emissions (CO_2) for boiling/kg butter	Total Emissions (CO_2)/kg butter
1	29.0	10.0	19.0	8.0	2.38	4.14	6.00
2	10.0	2.5	7.5	4.5	1.67	2.91	5.23
3	18.0	4.0	14.0	10.5	1.33	2.33	3.49
4	22.5	8.5	14.0	11.5	1.22	2.12	3.72
5	23.5	13.0	10.5	9.5	1.11	1.93	4.32
6	14.0	5.5	8.5	8.0	1.06	1.85	3.82
7	28.5	11.5	17.0	29.5	0.58	1.01	2.19
8	14.0	4.0	10.0	10.0	1.00	1.74	3.14
9	14.0	4.0	10.0	13.0	0.77	1.34	2.68
10	13.0	3.5	9.5	8.0	1.19	2.07	3.82
11	13.0	6.0	7.0	4.0	1.75	3.05	5.23
12	15.0	7.0	8.0	9.0	0.89	1.55	3.10
13	22.5	9.0	13.5	8.0	1.69	2.94	5.12
14	11.0	3.0	8.0	5.0	1.60	2.79	4.54
15	13.5	7.5	6.0	8.0	0.75	1.31	3.05
16	16.0	4.0	12.0	4.0	3.00	5.23	8.72
17	14.5	5.0	9.5	5.0	1.90	3.31	6.80
18	10.0	2.5	7.5	7.0	1.07	1.87	2.62
19	22.0	4.0	18.0	12.0	1.50	2.62	5.23

Table AF.4. Moisture Content Experiment at SeKaf Processing Center Field Study 2014.

Sample	Weight initial (g)	Weight final (g)	Producers label	Moisture content (%)
1	2.67	2.25	good	15.73
2	2.1	1.39	bad	33.81
3	3.72	3.22	good	13.44
4	2.68	1.77	bad	33.96
5	4.63	3.31	good	28.51
6	4.82	3.77	bad	21.78
Second Study				
7	7.85	7.11	good	9.43
8	6.69	6.07	good	9.27
9	5.55	5.03	good	9.37
10	10.9	9.31	good	14.59
11	11.28	9.27	good	17.82
12	7.39	6.47	good	12.45
13	5.73	4.12	good	28.10
14	5.84	4.5	good	22.95
15	9.29	8.09	good	12.92

Table AF.5. Material Energy Emissions (CO_2) $equivalent$ due to Diesel Engines during the Shea Butter Process, Field Study 2014.

Location	Kernels (kg)	Diesel initial (L)	Diesel final (L)	Cost (GH¢)	Weight of shea butter (kg)	Total diesel	Diesel (L)/shea butter (kg)	Emissions CO_2/Kg butter
Gushie	26	1.0	0.55	5	9.0	0.45	0.05	0.14
Gushie	34	1.0	0.45	5	12	0.55	0.05	0.13
Gushie	22	0.45	0.15	5	7.0	0.3	0.04	0.11
Tigla	26	4.5	4.2	5	13	0.3	0.02	0.06
Tigla	44	2.0	1.7	3	11	0.35	0.03	0.09
Tigla	44	1.7	1.1	3	17	0.55	0.03	0.09
Tigla	19	1.1	0.88	2	8.0	0.23	0.03	0.08

Appendix G. Human Energy Calculations of Shea Butter Processing Methods

This Appendix shows individual human energy calculations and PAR values for individual processing methods discussed in the results section.

Table AG.1. Human Energy (MJ/ 25 kg Shea Butter) Traditional Method, Dipale.

Labor	Activity Analogue	PAR	Hour/kg shea butter	Energy Expended (MJ/ 25 kg shea butter)
Collecting Shea Nuts	Picking fruit	3.3	2.1	36
Depulping	Shelling	1.6	0.19	1.0
Par-boiling	Cooking	1.8	0.37	2.0
Dehusking	Shelling	1.8	0.36	2.0
Sorting	Shelling	1.6	0.11	1.0
Crushing	Pounding Grain	5.6	0.53	18
Roasting	Cooking	1.8	0.10	1.0
Milling	Walking with 25-30 kg load	3.9	0.15	3.0
Kneading	III	4.81	0.49	14
Boiling	Cooking	1.8	0.16	1.0
Collecting Firewood	Collecting wood for fuel	3.3	0.44	8.0
Collecting Water	Collecting water	4.5	0.09	2.0
			Total	**89**

Table AG.2. Human Energy (MJ/ 25 kg Shea Butter) Improved Process (Travel the Crushing and Milling Machinery).

Labor	Activity Analogue	PAR	Hour/kg shea butter	Energy Expended (MJ/ 25 kg shea butter)
Collecting Shea Nuts	Picking fruit	3.3	2.1	36
Depulping	Shelling	1.6	0.19	1.0
Par-boiling	Cooking	1.8	0.37	2.0
Dehusking	Shelling	1.8	0.36	2.0
Sorting	Shelling	1.6	0.11	1.0
Crushing	Walking with 25-30 kg load	3.9	0.15	3.0
Roasting	Cooking	1.8	0.09	1.0
Milling	Walking with 25-30 kg load	3.9	.15	3.3
Kneading	III	4.81	0.49	14
Boiling	Cooking	1.8	0.16	10
Collecting Firewood	Collecting wood for fuel	3.3	0.43	7.0
Collecting Water	collecting water	4.5	0.09	2.0
			Total	**71**

Table AG.3. Human Energy (MJ/ 25 kg Shea Butter) Improved Processing Center (Mill, Crusher, Firewood, Water Access).

Labor	Activity Analogue	PAR	Hour/kg shea butter	Energy Expended (MJ/ 25 kg shea butter)
Collecting Shea Nuts	Picking fruit	3.3	-	0.0
Depulping	Shelling	1.6	-	0.0
Par-boiling	Cooking	1.8	-	0.0
Dehusking	Shelling	1.8	-	0.0
Sorting	Shelling	1.6	0.11	1.0
Crushing	Standing	-	-	00
Roasting	Cooking	1.8	0.09	1.0
Milling	Standing	-	-	0.0
Kneading	III	4.81	0.49	14
Boiling	Cooking	1.8	0.16	1.0
Collecting Firewood	Collecting wood for fuel	-	-	0.0
Collecting Water	Collecting water	-	-	0.0
			Total	**16**

Table AG.4. Human Energy (MJ/ 25 kg Shea Butter) Shea Kernel Processing, Dipale and Tigla.

Labor	Activity Analogue	PAR	Hour/kg shea butter	Energy Expended (MJ/ 25 kg shea butter)
Collecting Shea Nuts	Picking fruit	3.3	2.1	36
Depulping	Shelling	1.6	0.19	1.0
Par-boiling	Cooking	1.8	0.37	2.0
Dehusking	Shelling	1.8	0.36	2.0
Sorting	Shelling	1.6	0.11	1.0
Crushing	Walking with 25-30 kg load	3.9	-	0.0
Roasting	Cooking	1.8	-	0.0
Milling	Walking with 25-30 kg load	3.9	-	0.0
Kneading	III	4.81	-	0.0
Boiling	Cooking	1.8	-	0.0
Collecting Firewood	Collecting wood for fuel	3.3	.33	6.0
Collecting Water	collecting water	4.5	0.07	2.0
			Total	**49**

Table AG.5. Human Energy (MJ/ 25 kg Shea Butter) Improved Process (Community Mill and Crusher Access).

Labor	Activity Analogue	PAR	Hour/kg shea butter	Energy Expended (MJ/ 25 kg shea butter)
Collecting Shea Nuts	Picking fruit	3.3	2.1	36
Depulping	Shelling	1.6	0.19	1.0
Par-boiling	Cooking	1.8	0.37	2.0
Dehusking	Shelling	1.8	0.36	2.0
Sorting	Shelling	1.6	0.11	1.0
Crushing	Standing	-	.12	0.0
Roasting	Cooking	1.8	.09	1.0
Milling	Standing	-	.76	0.0
Kneading	III	4.81	.49	14
Boiling	Cooking	1.8	.16	1.0
Collecting Firewood	Collecting wood for fuel	3.3	.33	6.0
Collecting Water	Collecting water	4.5	0.07	2.0
			Total	**65**

Table AG.6. Human Energy (MJ/ 25 kg Shea Butter) Improved Process (Community Mill Access), Tigla

Labor	Activity Analogue	PAR	Hour/kg shea butter	Energy Expended (MJ/ 25 kg shea butter)
Collecting Shea Nuts	Picking fruit	3.3	2.1	36
Depulping	Shelling	1.6	0.19	1.0
Par-boiling	Cooking	1.8	0.37	2.0
Dehusking	Shelling	1.8	0.36	2.0
Sorting	Shelling	1.6	0.11	1.0
Crushing	Pounding Grain	5.6	0.53	18
Roasting	Cooking	1.8	0.09	1.0
Milling	Standing	-	.76	0.0
Kneading	III	4.81	0.49	14
Boiling	Cooking	1.8	0.16	10
Collecting Firewood	Collecting wood for fuel	3.3	0.43	7.0
Collecting Water	Collecting water	4.5	0.07	2.0
			Total	**85**

Appendix H. Percent Human Energy Expenditure per Activity of Different Shea Butter Processing Methods

This Appendix displays individual human energy bar graphs of different shea butter processes. Each activity is displayed in terms of percent of total energy expended per production of shea butter. This bar graph allows the most energy intensive activities for different processes to be easily recognized.

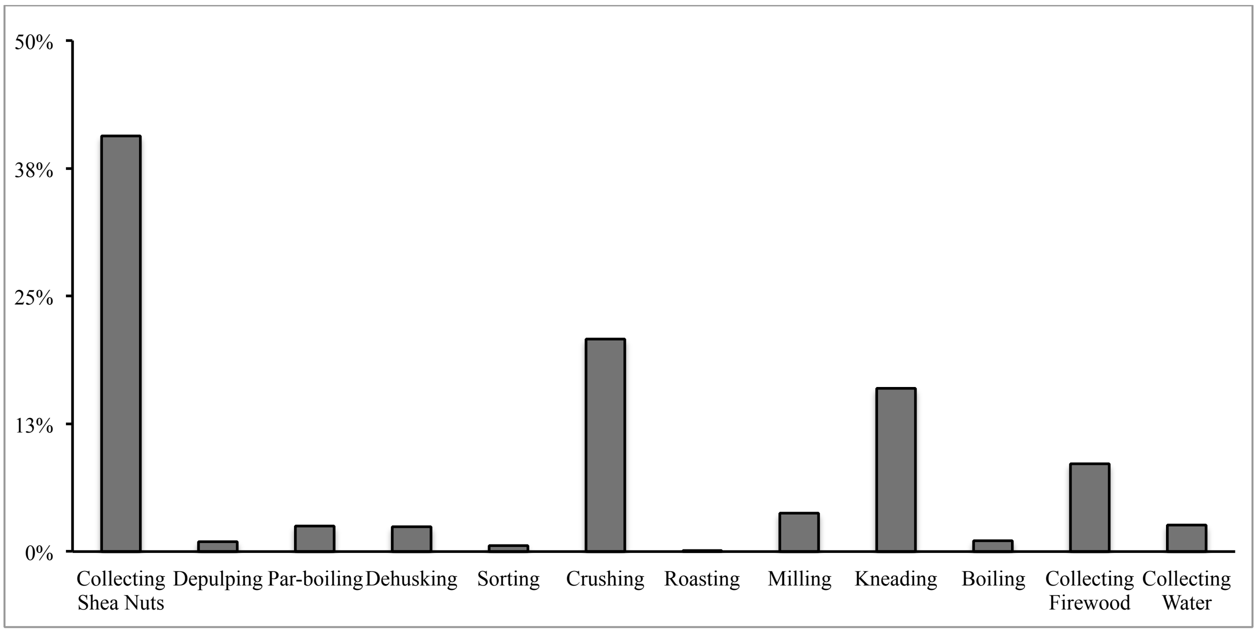

Figure AH.1. Percent human energy expenditure per activity of traditional shea butter processing, Dipale.

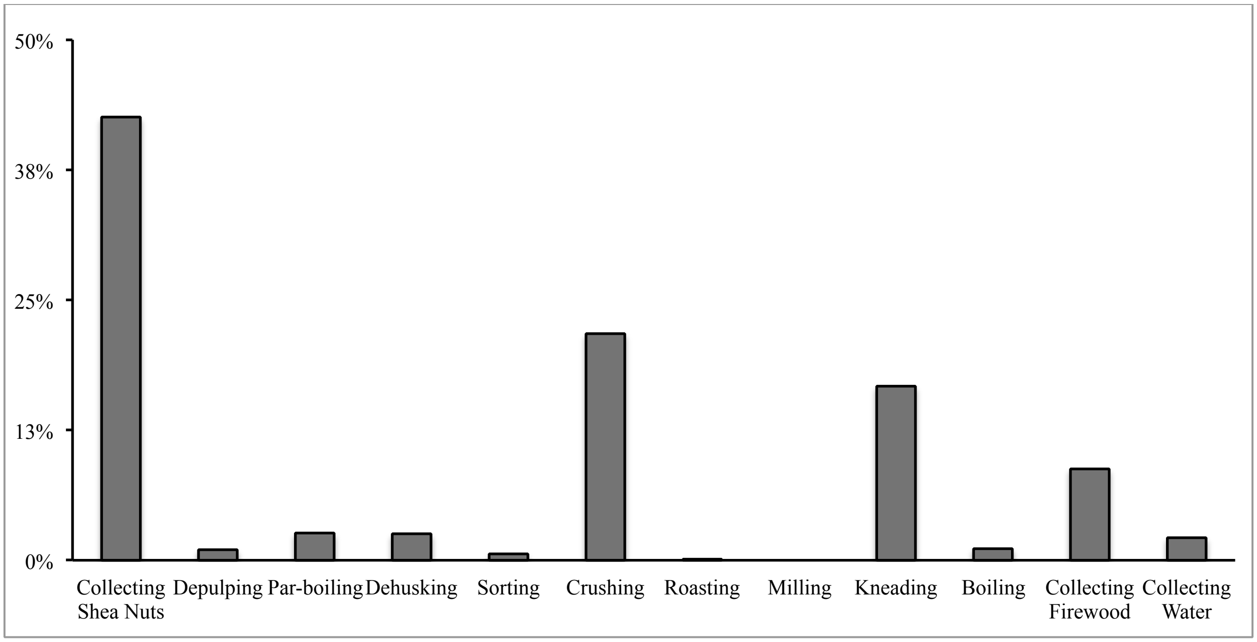

Figure AH.2. Percent human energy expenditure per activity of the improved shea butter production process, Tigla.

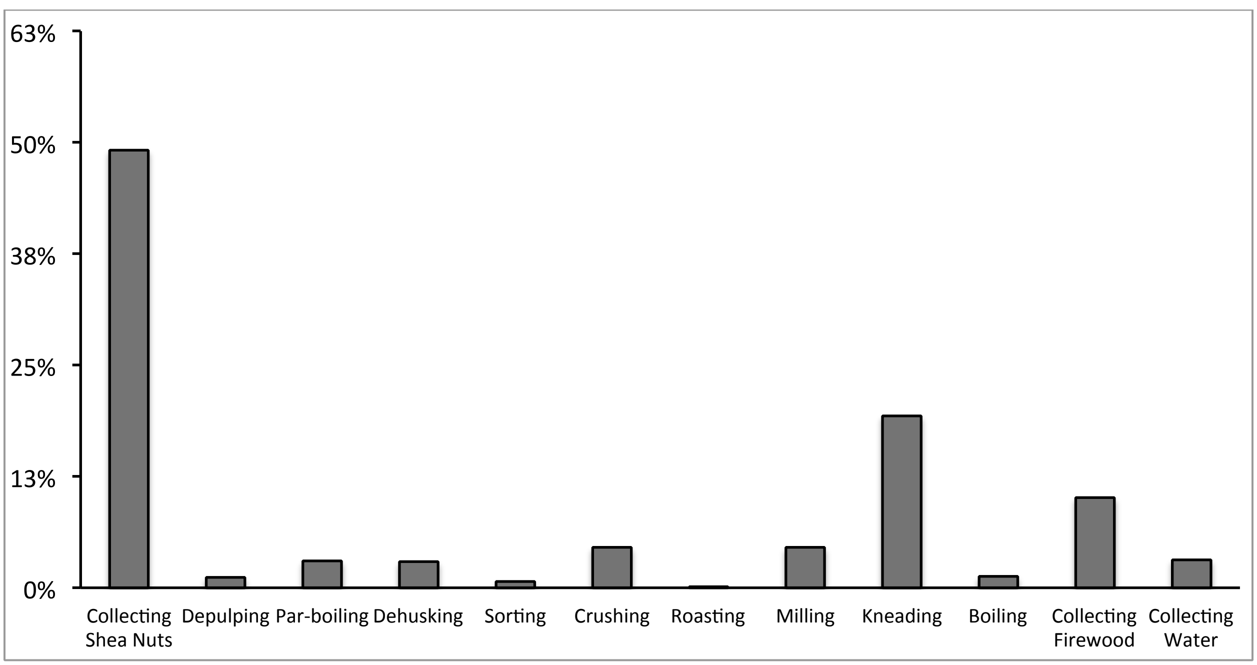

Figure AH.3. Percent human energy expenditure per activity of the improved shea butter production process (travel to mechanized crusher and mill).

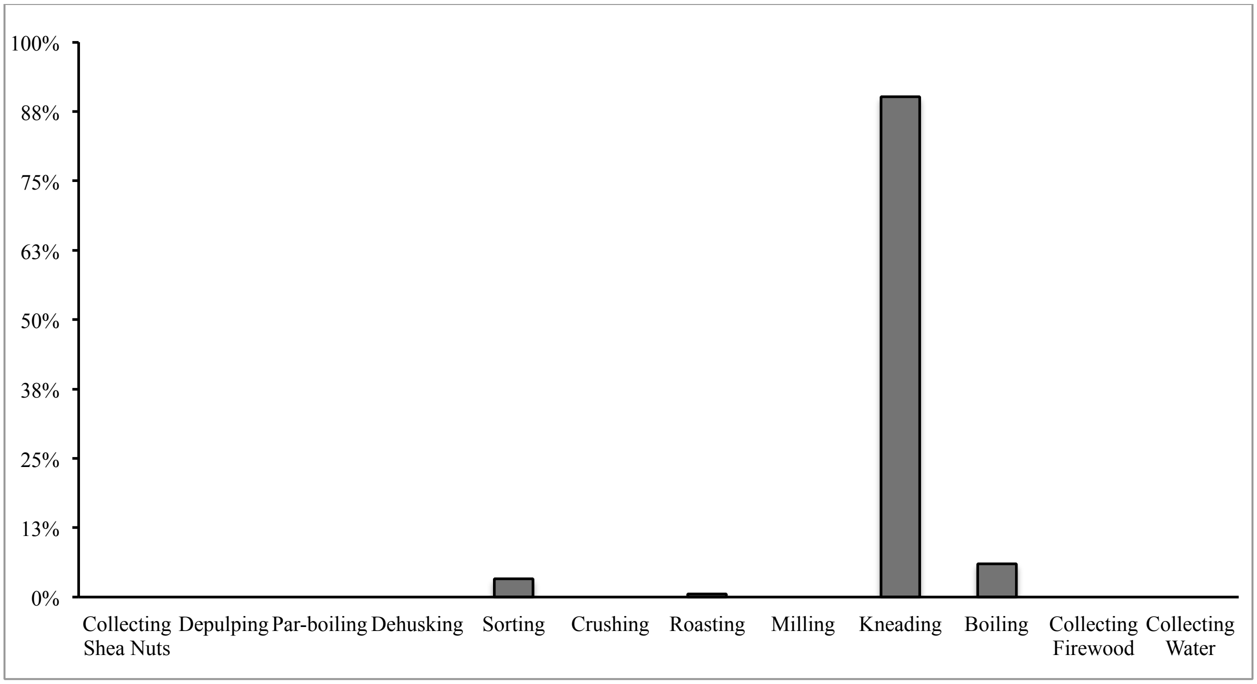

Figure AH.4. Percent human energy expenditure per activity of improved centralized processing center, SeKaf.

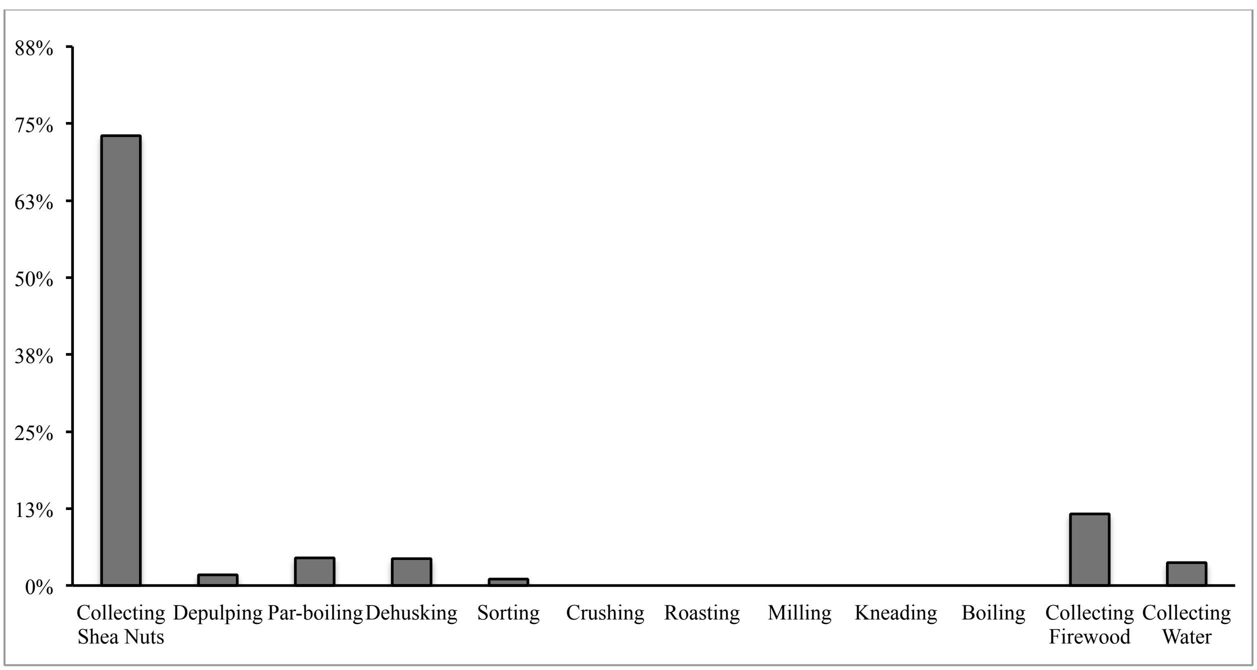

Figure AH.5. Percent human energy expenditure per activity of shea kernel processing, Tigla and Dipale.

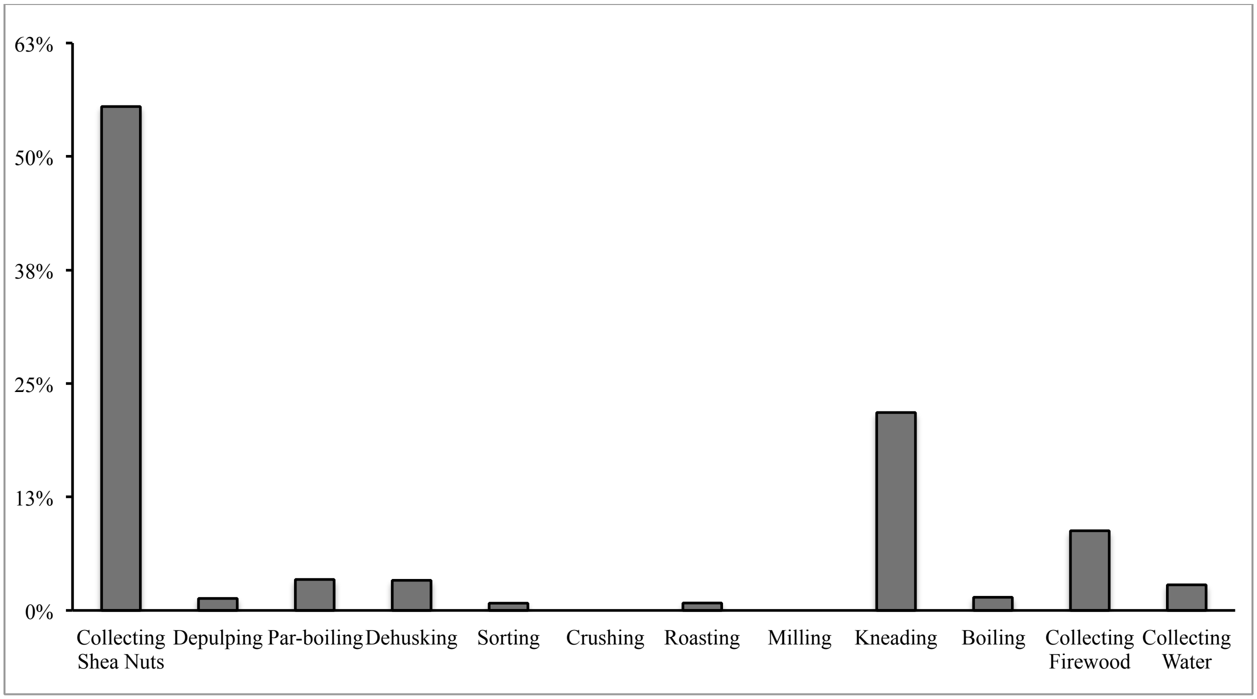

Figure AH.6. Percent human energy expenditure per activity of improved centralized processing center (including kernel processing), SeKaf.