RESEARCH PROGRAM ON Water, Land and Ecosystems

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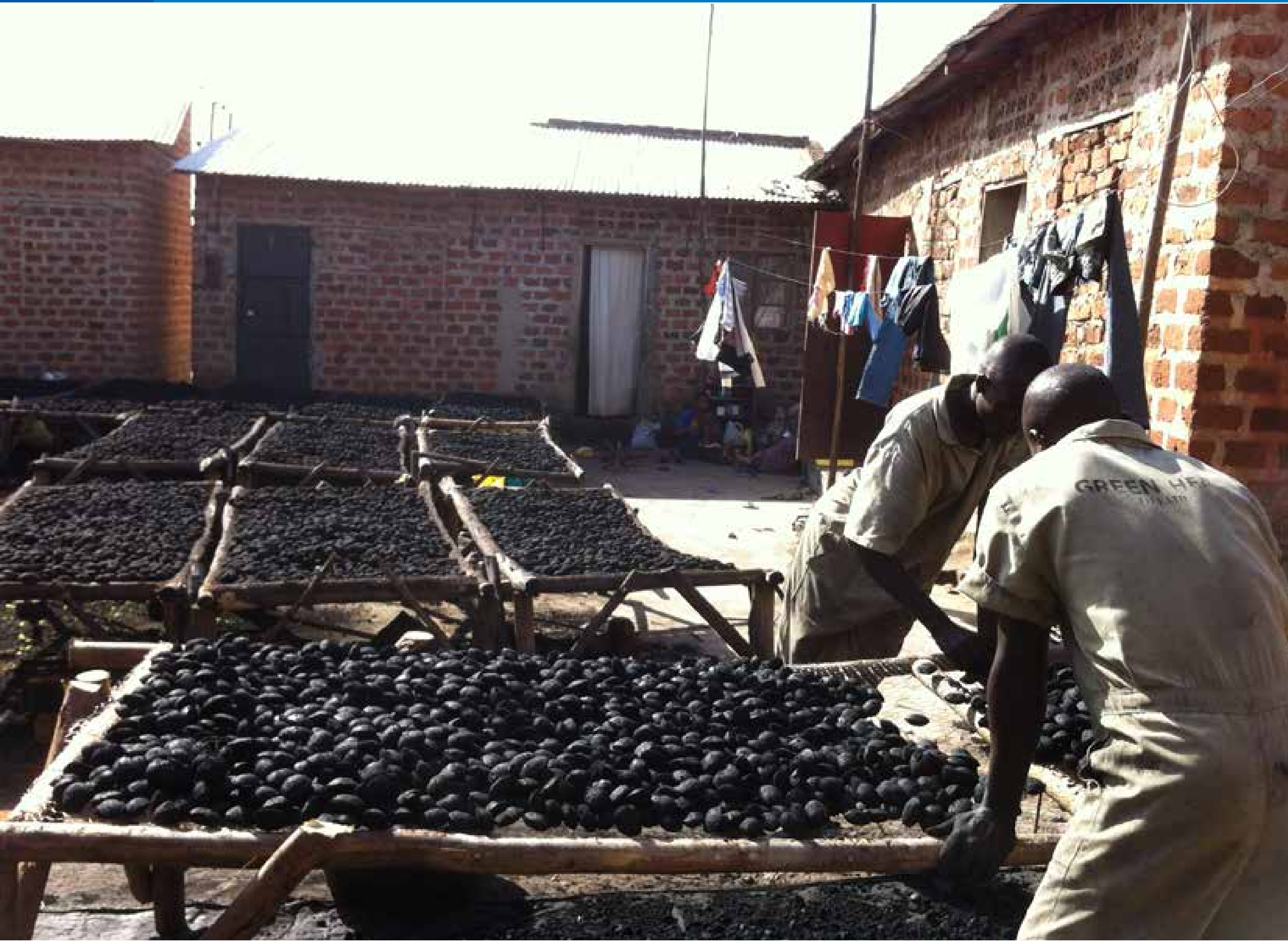
RESOURCE RECOVERY & REUSE SERIES 7

7

A Review on Production, Marketing and Use of Fuel Briquettes

Bernice Asamoah, Josiane Nikiema, Solomie Gebrezgabher, Elsie Odonkor and Mary Njenga



World Agroforestry Centre

About the Resource Recovery and Reuse Series

Resource Recovery and Reuse (RRR) is a sub-program of the **CGIAR Research Program on Water, Land and Ecosystems (WLE)** dedicated to applied research on the safe recovery of water, nutrients and energy from domestic and agro-industrial waste streams. This SRP aims to create impact through different lines of action research, including (i) developing and testing scalable RRR business models, (ii) assessing and mitigating risks from RRR for public health and the environment, (iii) supporting public and private entities with innovative approaches for the safe reuse of wastewater and organic waste, and (iv) improving rural-urban linkages and resource allocations while minimizing the negative urban footprint on the peri-urban environment. This sub-program works closely with the World Health Organization (WHO), Food and Agriculture Organization of the United Nations (FAO), United Nations Environment Programme (UNEP), United Nations University (UNU), and many national and international partners across the globe. The RRR series of documents present summaries and reviews of the sub-program's research and resulting application guidelines, targeting development experts and others in the research for development continuum.

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Bernice Asamoah, Josiane Nikiema, Solomie Gebrezgabher, Elsie Odonkor and
Mary Njenga

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Front cover photograph: Dry fuel production from organic waste in Uganda. *Photo:* Mary Njenga, ICRAF.

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Project

This research study is a contribution to the *Creating and capturing value* (CapVal) project and focuses on one of its components on energy recovery from municipal solid waste.

The CapVal project (2014-2019) supports both public and private sector-driven commercialization of reuse and recycling of waste to improve the sustainability of the sanitation value chain in Ghana. As part of the CapVal project, high-potential solutions are proposed to incentivize better local sanitation planning and management. These solutions aim to reduce waste transport costs, support the lifetime of landfills, and reduce health and environmental impacts, while improving the livelihoods of men/women farmers and contributing to food security.

Collaborators

This research study was a collaboration of the following organizations.

International Water Management Institute (IWMI)

World Agroforestry Centre (ICRAF)

Donors

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The findings and conclusions contained within are those of the authors and do not necessarily reflect positions or policies of the funders.

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ACRONYMS AND ABBREVIATIONS

DWS	Diverted waste streams
GHG	Greenhouse gas
HDPE	High-density polyethylene
LPG	Liquefied petroleum gas
MSW	Municipal solid waste
MWCC	Municipal waste composting char
PE	Polyethylene
PET	Polyethylene terephthalate
PP	Polypropylene
PPP	Public-private partnership
PS	Polystyrene
RDF	Refuse-derived Fuel

SUMMARY

In recent years, briquetting has aroused a great deal of interest because of the opportunity to utilize agricultural residues and the organic fractions of municipal solid waste (MSW) more efficiently with a potential reduction in environmental pollution levels. Where modern heating and cooking fuels for domestic, institutional, commercial and industrial use are not readily available, briquettes made from biomass residues could contribute to the sustainable supply of energy. This study reviews the briquette making process, looking at the entire value chain starting from the type and characteristics of feedstock used for briquette making to the potential market for briquettes in developing countries. It also analyzes the role that gender plays in briquette production. The study first introduces the chemical and physical properties of raw materials suitable for briquette making. The review extends to identifying the various processes involved in briquette production, as well as the combustion and emission properties of the briquettes. The potential market for briquettes in developing countries with examples from East Africa is presented. Finally, the study touches on the key drivers and challenges for the success of a briquette business, based on experience in East Africa.

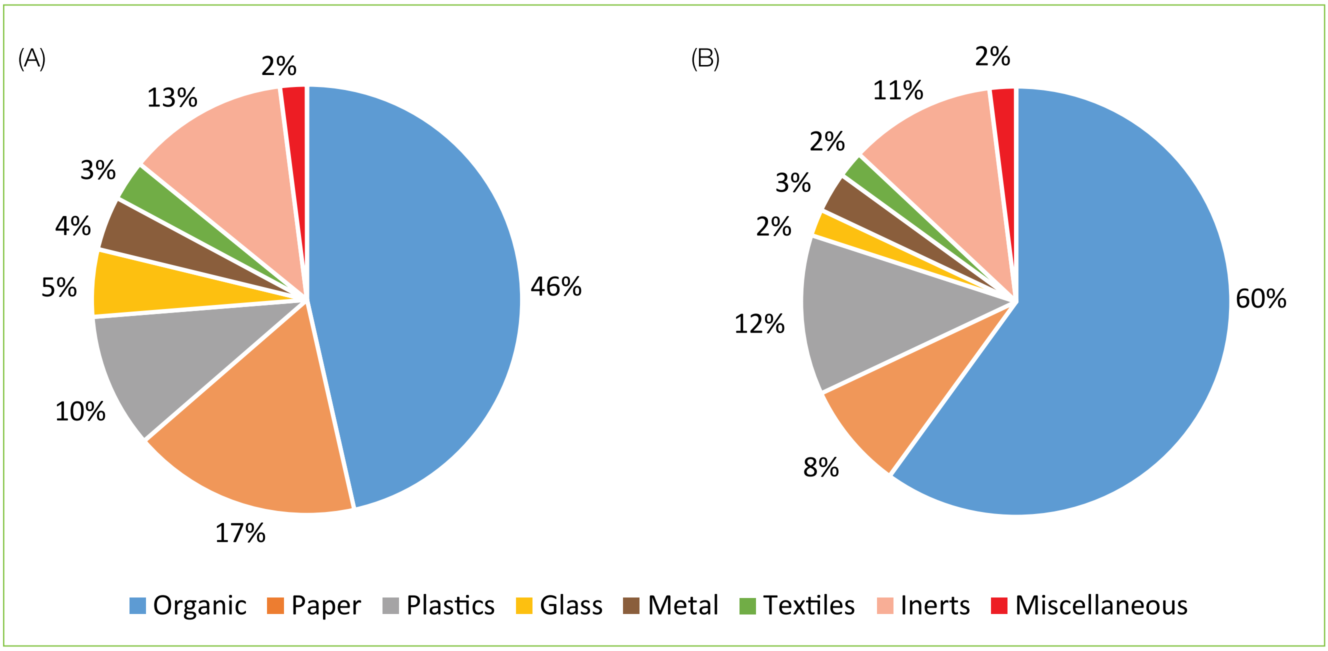
Depending on the raw materials used and technologies applied during production, fuel briquettes come in different qualities and dimensions, and thus require appropriate targeting of different market segments. Quality and burning efficiency of fuel briquettes depend on the characteristics of the raw materials (ideally with lower moisture content, volatile matter and ash content, and with higher fixed carbon content) used to produce the briquettes. Therefore, the raw materials used and the briquetting processes should satisfy these characteristics to obtain the required briquette quality. Key drivers of success in briquette production and marketing include ensuring consistent supply of raw materials with good energy qualities, appropriate technologies, and consistency in the quality and supply of the briquettes. Creating strong partnerships with key stakeholders, such as the municipality, financiers and other actors within the briquette value chain, and enabling policy are important drivers for the success of briquette businesses. Partnering with the private sector, for instance, for waste pre-processing and delivery significantly reduces the cost of production. Similarly, partnering with municipalities or other organizations for resources, such as land, can be important drivers.

1. INTRODUCTION

1.1. Composition of Municipal Solid Waste

Municipal solid waste (MSW) is the solid waste generated within a municipality by households, industries and commercial settings. The content of MSW and the amounts available are variable. In many cases, organic matter forms about 47-75% of the total available MSW (Annepu and Temelis 2013; Alhassan et al. 2010; Shaw 2008). Worldwide composition of MSW in terms of organic waste, paper, plastics, metals, glass and others is shown in Figure 1. The typical example of a specific country, i.e., Ghana, is also provided for comparison. The abundance of MSW and its negative effects if not disposed of properly (Giusti 2009; DEFRA 2004) creates an opportunity for this waste to be utilized in other sectors. In particular, the most abundant fraction, which is organic matter, has been successfully utilized for energy generation purposes, both at commercial and household levels.

FIGURE 1. COMPOSITION OF MUNICIPAL SOLID WASTE IN 2013: (A) GLOBAL AVERAGE, AND (B) GHANA.



Sources: Annepu and Temelis 2013; Hoornweg and Bhada-Tata 2012; Tadesse 2004.

1.2. Management of Municipal Solid Waste

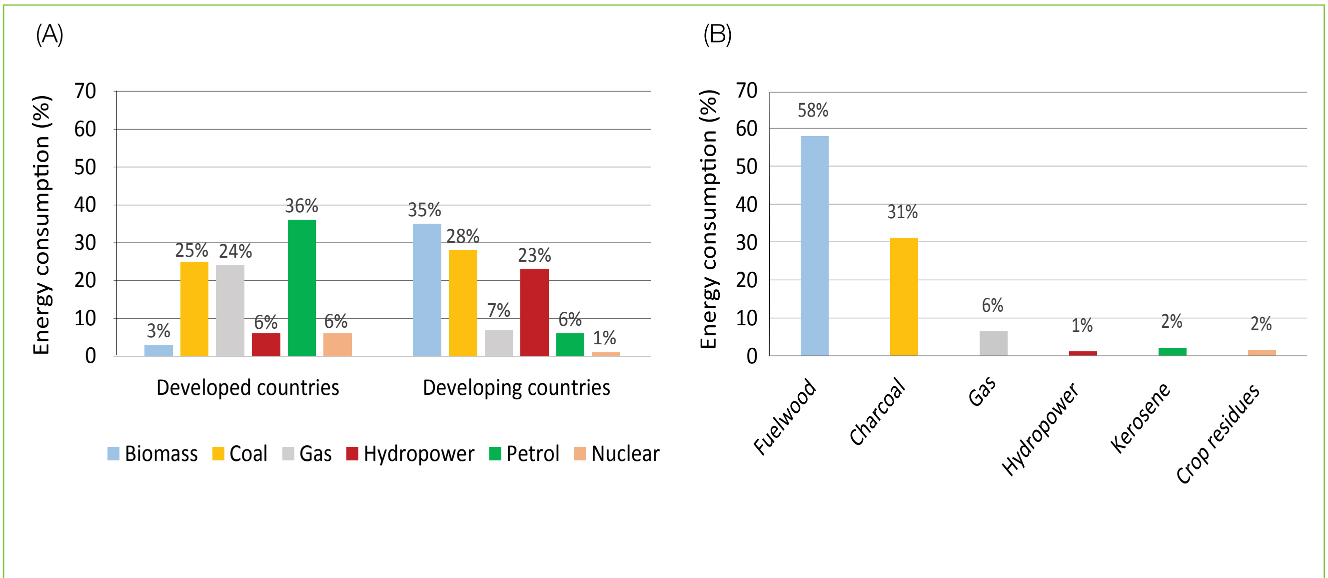
Management of MSW involves the proper containment, transportation, treatment and effective disposal of the treated waste (USAID 2009). In developing countries, these processes often do not occur as they should. Accumulation of the waste can hinder aesthetics of the environment, cause air and water pollution, and promote diseases such as cholera and malaria (Montgomery and Elimelech 2007). This could cause public health problems and lead to environmental degradation, thus contributing to constraints in the economy of many developing countries (Jones and Silva 2009).

1.3. Opportunities

Organic solid waste can be used to produce briquettes, biogas and even electricity, which are all energy sources needed to power many appliances for purposes such as cooking or heating (Obeng et al. 2009). As shown in Figure 2(A), the dominant energy sources in developed and developing countries are petroleum and biomass (such as wood), respectively (Gumartini 2009; Geyer and Iriarte 2007). It is also noted that, even in developed countries, such as those in Europe, the use of biomass as an energy source is increasing (24% increase between 1995 and 2013), replacing coal and petroleum. Recycling waste to produce energy is also becoming popular, and the selection of the recycling method depends on availability of the raw material and conditions of the environment, as well as the local context which determines market demand.

As shown in Figure 2(B), the dominating energy source in Ghana, a typical developing country without need for heating, is fuelwood (Ahiataku-togobo and Ofosu-Ahenkorah 2009), which could lead to land degradation when unsustainably produced or harvested. The negative impact on the environment resulting from the heavy use of fuelwood can be minimized through substitution, for example, with recycled solid waste-based fuel. In addition to contributing to solving sanitation problems, such solutions support a cleaner environment and the ability for afforestation to reduce greenhouse gas (GHG) emissions (Sparrevik et al. 2014). Significant environmental benefits lie in recycling waste for energy production (Ferrão et al. 2014; Halder et al. 2014).

FIGURE 2. ENERGY CONSUMPTION BY RESOURCE IN 2009: (A) GLOBAL AVERAGE, AND (B) GHANA.



Sources: Ahiataku-togobo and Ofosu-Ahenkorah 2009; Gumartini 2009; Geyer and Iriarte 2007.

1.4. Gendered Roles, and Access to, and Control of, Energy Resources for Cooking

Gender roles in sub-Saharan Africa often ascribe productive roles to men and reproductive roles, such as food preparation and collection of fuel and water, to women (Blackden and Wodon 2006). Although women are engaged in productive roles, their livelihood options are more restricted than those available to men. This is due to women's limited access to, and control of, resources such as land, water and trees (World Bank, FAO and IFAD 2009). Across Africa, rights of access to trees is defined by their commercial value (Kiptot 2015). Thus, with regards to the use of biomass, the role of women has been limited to the collection of fuelwood (small wood) for household cooking, while men were involved in the cutting of wood for sale or for the production of charcoal (Kiptot 2015; Obiri et al. 2014). As such, the role of women in sourcing fuel for cooking is absolutely vital for the family to survive. However, this non-paid labor is considered non-productive and jeopardizes their opportunities of generating income by, for example, using time which could alternatively be used for income generation. This contributes to making women more economically dependent.

A study in Ghana revealed that 88.2% of conventional charcoal producers are men as compared to 11.8% of women. The heavy dominance of men in charcoal production was attributed to the labor intensity of the production process, such as cutting of trees, packing, casting sand and grass over the piled wood, and setting fire, which generally women found difficult (Obiri et al. 2014). These findings reported for Ghana are quite similar in other developing countries. In general, women's reproductive role is limited to the use of fuelwood for cooking, baking, smoking meat or fish, lighting, mosquito repellent, sometimes heating houses and water for bathing (Carr and Hartl 2010).

Beyond their reproductive roles, studies have shown that women in both affluent and poor neighborhoods in self-employment use fuelwood in their home-based industries (Tsikata 2009; Clancy et al. 2002). These home businesses for women take the form of baking, sewing, food services, brewing of local beer and manufacturing of artifacts, among others. These types of enterprises that women are traditionally involved in are energy intensive and rely on biomass fuels. Thus, these women often experience the environmental and occupational challenges of their living space more intensely, as we will discuss in detail in the upcoming sections. In food processing enterprises, it has been estimated that energy costs are 20-25% of the total inputs in developing countries (Clancy et al. 2002). The continuously high rate of urbanization with the emergence of informal settlements around urban areas makes the situation worse (increasing the energy cost) for women as energy is needed for these small-scale enterprises, which can contribute to economic survival and growth (Davidson et al. 2007).

The use of multiple sources of energy for household cooking (e.g., natural gas, charcoal, firewood, kerosene and other fuels) is dependent on different factors. These include income levels, varieties of food cooked, household size, existence of cooking facilities (external or internal) and availability of electricity for lighting. Wealthier people are also better able to afford appliances that make use of modern energy carriers. Those who are reliant on biomass fuels are still often able to purchase more fuel-efficient stoves (Energy Commission of Ghana 2014; Skutsch and van Rijn 2002; Clancy et al. 2002). In urban and peri-urban areas, cleaner fuels such as liquefied petroleum gas (LPG) or electricity are often too expensive for most women. Shortages of particular fuels, the lack of distribution networks and failures in the distribution system further aggravate the situation. Thus, even in urban and peri-urban areas, most women continue to depend heavily on biomass fuels (charcoal, firewood) for their activities (Desalu et al. 2012).

Modern fuels, such as LPG, electricity or kerosene are produced in big industries under the formal sector (government, public-private partnerships [PPPs]), while the supply of biomass fuels, such as wood and charcoal, is still largely based in the informal sector. Although the supply of biomass fuel for the cities is an informal trade, it is a commercial activity, the turnover of which in some cases exceeds that of the electricity sector (Clancy et al. 2002).

The role of women, be it reproductive or productive, is heavily dependent on fuel, as mentioned previously. Exploring opportunities for briquette production and use presents an occasion to understand how these activities of men and women can be properly designed for the benefit of everyone.

2. RAW MATERIALS

2.1. Types of Waste Used for Producing Briquettes

2.1.1. Municipal Solid Waste

Production of fuel briquettes from MSW has proven to be successful in some developing countries (Shafie et al. 2012). The abundance and availability of this waste makes it a suitable, potentially cost-effective and reliable raw material for producing briquettes (Ahiduzzaman and Sadrul Islam 2013; Silalertruksa and Gheewala 2013; GVEP International 2010; Wu et al. 2010; Pipatti et al. 2006). In theory, sufficient waste may be obtained for producing briquettes. However, given that certain types of materials are suitable as feedstock, critical consideration of the available types of waste is necessary before commencement of briquette production (Modak 2010). The type of material also depends on the user market, since some types may not be suitable for household use.

Examples of MSW fractions that have been used as key components for fuel briquette production are detailed in Table 1. It is noted that some waste materials such as sawdust or various agro-residues are occasionally not accounted for in the municipal organic solid waste, while they are potentially important in briquette production (Proparco's Magazine 2012; Pipatti et al. 2006; Hoornweg 1999).

The raw materials used have an effect on the properties of the briquettes produced. For example, the use of sawdust can result in higher heating value as compared to the use of paper for producing briquettes. However, under individual optimized production conditions, both types of waste briquette may end up having similar heating efficiencies (Roy and Corscadden 2012).

2.1.2. Industrial Waste

It is possible to use industrial waste for briquette production. In particular, waste paper (Ibrahim et al. 2012), sewage sludge (Boss and Shepherd 2001), sludge as in products from steel industries (Mills et al. 2014), spent bleaching earth from refined palm oil industries (Suhartini et al. 2011) and recyclable plastics (Gug et al. 2015), such as high-density polyethylene (HDPE), polyethylene (PE), polypropylene (PP), polyethylene terephthalate (PET) and polystyrene (PS), are suitable for producing quality briquettes. These added plastics can lead to better densification and high calorific value of briquettes due to their high lignin content that can bond with other materials. In terms of their binding ability, PP and HDPE are better than PET due to their low softening temperature and lower oxygen content. However, addition of such plastics can result in harmful emissions, such as dioxins (Gug et al. 2015).

2.1.3. Sludge

Various types of sludge can be used in briquette production. These include sewage sludge, which is an organic by-product of domestic, municipal or industrial wastewater treatment plants applying biological treatment methods (Supatata et al. 2013). There is also fecal sludge, which is collected from septic tanks or pit latrines located in households and community or commercial toilets. Considering the case of Ouagadougou in Burkina Faso (a typical developing country), a city with about two million inhabitants, approximately 1,000 metric tonnes of fecal sludge are generated with only 20-50% being transported to treatment plants (Tanoh 2016). Producing fuel briquettes is an option for treatment and recycling of this type of waste, next to biogas which is commonly produced from fecal and sewage sludges (Diener et al. 2014). When the moisture content of sludge-based fuel briquettes is less than 14%, it has a calorific value (17-25 mega-joules (MJ)/kg) equivalent to that of fuel coal, which makes it very suitable for use as a source of fuel briquette (Tandukar and Heijndermans 2014). However, digested sludge usually has a lower calorific value (up to 50% less) than non-digested sludge (Kliopova and Makarskienė 2012).

The main technical challenge in recycling sludge into briquettes is linked to its high moisture content. Another disadvantage is that sludge is known to contain pathogens which are potentially harmful to humans. Therefore, care must be taken during the handling of sludge. The good news is that carbonization of the dried sludge in a kiln is a good process that kills pathogens (Wang et al. 2013). Examples of recycling sludge into

TABLE 1. ORGANIC WASTE USED IN DIFFERENT COUNTRIES FOR PRODUCING BRIQUETTES.

RAW MATERIALS	COUNTRY	SOURCES
Agro-residues	China	Chen et al. 2009
Banana rachis	Colombia	Granados et al. 2014
Carton and textiles	Estonia	Kers et al. 2010
Charcoal dust/fines	Kenya, Uganda	Njenga et al. 2013a, 2013b
Coffee husk/wood residues	Brazil, Colombia	Granados et al. 2014; Felfli et al. 2011
Corn cob	Unites States of America	Kaliyan and Vance Morey 2010
Lignite	Turkey	Beker and Kii 1996
Oil palm	Malaysia	Granados et al. 2014; Shuit et al. 2009
Palm kernel shells	Indonesia	Bazargan et al. 2014
Plastics	United States of America	Gug et al. 2015
Rice husk	Colombia, India	Granados et al. 2014; Gadde et al. 2009
Rice straw	India, Southern Taiwan, Thailand 2009;	Silalertruksa and Gheewala 2013; Gadde et al. Tsai et al. 2006
Sawdust/waste papers	Colombia, Kenya, Peru	Granados et al. 2014; Ngusale et al. 2014; Sánchez et al. 2014; Njenga et al. 2013a
Sorghum stalk/corn stover/wheat straw	Unites States of America	Theerarattananoon et al. 2011
Sugarcane bagasse/coconut shells	Colombia, Taiwan	Granados et al. 2014; Tsai et al. 2006
Switch and hay grass	Canada	Roy and Corscadden 2012
Vegetable waste	India	Srivastava et al. 2014

energy (UNEP 2009; Kliopova and Makarskienė 2012) include the following:

- Fuel type 1: Carbonization of dried sludge to create smokeless fuel at 25% moisture content.
- Fuel type 2: Solar drying to generate dry sludge material with 5% moisture content.
- Fuel type 3: Mixing 80% of sludge with 19% of sawdust and 1% of lime, yielding a heating value of 15.5 MJ/kg.

Sludge with a moisture content of 40% can also be used as a binder. It can then be added to MSW, such as sawdust and paper, to produce briquettes (the carbonization process is not carried out).

2.1.4. Key Characteristics of the Feedstock

There are two main groups of characteristics that must be assessed to establish the suitability of waste to be used as feedstock for briquette production. The proximate analysis provides the potential efficiency and durability of the briquettes that will be produced. This requires the following organic solid waste properties:

- **Total carbon content:** Represents the amount of carbon available in the waste material which could eventually be burned for heat to be released.
- **Volatile matter**: This is the part of biomass that may be released when the biomass is heated up, for example, during carbonization. On the other hand, high volatile matter may result in the high release of emissions during burning. Therefore, low volatile matter is of importance.
- **Fixed carbon:** In the case of carbonization, this parameter is useful because it determines the amount of solids remaining once the carbonization process has been completed, i.e., used subsequently to produce briquettes. In this case, a higher carbon content in feedstock is likely to result in long-lasting and mechanically strong carbonized briquettes.
- **Ash content.** Ash is a powdery residue that remains after burning of a material. It is comprised of non-combustible materials (e.g., minerals). A higher ash content will result in ash slagging. This inhibits the combustion process by supporting overheating of the burning device and subsequently its corrosion. Therefore, an optimum ash content in feedstock is needed to control the burning process and to maintain the machine parts.
- **Moisture content:** Higher moisture content in feedstock may increase the production cost in terms of energy, due to the fact that more energy is required to reduce the water content during drying and densification. Lower moisture content may cause flakiness in the raw materials. This implies that moisture is also needed in the right amount to assist the bonding process of the feedstock.
- **Bulk density:** Higher bulk density results in high durability, such as resistance to shear stress. It may increase the cost involved in transporting the raw material in terms of its weight or volume depending on the scenario - high and low density, respectively.
- **Particle size:** The use of a smaller particle size tends to increase the bonding ability of the raw materials used for producing briquettes. On the other hand, using different particle sizes also enhances the bonding ability, because larger particles get filled with the smaller particles to form an interlocking bond.
- **Calorific value:** This determines the amount of energy released during complete combustion of a unit mass of briquette.

A good quality, efficient fuel briquette depends on lower moisture content, volatile matter and ash content with a higher fixed carbon content. Therefore, the raw materials and the briquetting processes should ensure that this is achieved in order to obtain the required briquette quality.

The second group of characteristics, which is the ultimate analysis, involves quantifying elements contained in the waste. These factors influence the combustion behavior, which is the levels and types of emissions that will be generated during usage of the briquettes (Roy and Corscadden 2012). This is of great concern especially for indoor use as it determines air quality. Key gases to monitor include the following:

- **Carbon monoxide (CO)** emission is attributed to the excess air factor (the higher the air factor used for combustion, the lower CO emissions). CO emissions may also result from low combustion temperature, poor mixing of fuel with combustion air and short combustion time.
- **Fine particulate matter ($PM_{2.5}$):** Emission of $PM_{2.5}$ (i.e., particles having a size below 2.5 µm) can be also be attributed to low combustion temperatures.
- **Nitrogen oxides (NO_x)** content is proportional to the nitrogen content in the feedstock. The higher the nitrogen content, the higher NO_x emissions. NO_x may also be produced at high temperature in boilers/kilns, even in the absence of organic nitrogen.
- **Sulfur oxides (SO_x)** content is proportional to the sulfur content in feedstock.

Hydrogen results in water formation after combustion. High oxygen levels improve the burning potential of the briquette and reduce the burning temperature. Chlorine and sulfur affect the acidity levels of emissions. Therefore, their respective concentrations must be reduced to create an acid-free environment.

The optimal values obtained for specific characteristics of selected solid wastes used for briquette production and the sources of these data are given in Table 2.

TABLE 2. PHYSICAL AND CHEMICAL PROPERTIES OF SELECTED SOLID WASTES USED FOR BRIQUETTE PRODUCTION.

RAW MATERIALS	PROXIMATE ANALYSIS						ULTIMATE ANALYSIS						SOURCES
	MOISTURE CONTENT (%)	ASH CONTENT (%)	FIXED CARBON (%)	CALORIFIC VALUE (MJ/Kg)	BULK DENSITY (Kg/m³)	VOLATILE MATTER (%)	CARBON (%)	HYDROGEN (%)	OXYGEN (%)	NITROGEN (%)	SULFUR (%)	CHLORIDE (%)	
Coconut shells/ husks	7.5-18.1	0.5-5.9	17.0-20.7	15.5-23.0	NA	76.0-81.4	47.0-63.5	5.8-6.7	28.3-45.2	0.3-0.8	0.1-0.3	0.1-1.0	Bazargan et al. 2014; Nhuchhen and Salam 2012; Neves et al. 2011; Tsai et al. 2006; Chen et al. 2009; Jenkins et al. 1998
Corn cob/ husk/straw/ stover	7.0-9.3	4.6-11.8	6.7-16.8	NA	1,017.2	72.2-84.3	45.4-51.2	5.0-6.2	33.0-46.4	0.0-0.9	0.0-0.2	0.2	Neves et al. 2011; Yuan et al. 2010; Chen et al. 2009; Jenkins et al. 1998
Grass	3.5-5.0	6.7-22.5	9.2-14.3	12.6-17.4	650.9	63.3-76.7	42.7-46.7	5.6-6.8	37.4-44.6	0.7-4.2	0.0-1.7	0.0-0.2	Haykiri-Acma et al. 2013; Hedman et al. 2005; Jenkins et al. 1998
Groundnut shell	1.6	1.5-1.9	17.1-19.6	19.0	NA	77.5-81.5	NA	NA	NA	NA	NA	NA	Veeresh and Narayana 2013
Palm oil fiber/shell	4.2-36.7	4-7.3	9.9-10.5	18.4-35.5	NA	78.3-78.9	42.5-42.9	6.4-6.7	42.6-43.3	1.0-1.1	0.1	0.1	Granados et al. 2014; Nhuchhen and Salam 2012; Chen et al. 2009; Jenkins et al. 1998
Paper waste	7.4-12.6	1.2-15.5	NA	13.0	NA	65.5	35.2-48.0	4.9-6.6	51.3-36.8	0.1-0.2	0.1	NA	Neves et al. 2011; Jenkins et al. 1998
Refuse-derived fuel (RDF)	5.1-16.3	1.2-28.0	8.3-12.1	13.5-22.0	NA	58.4-83.0	32.5-46.0	4.6-6.6	36.0-49.3	0.3-2.7	0.7	0.3	Granados et al. 2014; Chen et al. 2009; Hedman et al. 2005

(Continued)

TABLE 2. PHYSICAL AND CHEMICAL PROPERTIES OF SELECTED SOLID WASTES USED FOR BRIQUETTE PRODUCTION. (Continued)

RAW MATERIALS	PROXIMATE ANALYSIS						ULTIMATE ANALYSIS						SOURCES
	MOISTURE CONTENT (%)	ASH CONTENT (%)	FIXED CARBON (%)	CALORIFIC VALUE (MJ/Kg)	BULK DENSITY (Kg/m³)	VOLATILE MATTER (%)	CARBON (%)	HYDROGEN (%)	OXYGEN (%)	NITROGEN (%)	SULFUR (%)	CHLORIDE (%)	
Rice husk/ straw	5.1-15.5	7.9-23.5	14.2-17.5	14.2-20.5	327	56.1-68.3	32.6-55.0	4.1-8.1	32.8-42.1	0.2-2.7	0.1-0.4	0.1-0.7	Granados et al. 2014; Ramírez-gómez et al. 2014; Ahiduzzaman and Sadrul Islam 2013; Lim et al. 2012; Nhuchhen and Salam 2012; Felfli et al. 2011; Neves et al. 2011; Chen et al. 2009; Chou et al. 2009a; Tsai et al. 2006; Blesa et al. 2001
Sawdust	1.8-9.8	0.2-5.6	2.2-21.6	17.5-34.3	133-210	77.7-88.6	48.3-50.8	5.5-7.0	41.2-46.5	0.1-1.5	< 0.01	NA	Granados et al. 2014; Ramírez-gómez et al. 2014; Prasityousil and Muenjina 2013; Li et al. 2012; Felfli et al. 2011; Neves et al. 2011; Blesa et al. 2001; Veeresh and Narayana 2013
Sewage and fecal sludge	80.0-97.0	42-57.1	6.9	8.6-11.0	NA	36.1-50.0	22.2	3.34	70.4	3.3	0.7	NA	Supatata et al. 2013; Schulz 1998
Pulp and textile sludge	65-80	53.6-54.3	4.2-8.1	8.7-12.0	NA	45.7-46.4	18.5-32.2	1.8-5.7	59.0-78.8	0.8-1.4	1.64	0.07-0.1	Chiou and Wu 2014

(Continued)

TABLE 2. PHYSICAL AND CHEMICAL PROPERTIES OF SELECTED SOLID WASTES USED FOR BRIQUETTE PRODUCTION. (Continued)

RAW MATERIALS	PROXIMATE ANALYSIS						ULTIMATE ANALYSIS						SOURCES
	MOISTURE CONTENT (%)	ASH CONTENT (%)	FIXED CARBON (%)	CALORIFIC VALUE (MJ/Kg)	BULK DENSITY (Kg/m³)	VOLATILE MATTER (%)	CARBON (%)	HYDROGEN (%)	OXYGEN (%)	NITROGEN (%)	SULFUR (%)	CHLORIDE (%)	
Shrubs	40.7-48.7	0.1-1.2	12.6-25.8	NA	507.0-1,010.8	73.0-81.5	NA	NA	NA	NA	NA	NA	Ramírez-gómez et al. 2014; Nhuchhen and Salam 2012; Alves et al. 2010; Kinsey et al. 2009; Samuelsson et al. 2009
Tamarind fruit shell	2.8-3.2	3.1-3.4	19.3-21.8	15.1	NA	74.0-78.3	NA	NA	NA	NA	NA	NA	Veeresh and Narayana 2013
Wood	5.3-15.5	0.0-7.5	14.6-17.4	16.6-19.0	284.0-1,026.7	74.7-85.0	47.6-53.6	5.6-7.7	36.6-46.0	0.1-0.2	< 0.01	0.0-0.1	Ramírez-gómez et al. 2014; Shen et al. 2014; Alves et al. 2011; Lamberg et al. 2011; Neves et al. 2011; Hedman et al. 2005

Note: NA - Not available

2.1.5 Properties of Waste Used as Feedstock

To select the right materials for briquette production, it is important to consider the overall characteristics of the individual or mixture of wastes used as feedstock. Given the high variability of waste types, it is nearly impossible to analyze their impact on briquette quality in a systematic way. However, based on some experiments using palm fruit bunches, coconut shells and fibers, peanut shells, vegetable waste, rice husk and sawdust, some conclusions were reached on the desirable characteristics of raw materials used, which can inform other cases. As shown in Table 3, these characteristics influence the production of briquettes and the quality of briquettes in terms of impact strength, water resistance and tensile strength.

2.2. Use of Binders

2.2.1. Importance of Binders in Briquette Production

Binders are added to raw materials that cannot alone densify to form strong briquettes. The addition of a binder results in enhanced bonding and more stable properties in the briquettes produced (Bhattacharya et al. 2002; Wamukonya and Jenkins 1995). The amount of binder to be added depends on the binding properties of the raw material and the binding agent. The densifying and binding ability of the briquette machine also determines whether a binding agent is necessary or not. That is, use of a briquette machine with high pressure would reduce the need for use of a binding agent.

Binders having good binding ability include biodegradable paper soaked in water, subsoil, lignin, fibers, glycerine, char, pitch, molasses, plastics and starch (Bazargan et al. 2014; Massaro et al. 2014; Okegbile et al. 2014; Haykiri-Acma et al. 2013; Njenga et al. 2013a; Prasityousil and Muenjina 2013; Fengmin and Mingquan 2011; Chou et al. 2009b; Hedman et al. 2005; Rubio et al. 1999). In wood cells, bonds are caused by lignin. Therefore, materials that contain lignin may be easier to mould using a high pressure briquette machine, because lignin in this case acts as a binder (Ngusale et al. 2014). A lignin content of 3-6% in vegetable waste produced stable briquettes with a calorific value of 10-14 MJ/kg (Srivastava et al. 2014; Kaliyan and Vance Morey 2010). Lignin content of feedstock can be measured to identify whether other binders may be needed or not (Blesa et al. 2003). For example, the mixture comprising 17% municipal waste composting char (MWCC), 66% sawdust and 17% slop waste was found to be optimal. The addition of slop waste as a binder increased the compressibility strength of the briquettes (Ngusale et al. 2014; Prasityousil and Muenjina 2013; Emerhi 2011; Chou et al. 2009b; Yaman et al. 2000; Demirbaş 1999). Including starch in the briquetting process has shown to have increased the tensile strength (the resistance of briquettes to applied stress) from 40 kilo-newtons (kN)/m^2 to more than 800 kN/m^2 (Bazargan et al. 2014).

An optimum amount of a material with good binding ability is needed in the feedstock to enable processing. Based on some recent experiments, it can be established that 6% to

TABLE 3. PHYSICAL AND CHEMICAL CHARACTERISTICS OF BIOMASS REQUIRED FOR BRIQUETTE MAKING.

	PROPERTIES	UNIT	REQUIREMENT	SOURCES
Proximate analysis	Moisture content	%	6-14	Ngusale et al. 2014; Kers et al. 2010; Faizal et al. 2010
	Ash content	%	Less than 4% to avoid slagging	Faizal et al. 2010
	Particle size	mm	1-10 mm size with 10-20% powdery*	Carone et al. 2011; Kers et al. 2010; Chou et al. 2009a; Grover and Mishra 1996
	Fixed carbon	%	9-25	Alves et al. 2010; Faizal et al. 2010
	Calorific value	MJ/kg	10-35	Srivastava et al. 2014
	Bulk density	kg/m^3	More than 50	Grover and Mishra 1996
	Heating value	MJ/kg	12-20	Shen et al. 2014; Neves et al. 2011
	Volatile matter	%	50-90	Felfli et al. 2011; Neves et al. 2011
Ultimate analysis	Carbon (C)	%	40-55	Ramírez-gómez et al. 2014; Nhuchhen and Salam 2012; Hedman et al. 2005
	Hydrogen (H)	%	5-8	Ramírez-gómez et al. 2014; Liu et al. 2013; Hedman et al. 2005
	Oxygen (O)	%	35-48	Ramírez-gómez et al. 2014
	Nitrogen (N)	%	0-1	Ramírez-gómez et al. 2014; Jenkins et al. 1998
	Sulfur (S)	%	0-2	Ramírez-gómez et al. 2014; Blesa et al. 2001
	Chloride (Cl)	%	0-1	Granados et al. 2014; Ramírez-gómez et al. 2014

Note: *Finer particles that enhance proper bonding by occupying the pore spaces between particles.

25% of such a material should be in the feedstock for optimal briquetting (Phonphuak and Thiansem 2012; Vassilev et al. 2012; Fengmin and Mingquan 2011; Stelte et al. 2011; Chin and Siddiqui 2000). However, it is important to state that the binding requirement and effectiveness is a complex science which is affected by many factors, some being external to the binder itself, including the moisture level.

The binding properties of some raw materials and other binders are enhanced by favorable process parameters, such as high temperature, during their pretreatment or densification. Binders plasticize and soften in high temperature, and this helps in the binding process (Ngusale et al. 2014). As an illustration, an experiment was conducted on the use of golden horn sediments (organic substance and clay obtained from golden horn estuaries) in producing fuel briquettes. Increase in the binding property of the material was achieved by placing it under a moderate temperature (100 °C to 150 °C) for 2 to 4 hours, or by adding chemical agents such as lime. The good binding ability improved the compressive strength (strength determines the durability of the briquette in terms of its resistance to stress) of the briquette up to 9.9-28.8 MPa (Alaru et al. 2011; Shaw et al. 2009; Celik and Elbeyli 2004).

2.2.2 Amount of Materials and Binders

To improve the characteristics of the feedstock used in briquette production, raw materials can be mixed. In this process, cost implications and the potential benefit should be considered. Binders can be added during mixing of the feedstock or after carbonization of the feedstock for non-carbonized and charcoal briquettes, respectively (Kiatgrajai et al. 1991). The increase in mechanical strength may also cause a decrease in the combustibility of briquettes. Table 4 shows some mix ratios of materials used in briquette production.

TABLE 4. MIX RATIOS OF MATERIALS USED IN BRIQUETTE PRODUCTION.

RAW MATERIALS/*BINDERS*	PERCENTAGE OF MATERIALS (%)	EXTRA REMARKS/SOURCE
	Production of non-carbonized briquettes	
1. RDF[1]	100	Sample 1 had the highest bulk density.
2. RDF	80	However, samples 2, 3 and 5 had the highest strength.
Disintegrated carbon waste[2]	20	Sample 4 had a higher ash content and was hence not
3. RDF	50	suitable for use. Increasing temperature and pressure
Disintegrated carbon waste	50	increases the strength and quality of the briquettes, but the
4. RDF	96	quality may reduce if its optimum characteristics are
Cement	*4*	exceeded.
5. RDF	80	Kers et al. 2010
Wood sawdust	*20*	
Palm biomass Water *Waste glycerol*	50 10 *40*	The addition of waste glycerol enhanced the bonding properties of the material during briquetting. Shuit et al. 2009
Palm kernel shells *Water* *Starch*	70 *20* *10*	Palm kernel shells with starch increased tensile crushing strength of briquettes from 40 kN/m^2 to 800 kN/m^2. Bazargan et al. 2014
Palm kernel shells *Molasses*	75 *25*	25% of molasses was better compared to 15% and 20% of molasses, since it provided a good bond between the material. Bazargan et al. 2014
Sawdust Wood ash *Starch* *Cow dung*	48 10 *21* *21*	Sawdust with starch produced better briquettes with a calorific value up to 138.6 MJ/kg. Emerhi 2011

(Continued)

TABLE 4. MIX RATIOS OF MATERIALS USED IN BRIQUETTE PRODUCTION. (CONTINUED)

RAW MATERIALS/*BINDERS*	PERCENTAGE OF MATERIALS (%)	EXTRA REMARKS/SOURCE
Diverted waste streams (DWS)[3] Styrofoam *Plastics*	70 5 *25*	The addition of plastics increased the strength (bonding) of the the briquettes due to its melting property. Gug et al. 2015
Rice straw Sawdust	60, 80, 100 40, 20, 0	60% and 40% of rice straw and sawdust, respectively, increased the compressive strength of briquettes, indicating good briquetting properties in sawdust. Chou et al. 2009a
Production of charcoal-based briquettes		
Coal fines Shredded wood Ground rubber *Water*	77 9 4 *10*	The characteristics and final quality of the product were not stated, but it was identified that coal fines and shredded wood were the most suitable materials to be used. Con and Birdwell 2003
Coal fines Shredded wood Ground rubber	51 39 10	
Shredded wood *Pyrolysis oil*	60 *40*	
Bio-binder (direct liquefaction) Shredded wood	80 20	
Coal fines Shredded wood Shredded paper Shredded RDF Ground rubber Cotton stocks	20 30 30 10 5 5	
Shredded green waste Shredded waste lumber Shredded waste pallets Sawdust	60 20 10 10	

Notes:

[1] RDF is mixed municipal waste consisting of 38% wood chips from softwood, 45% disintegrated carbon waste, 11% disintegrated PET bottles and 6% textile waste.

[2] Disintegrated carbon waste is shredded wood.

[3] Diverted waste streams, e.g., plastics, wood, paper and solid trash from landfills.

2.3 Pretreatment of Feedstock for Producing Briquettes

2.3.1 Adjustment of the Moisture Content

Moisture content influences the quality of the briquette produced by forming a solid bridge between particles (Bazargan et al. 2014). Low moisture may cause roughness and thus inhibit effective bonding of the materials. This will decrease the tensile strength of the briquettes (Nyakuma et al. 2014). On the other hand, high moisture content may increase the cost in drying the materials, as more energy will be required for water evaporation (Shen et al. 2014). Optimum moisture content varies with the type of feedstock, but it is recommended that a level between 10% and 15% is maintained. In practice, the level is between 6% and 23% (Stolarski et al. 2013; Zhang et al. 2013; Theerarattananoon et al. 2011; Kaliyan and Vance Morey 2009; Andrejko and Grochowicz 2007; Yaman et al. 2000; Singh 1998).

2.3.2 Adjustment of the Particle Size

It is sometimes required to adjust the particle size to allow durable briquettes to be produced. When mixing different particle size materials, inter-particle bonding with nearly no inter-particle spaces between materials could be created, and this yields briquettes with high impact and tensile strength (Srivastava et al. 2014; Kaliyan and Vance Morey 2009; Hedberg et al. 2002; Blesa et al. 2001). According to many studies, the recommended particle size of biomass used for producing both charcoal-based and non-carbonized briquettes ranged below 6 mm (Bazargan et al. 2014; Andrejko and Grochowicz 2007).

2.3.3 Preheating Processes

Preheating of raw materials prior to commencing the briquette making process is often necessary to overcome the challenges of low density, low heating value, high moisture content and low fixed carbon content of the feedstock. It is also necessary to avoid difficult transportation, poor grindability, soot formation and hygroscopic nature. Furthermore, preheating has the advantage of reducing the bacterial counts (Li et al. 2012; Kaliyan and Vance Morey 2009, 2010; Marsh et al. 2007). Preheating is encouraged to increase the binding properties, especially in situations when plastic is a material included and melting of the lignin content of the plastic increases, enabling it to bond with other materials (Kers et al. 2010; Con and Birdwell 2003). The increase in the bonding properties of materials may require less pressure during densification. In their experiment, pressure decreased from 180 Mega-pascals (MPa) to 30 MPa when materials were preheated prior to the briquetting process (Du et al. 2014; Bhattacharya et al. 2002).

For briquettes produced from carbonized raw waste, the preheating step may involve oven drying with lower temperatures of 105 °C (Liu et al. 2013) or just sun drying as compared to the non-carbonization process of biomass, which will need higher temperatures of up to 200 °C (Granados et al. 2014). Tables 5 and 6 show some preheating processes, the materials used and the quality of the non-carbonized and carbonized briquettes that were produced, respectively. The preheating condition that is relevant in many cases in developing countries is drying.

TABLE 5. PREHEATING CONDITIONS FOR BRIQUETTES PRODUCED FROM NON-CARBONIZED WASTE AND ITS IMPORTANCE.

PREHEATING METHOD	RAW MATERIALS	OPERATING CONDITIONS			BENEFITS	SOURCE
		TEMPERATURE (°C)	RETENTION TIME (MINUTES)	PREHEATING PROCESS		
Steam auto-hydrolysis	Poplar wood, wheat straw	200-205	4-6	Biomass was preheated at 200-205 °C with the application of 1-3 MPa of pressure. This preheating of biomass was carried out by SunOpta Bioprocess Inc. (Canada).	Increase in density and tensile strength due to the presence of lignin.	Shaw et al. 2009
Thermal pretreatment	Palm kernel shell biochars	240-260	30-90	Biomass was heated at a temperature between 240 and 260 °C. The heated biomass was left to cool prior to densification to avoid fire hazards.	Calorific value increased from 19 to 23 MJ/kg. Also, biodegradation ceased, allowing longer storage durations of the briquettes. In addition, treated biomass becomes brittle and this makes grinding easy. Heating value increased from 5% to 16% due to an increase in carbon content and a decrease in hydrogen and oxygen.	Bazargan et al. 2014
Torrefaction	Sugarcane bagasse, banana rachis, rice husk, palm oil fiber, sawdust, coffee waste	200-300	< 60	Biomass was first dried at a temperature of 23 °C, exposed to 400 watts (W)/m^2 of solar radiation for 12 hours and ground to obtain a particle size of 150 μm before torrefaction. Torrefaction was carried out in APT LINSEIS-type Thermo-gravimeter analyzer Simultaneous Thermal Analysis (STA) 1600 (TGA) at 200-300 °C for 30 minutes.	Degradation of the lignocellulosic components and increase in the heating value of the briquette. Heating value increased by 5% to 15%.	Granados et al. 2014

TABLE 6. PREHEATING CONDITIONS FOR BRIQUETTES PRODUCED FROM CARBONIZED WASTE AND ITS IMPORTANCE.

PREHEATING METHOD	RAW MATERIALS	OPERATING CONDITIONS			BENEFITS	SOURCE
		TEMPERATURE (°C)	RETENTION TIME (MINUTES)	PREHEATING PROCESS		
Drying	Bamboo	105	480 and then 120	Before carbonization, bamboo was oven dried at 105 °C for 8 hours, cooled in a desiccator and then oven dried again at the same temperature for 2 hours.	Stabilization of the moisture content in bamboo.	Liu et al. 2013

3. PROCESS OF PRODUCING BRIQUETTES

This section discusses the different processes and factors affecting the quality of carbonized (charcoal) or non-carbonized briquettes that are produced. Non-carbonized briquettes (type 1) in Figure 3 are produced using corn cob, rice husk, sawdust and coffee waste. Type 1 briquettes are produced through the densification of raw waste materials. Charcoal briquettes (type 2) in Figure 4 are produced with char dust, waste paper, coffee husk and bamboo. In this case, type 2 briquettes were produced through densification of raw material that was already carbonized. However, it is also possible to carbonize type 1 briquettes to form type 2 briquettes.

FIGURE 3. NON-CARBONIZED BRIQUETTES.

Photos: Solomie Gebrezgabher, IWMI.

FIGURE 4. CHARCOAL BRIQUETTES.

(A) (B) (C)

Photos: (A) and (C): Mary Njenga, ICRAF; and (B) Solomie Gebrezgabher, IWMI.

3.1. Production of Briquettes from Non-carbonized Waste

Table 7 presents a summary of the experiments conducted on raw materials and the processes applied in the production of non-carbonized briquettes, and the resultant quality of the briquettes.

TABLE 7. PROPERTIES OF RAW MATERIALS, PROCESSES APPLIED AND THE QUALITY OF THE NON-CARBONIZED BRIQUETTES PRODUCED.

RAW MATERIALS/ *BINDERS OR ADDITIVES*	**OPTIMAL CHARACTERISTICS OF RAW MATERIALS**			**BRIQUETTE MACHINE**		**PROCESS**	**QUALITY OF BRIQUETTES**	**SOURCE**
	PARTICLE SIZE (mm)	**MOISTURE CONTENT (%)**	**MIXING RATIO (% MASS)**	**PRESSURE (MPa)**	**TEMPERATURE (°C)**			
Wood Carton Plastics Textiles	< 6	10-18	38 45 11 6	150-250	120-160	Raw materials were ground, dried and briquetted using briquetting press.	Addition of wood and paper increased the compressive strength of briquettes from 4 MPa to about 20 MPa. Increase in the compressive strength of the briquette enhanced its durability, since absorption of atmospheric humidity decreases.	Kers et al. 2010
Sawdust Peanut shells Coconut fibers Palm fruit fibers *Cassava starch*	0.15-0.85	5-30	25 10 30 10 25	5-7	NA	Materials were ground and densified using piston and die press.	Sawdust helped to produce the best quality briquettes with low combustion rates and rice husk produced low-quality briquettes. The use of starch increased the quality of the briquettes. Rice husks produced better briquettes when water is used as a binder. The lowest quality briquettes were produced when the moisture content was around 20%.	Chin and Siddiqui 2000
Domestic Solid Waste Styrofoam Plastics	8	0.4-10.3	70 5 25	1-10	125 and 150	Materials were ground, either preheated for 1 hour at 50 °C and 4 hours at 100 °C or they are not preheated. They were then densified using hydraulic press.	The addition of plastics improved the density hardness and higher energy. Increase in temperature and optimization of temperature increased the density and strength of the briquettes.	Gug et al. 2015

(Continued)

TABLE 7. PROPERTIES OF RAW MATERIALS, PROCESSES APPLIED AND THE QUALITY OF THE NON-CARBONIZED BRIQUETTES PRODUCED. (Continued)

RAW MATERIALS/ *BINDERS OR ADDITIVES*	**OPTIMAL CHARACTERISTICS OF RAW MATERIALS**			**BRIQUETTE MACHINE**		**PROCESS**	**QUALITY OF BRIQUETTES**	**SOURCE**
	PARTICLE SIZE (mm)	**MOISTURE CONTENT (%)**	**MIXING RATIO (% MASS)**	**PRESSURE (MPa)**	**TEMPERATURE (°C)**			
Caragana korshinskii Kom[1]	0.16-5	5-17	100	10-170	70-150	Materials were ground, dried to the desired moisture content and then preheated at 105 °C for 72 hours. It was then compacted using a piston and mould machine.	Decrease in particle size, moisture content (5-17%) and increase in temperature (90-150 °C) with an optimum pressure (50-110 MPa) helped to achieve quality briquettes in terms of increased density, durability, impact resistance and compressive strength.	Zhang and Guo 2014
Norway spruce	0.5-3.15	6.3-14.7	100	46-114	26-144	Raw materials were dried (50 °C for 8 hours), ground and densified using pellet press.	Moisture content of 6.3% and increase in temperature to 144 °C did not have a significant effect on the durability of the briquettes produced.	Rhén et al. 2005
Biomass (molasses, pine cone, olive refuse, sawdust, paper mill waste and cotton refuse) *Lignite*	≤ 0.25	6-14.7	70-100 0-30	50 and 250	NA	A 400 g sample was stabilized by allowing it to rest under ambient temperature, ground and then briquetted using a hydraulic piston. Initial moisture content of the lignite was 40.7% and then dewatered to obtain a moisture content of 10-30%.	The mechanical strength of the briquettes was increased with the addition of the biomass. Paper mill waste, olive oil and sawdust increased the shatter index, water resistance and compressive strength of the briquettes, respectively.	Yaman et al. 2001
Soda weed, *Sawdust, walnuts*	1-10	7-10	NA	31.4	85-105	Material was ground and densified using a hydraulic press.	Higher moisture content was not suitable; same for lower pressures. Addition of awdust and walnuts increased the strength of the briquettes and also the density from 800 kg/m^3 to 1,150 kg/m^3.	Yumak et al. 2010

(Continued)

TABLE 7. PROPERTIES OF RAW MATERIALS, PROCESSES APPLIED AND THE QUALITY OF THE NON-CARBONIZED BRIQUETTES PRODUCED. (Continued)

RAW MATERIALS/ *BINDERS OR ADDITIVES*	OPTIMAL CHARACTERISTICS OF RAW MATERIALS			BRIQUETTE MACHINE		PROCESS	QUALITY OF BRIQUETTES	SOURCE
	PARTICLE SIZE (mm)	MOISTURE CONTENT (%)	MIXING RATIO (% MASS)	PRESSURE (MPa)	TEMPERATURE (°C)			
Sawmill dust Press dug Groundnut shell	5	0.34-0.41	50 33 17	NA	NA	Materials were grounded, exposed to sunlight to reduce the moisture content and then densified using a piston press.	This type of briquette showed better characteristics for both physical and combustion parameters as compared to briquettes produced using a higher percentage of press dug or groundnut shell. The bulk density, ash content and durability achieved were 2,325 kg/m^3, 34% and 100, respectively. The combustion achieved was 66% as compared to 60% in the briquettes produced using a higher percentage of press dug or groundnut shell.	Veeresh and Narayana 2013
Sewage sludge Sawdust Peat	NA	8-12	40 50 10	5-20	NA	Sewage sludge was composted and then sawdust and peat were added. It was then pressed to produce the briquette.	The calorific value improved with less moisture content. At a moisture content of 12%, the calorific value was 16.9 MJ/kg as compared to 19.0 MJ/kg when the sample had a moisture content of 8%. Also, 100% composted sewage sludge used to produce briquettes provided a calorific value as low as 3.8 MJ/kg as compared to the 16.9 MJ/kg achieved when sawdust and peat were added. On the other hand, high nitrogen and sulfur contents of 1.8 and 0.59, respectively, were achieved as compared to the nitrogen and sulfur contents of 1.13 and 0.14, respectively, that were achieved when sawdust and peat were added.	Kliopova and Makarskienė 2012

(Continued)

TABLE 7. PROPERTIES OF RAW MATERIALS, PROCESSES APPLIED AND THE QUALITY OF THE NON-CARBONIZED BRIQUETTES PRODUCED. (Continued)

RAW MATERIALS/ *BINDERS OR ADDITIVES*	OPTIMAL CHARACTERISTICS OF RAW MATERIALS			BRIQUETTE MACHINE		PROCESS	QUALITY OF BRIQUETTES	SOURCE
	PARTICLE SIZE (mm)	MOISTURE CONTENT (%)	MIXING RATIO (% MASS)	PRESSURE (MPa)	TEMPERATURE (°C)			
Sewage sludge *Burned lime*		23.5	90 10	18-51	NA	Sewage sludge was homogenized by mixing it in a mixer with preheated water jacket. Lime is included to avoid slagging and bring the samples together. Samples were then put in a hopper and densified using a roller press (LPW 450).	Briquettes produced from this sample achieved a bulk density, calorific value, water resistance and compressive strength of 1,540 kg/m^3, 8.6 MJ/kg, > 99% and 500 kN/m^2, respectively. However, a high ash content of 40% was achieved, which may not be good for combustion purposes.	Magdziarz et al. 2011

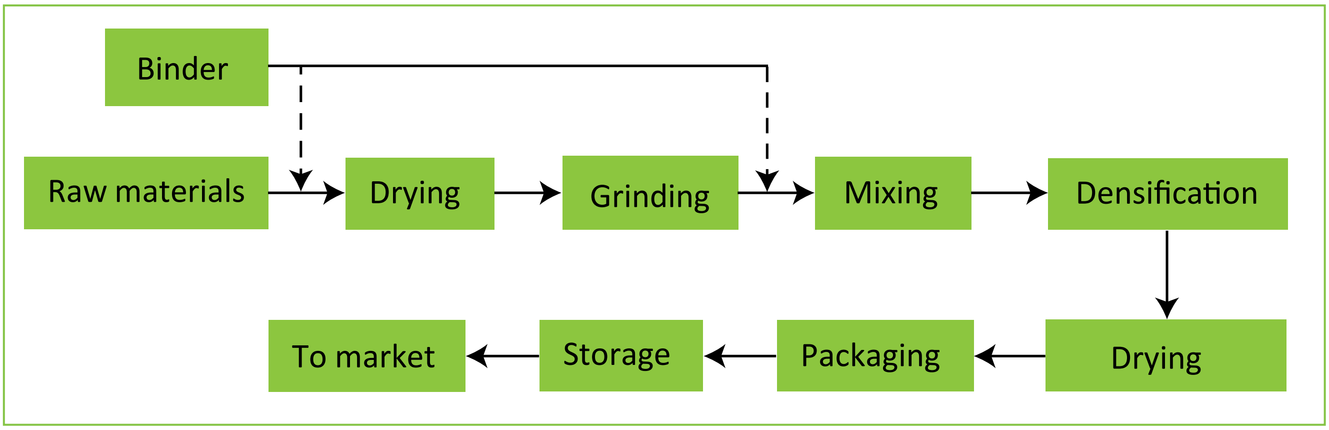
Note: [1] *Caragana korshinskii Kom* is a drought-resistant, leguminous shrub mostly grown in China.

NA - Not available

3.1.1. Operating Parameters in Production

The general production process for non-carbonized briquettes is shown in Figure 5. Materials such as sawdust and agro-residues can be used for producing non-carbonized briquettes. If densification pressure is adequate, no extra binder is added (Ngusale et al. 2014; Modak 2010; Chou et al. 2009b; Kiatgrajai et al. 1991). During the briquetting process, operating parameters, such as temperature, pressure and compaction time, achieved by the briquetting machine need to be optimized in order to produce good quality non-carbonized briquettes.

FIGURE 5. FLOW DIAGRAM SHOWING THE PROCESSES FOLLOWED IN THE PRODUCTION OF NON-CARBONIZED BRIQUETTES.



Control of temperature during briquette production enhances production efficiency and improves the durability and strength of the final briquette. According to many studies on the use of different feedstock, optimum temperatures during the densification of non-carbonized briquettes ranged between 100 °C to 250 °C (Ahiduzzaman and Sadrul Islam 2013; Alaru et al. 2011; Stelte et al. 2011; Chou et al. 2009b; Marsh et al. 2007). An experiment carried out by Carone et al. (2011) concluded that high process temperature coupled with low moisture content (10-15%) and reduced particle sizes (4 mm) helped to achieve high density and compressive strength of briquettes, i.e., desirable characteristics for this type of briquette.

The optimum pressures that have been used for producing non-carbonized briquettes ranged from 50 MPa to 250 MPa for different feedstock characteristics (Alaru et al. 2011; Suhartini et al. 2011; Amaya et al. 2007; Yaman et al. 2001; Rubio et al. 1999). The optimum compression time ranged between 4 and 25 minutes (Bazargan et al. 2014; Kaliyan and Vance Morey 2010). The compression time requirement increases with a decrease in the applied pressure. With a pressure of 80 MPa and 150 MPa, briquettes were produced with a compaction time of 25 minutes and 6 minutes, respectively (Yaman et al. 2000). Optimum compression time is necessary for each feedstock due to the reversible nature of plastic deformation, which causes sudden dilation and may create fractures and splits in the briquettes.

Screw press and piston press are the two machines that have been regularly used to produce non-carbonized briquettes. The screw press operates by extruding feedstock continuously through a heated taper dye. The dye is heated externally to reduce friction. The advantages of using this type of machine are that it generates less noise during operation and can alternatively be used for producing carbonized briquettes. The disadvantages are the high wear and tear of the screw and large power consumption, and the fact that it requires a particular particle size and homogeneity of the raw material (Hu et al. 2014; Ahiduzzaman and Sadrul Islam 2013; Chen et al. 2009; Zeng et al. 2007; Bhattacharya et al. 2002; Blesa et al. 2001; Lin 1998).

For piston press, feedstock is punched into a dye by a reciprocating ram with high pressure. This compresses the biomass to produce the briquettes. The advantages of using a piston press are that it is made of durable wearing parts and has low power consumption. The disadvantages are the need for higher maintenance and the fact that it cannot be used to produce carbonized briquettes (Hu et al. 2014; Alves et al. 2011; Chen et al. 2009; Zeng et al. 2007; Hedman et al. 2005; Johansson et al. 2003; Coates 2000).

As shown in Table 8, different non-carbonized briquette sizes have been generated from different sources of solid waste, although the reasons for choosing the sizes were not reported. Most briquettes are created in a cylindrical shape. One typical exception is the briquette made from rice bran (Chou et al. 2009b), which was created in a rectangular shape with a size of 40 mm (width), 40 mm (length) and 35 mm (height).

TABLE 8. SIZES OF BRIQUETTES PRODUCED FROM DIFFERENT MATERIALS.

RAW MATERIALS	SIZE (mm)		SOURCE
	DIAMETER	HEIGHT	
Shrubs	70	Random	Alaru et al. 2011
Corn cob/switch grass	20-22	17-25	Kaliyan and Vance Morey 2010
Groundnut shell powder	35	12-18	Singh et al. 2007
Spent bleaching earth	80 external, 20 internal	50	Suhartini et al. 2011
Lignite and rice straw	18	20	Zhang et al. 2001

3.1.2. Drying and Storage

Briquettes produced, depending on their moisture content, may require drying before they can be stored or transported to users. Due to the abundance of sun in most developing countries, 3 to 4 days sun drying at a temperature greater than 25 °C can be suitable for drying these briquettes (Blesa et al. 2003; Ngusale et al. 2014). After drying, briquettes can also be stored at room temperature (typically 20 °C) and allowed to cool for 24 hours before use (Andrejko and Grochowicz 2007). Storage at higher temperatures can make briquettes too dry and result in difficulty to ignite, while low temperature would make the briquettes soft and not durable during burning.

3.1.3. Use

To validate whether non-carbonized briquettes can be effectively used as fuel, for example, for cooking, factors such as the average time for briquettes to ignite and the amount of smoke produced by the briquettes can be considered (Onchieku et al. 2012; Njenga et al. 2009). Also, the time taken to cook food with the briquettes (which is an indication of the energy released and temperature attained), the time taken for briquettes to turn into ashes (combustion duration) and the amount of briquettes used could be measured. These are not standard methods. However, a standardized method could be applied to various briquette types to allow comparison between them. An example of the results is given in Table 9.

TABLE 9. TIME INTERVALS FOR THE USE OF DIFFERENT BRIQUETTE TYPES.

RAW MATERIALS/ *BINDERS*	TIME TAKEN TO* (MINUTES)			BURNING CHARACTERISTICS	SOURCE
	IGNITE	BOIL	EXTINGUISH		
Charcoal dust, maize cob, *waste paper*	12	184	204	Very little smoke and the briquette burns with a small yellow glowing flame	Njenga et al. 2009
Charcoal dust, *waste paper*	11	136	189	No smoke and the briquette burns with a small yellow glowing flame	
Charcoal dust, sawdust, *waste paper*	15	127	191	Very little smoke and the briquette burns with a small yellow glowing flame	
Wood charcoal[1]	11	NA	117	Very little smoke and the briquette burns with a yellow glowing flame	

Note: * This is based on a standardized method, i.e., using 400-433 kg of briquette to cook githeri (mix of green maize and dry beans, a Kenyan meal) (Njenga et al. 2009).
[1] This is a conventional charcoal product.
NA - Not available

3.1.4. Quality Parameters

Non-carbonized briquettes have the advantage of igniting easily. However, the related disadvantage is that they do not last long because of their soft texture. They also produce a lot of smoke compared to charcoal briquettes due to poorer combustion characteristics (Kaliyan and Vance Morey 2009; Bhattacharya et al. 1989). The other quality parameters used in assessing briquettes include durability, strength and density. The features vary according to raw materials and the production parameters used.

Durability is a measure of the ability of the briquettes to withstand destructive forces such as compression, impact and shear during handling and transportation (Kaliyan and Vance Morey 2010). The compressive forces lead to crushing of the briquettes while impact forces cause them to shatter, e.g., during emptying and dumping of the briquettes. Table 10 shows the optimum range of durability values for non-carbonized briquettes.

TABLE 10. OPTIMUM DURABILITY VALUES FOR NON-CARBONIZED BRIQUETTES.

TEST	UNIT	REQUIREMENT	SOURCE
Compression/tensile strength[a]	kN/m^2	40 to > 800	Bazargan et al. 2014; Beker and Kii 1996
Impact/shatter index[b]		50-167	Bazargan et al. 2014; Beker and Kii 1996
Shear forces/water resistance[c]	%	95 and above. Around 50 suggests that briquettes should not be exposed to wet conditions.	Bazargan et al. 2014

Notes:
[a] Compression/tensile strength involves placing the briquette in between two stainless steel plates. The top plate is then lowered at a speed of 0.5 mm/second to make contact with the briquette until it begins to crush. Crushing can be done perpendicular or parallel to the cylindrical axis of the briquette and thus termed as tensile strength and compression strength, respectively. The force and displacement are recorded in real time using a computer. This compression/tensile strength (σ) is then recorded as shown in equation (1):

$$\sigma = 2F/Dh \qquad (1)$$

Where: F is the maximum force at which the briquette failed and recorded from graphs, D is the diameter of the briquette and h is the height of the briquette.

[b] Impact/shatter index: This can be done by dropping the briquette four times from a height of 1.85 m onto a metal surface. The briquette can also be dropped 10 times from a height of 1 to 2 m onto a concrete surface. The weight of the briquette retained is then recorded. The impact index (IRI) can then be analyzed as shown in equation (2):

$$IRI = 100 \times n_d/n_p \qquad (2)$$

Where: n_d is the number of drops of the briquette and n_p is the number of pieces of broken briquette.

[c] Shear forces/water resistance: This can be measured by immersing the briquette in water at room temperature for 30 minutes. It is then removed, wiped clean of surface water and weighed to identify the amount of water absorbed. Water resistance (WR) is then calculated as shown in equation (3):

$$WR = 100 - \text{percentage of water absorbed by the briquette after immersion in water} \qquad (3)$$

3.1.5. Costs of Production

Typical cost analyses that have been conducted on the production of non-carbonized briquettes are given in Table 11. As a general observation, technical investigations do not provide production cost details, which explain the scarcity of data. It appears that the costs involved in the sourcing of raw materials and transportation (51-83%) are the main expenditure categories and this severely affects the production cost. The quality and characteristics of the final product determine the market value to users (Hu et al. 2014; Tripathi et al. 1998).

TABLE 11. COSTS INVOLVED IN BRIQUETTE PRODUCTION.

BRIQUETTE QUANTITY	SPECIFIC COSTS INVOLVED IN PRODUCING BRIQUETTES PER ANNUM (X 10^4 USD)						TOTAL COST (X 10^4 USD)	SOURCE
	RAW MATERIAL	ELECTRICITY	PACKING OF FINAL PRODUCT	LABOR	MAINTENANCE	MISCELLANEOUS		
2 x 10^4 metric tonnes per annum[a]	49.5	13.1	16.0	10.4	0.5	7.5	97.0	Hu et al. 2014
Up to 2,250 kg/h[b]	19.0	0.3	NA	0.4	0.2	2.9	22.8	Tripathi et al. 1998

Notes:
[a] Material used for briquette production is corn stalk.
[b] Materials used for briquette production include sawdust, shells and coffee husk.
NA - Not available

3.2. Production of Briquettes from Carbonized Waste

Table 12 presents a summary of the production and quality of carbonized briquettes.

3.2.1. Operating Parameters in Production

Carbonization (also called pyrolysis) is an anaerobic decomposition process at high temperature, i.e., biomass is "burned" in the absence of, or limited, oxygen (Haykiri-Acma et al. 2013). This decreases the volatile matter and moisture content of the raw material, but results in high carbon content of the carbonized material. Subsequently, this allows the briquettes to be long-lasting, cause lower toxic gas emissions and have high mechanical strength (Onchieku et al. 2012). Carbonization can be applied to raw waste or to non-carbonized briquettes. In the latter case, the shape of the briquette may then be distorted (Rubio et al. 1999).

The general processes followed in the production of carbonized (charcoal) briquettes are shown in Figure 6. Carbonization is often carried out in batch reactors, and is mostly affected by temperature, pressure and reaction time (Amaya et al. 2007). Manually operated briquette machines and kilns can be used in low-scale briquette production while mechanically operated machines are applied in large-scale production.

In order to reduce the demand of energy during carbonization, raw materials need to be dry with a moisture content below 15%. Also, due to loss of binding elements in raw materials during carbonization, a binder with high binding property needs to be used (Liu et al. 2013; Ndiema et al. 2002).

In a typical case, sewage and fecal sludges are dewatered (e.g., through centrifugation) and then dried (e.g., in a rotary kiln or in drying beds) to reduce the moisture content to 18%. The sludge is then carbonized at a temperature above 300 °C for 2 hours. MSW, such as water hyacinth, sawdust and sedge, has been typically added to the sludge when producing briquettes. The mixture comprising carbonized sludge and possibly MSW is then ground, sieved and may be mixed with 10%-12% of binder (as needed). Water soluble organic binders, such as paper, lime, molasses or starch, may be included. Lime is added to avoid slagging, which happens sometimes. The particle size and moisture content of this mix are typically 0.07-0.3 mm and 6-12%, respectively. After the raw material is mixed with the binders, the feedstock can be densified with a pressure of 5.5-34.5 MPa to form the briquettes using, for example, an extruder/rotary press (Supatata et al. 2013).

Such briquettes produced do not smell and are free from any bacteria because of the carbonization during pre-processing of the sludge (Supatata et al. 2013). Typically, the calorific value ranged between 13.8 and 25.6 MJ/kg, which can be compared with fuelwood. The impact resistance and compressive strength at 79 and 400 kN/m^2, respectively, were achieved and increased when 10% of starch was added as a binder (Liu et al. 2013)

Screw press has been used to produce carbonized briquettes, as discussed under section 3.1.1, but hydraulic press can also be used. In hydraulic press, energy is transferred to the piston from an electric motor through a high pressure hydraulic oil system. It has the advantage of being easy to use with low maintenance and low energy consumption. The disadvantages of using the hydraulic press in producing carbonized briquettes are its slower press cylinder, and lower density and lower abrasion resistance of the briquette produced (Haykiri-Acma et al. 2013; Chen et al. 2009; Zeng et al. 2007; Moran 2002).

Carbonized briquettes have also been produced in different sizes as shown in Table 13. All the sizes were made in cylindrical shapes with a diameter of 10-100 mm and a length of 15-300 mm.

TABLE 12. PROPERTIES OF RAW MATERIALS, PROCESSES APPLIED AND THE QUALITY OF CARBONIZED BRIQUETTES PRODUCED.

RAW MATERIALS/ *BINDERS OR ADDITIVES*	**OPTIMAL CHARACTERISTICS OF RAW MATERIALS**			**BRIQUETTE MACHINE**		**CARBONIZATION**		**PROCESS DESCRIPTION**	**QUALITY OF BRIQUETTES**	**SOURCE**
	PARTICLE SIZE (mm)	**MOISTURE CONTENT (%)**	**MIXING RATIO (% MASS)**	**PRESSURE (MPa)**	**TEMPERATURE (°C)**	**PRESSURE (MPa)**	**TEMPERATURE (°C)**			
Sewage sludge Water hyacinth *Starch*	0.07 and 0.3	6-12	25 75 15	5.5-34.5	NA	NA	300-750	Dewatering of sludge and pyrolysis were carried out at a temperature range of 300 °C-750 °C. Afterwards, the sample was dried in a rotary kiln. It was ground, sieved and mixed with starch. It was then densified to form the briquettes using extruder/rotary press. Briquettes were then dried at a temperature of 75 °C for 48 hours.	Briquettes produced did not smell and were free from any bacteria. The calorific value ranged between 12.5 and 25.6 MJ/kg, which can be compared with fuelwood. The impact resistance and compressive strength at 79 and 400 kN/m^2, respectively, were achieved when 10% of starch was added as a binder. Further drying of the briquettes produced inhibits biological activities and enhances mechanical strength.	Demirbaş 2003; Supatata et al. 2013
Eucalyptus wood Rice husk *Grape fruit waste*	< 0.18	7-13	45 45 10	140	60-85	NA	500	Material (eucalyptus wood and rice husk) was carbonized at a temperature of 500 °C for 2 hours. It was then crushed, sieved, mixed with the binder and densified using a hydraulic press.	Moisture content of 7-13%, pressure of 140 MPa and a temperature of 60-85 °C were the optimum parameters to produce the required briquette with improved mechanical strength. Thus, the impact resistance index was recorded above 200%.	Amaya et al. 2007

(Continued)

TABLE 12. PROPERTIES OF RAW MATERIALS, PROCESSES APPLIED AND THE QUALITY OF CARBONIZED BRIQUETTES PRODUCED. (Continued)

RAW MATERIALS/ *BINDERS OR ADDITIVES*	OPTIMAL CHARACTERISTICS OF RAW MATERIALS			BRIQUETTE MACHINE		CARBONIZATION		PROCESS DESCRIPTION	QUALITY OF BRIQUETTES	SOURCE
	PARTICLE SIZE (mm)	MOISTURE CONTENT (%)	MIXING RATIO (% MASS)	PRESSURE (MPa)	TEMPERATURE (°C)	PRESSURE (MPa)	TEMPERATURE (°C)			
Char fines Corn stover *Waste paper*	0.16-5	10	50 20 30	4-60	160-280	NA	300	Corn stover was ground before carbonization in a kiln above 300 °C. Carbonized corn stover and char fine samples were mixed with waste paper and densified with a piston press.	There was an increase in calorific value when the carbonized briquette was compared with the non-carbonized briquette. The calorific value achieved was 25-30 MJ/kg and 15 MJ/kg for carbonized and non-carbonized briquettes, respectively.	Ngusale et al. 2014
Bagasse *Clay* *Molasses*	NA	< 18	80 10 10	0.25-1	NA	NA	NA	Bagasse was carbonized in a brick-built kiln and mixed with clay and molasses in a drum mixer. The mixture was then densified using a piston press.	Ash content, calorific value and volatile matter were 36%, 19 MJ/kg and 27%, respectively. The briquette was densified with 1 MPa and it produced a little smoke and lasted longer compared to the briquette densified with 0.25 MPa. It was recommended for domestic use.	Onchieku et al. 2012

(Continued)

TABLE 12. PROPERTIES OF RAW MATERIALS, PROCESSES APPLIED AND THE QUALITY OF CARBONIZED BRIQUETTES PRODUCED. (Continued)

RAW MATERIALS/ *BINDERS OR ADDITIVES*	OPTIMAL CHARACTERISTICS OF RAW MATERIALS			BRIQUETTE MACHINE		CARBONIZATION		PROCESS DESCRIPTION	QUALITY OF BRIQUETTES	SOURCE
	PARTICLE SIZE (mm)	MOISTURE CONTENT (%)	MIXING RATIO (% MASS)	PRESSURE (MPa)	TEMPERATURE (°C)	PRESSURE (MPa)	TEMPERATURE (°C)			
Olive stones *Molasses*	≤ 1	NA	85 15	125	25	NA	400-600	Pyrolysis was carried out in a thermogravimetric device. Olive stones were carbonized and mixed with molasses prior to densification into briquettes using a plug and mould press.	Materials carbonized at a temperature of 600 °C showed lower volatile matter (9-11%) and high calorific value (30-35 MJ/kg) as compared to pyrolysis at 400 °C which showed high volatile matter (21-27%) and low calorific value (25-29 MJ/kg). Reducing sulfur content was also another benefit.	Blesa et al. 2001
Low rank coal Coal pitch	0.3-0.5	NA	NA	125	25	NA	500-850	Materials were crushed and densified into briquettes using a hydraulic press. The briquettes were then carbonized in a vertical fixed bed.	Impact resistance and compressive strength improved significantly by 18% when the briquettes were aarbonized with o the addition f the binder (coal pitch).	Rubio et al. 1999

Note: NA - Not available

FIGURE 6. FLOW DIAGRAM SHOWING THE PROCESSES FOLLOWED IN THE PRODUCTION OF CARBONIZED (CHARCOAL) BRIQUETTES.

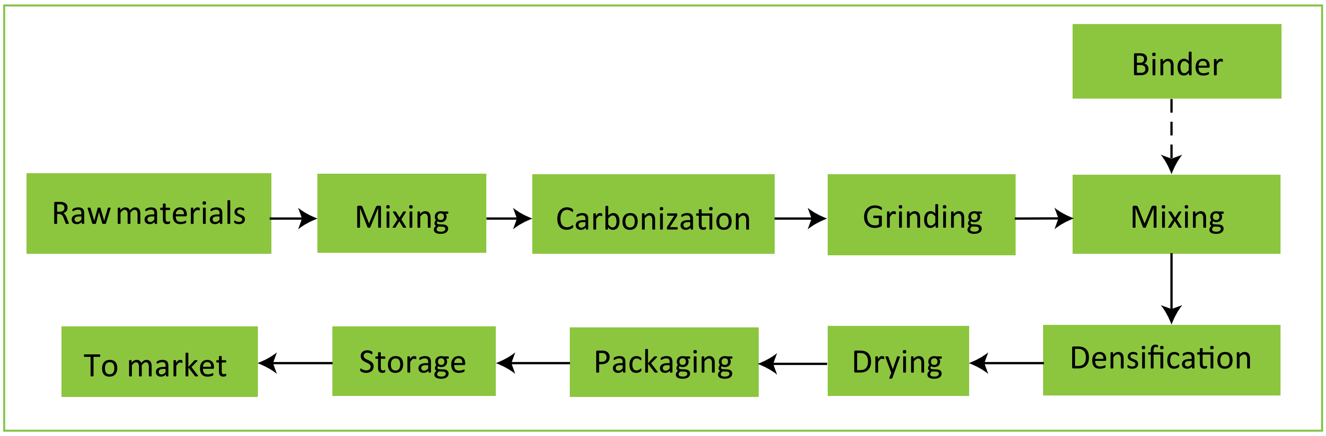


TABLE 13. SIZES OF CHARCOAL-BASED BRIQUETTES PRODUCED FROM DIFFERENT MATERIALS.

RAW MATERIALS	SIZE (mm)		SOURCES
	DIAMETER	LENGTH	
Tree species	70	200	Alves et al. 2011; Hedman et al. 2005
Sawdust	10	15-250	Katinas et al. 2007; Blesa et al. 2001
Wood	100 and 30 bore in the center	300	Schmidl et al. 2008
Char and sawdust	38 external, 13 internal	150	Prasityousil and Muenjina 2013
Chars	10	15	Rubio et al. 1999

3.2.2. Drying and Storage

Briquettes made from carbonized MSW take about 3 to 4 days to dry in the open depending on the weather; temperatures of 25 °C to 40 °C are suitable (Kaliyan and Vance Morey 2010; Ngusale et al. 2014). Sludge-based briquettes can be dried at 25 °C and 75 °C for 3 days and 2 days, respectively (Supatata et al. 2013). This further drying of briquettes is meant to inhibit biological activity during storage and enhance the mechanical strength of briquettes (Liu et al. 2013). The drying periods also depend on the size and type of material used for producing the briquettes.

3.2.3. Use

Table 14 shows the time taken for a typical bagasse-based briquette to ignite, boil and extinguish, and the burning characteristics, as compared to the performance of conventional charcoal obtained from *Eucalyptus grandis* and wood. These are analyzed to ensure durability and assess the level of air pollution that may be generated from the briquette.

3.2.4. Quality Parameters

In general, charcoal briquettes exhibit certain qualities, such as low smoke emissions, compared to non-carbonized briquettes. They also have low ash content, non-sparkling characteristics and long-lasting fire, and they cannot be destroyed by termites (Habib et al. 2014). In many situations, marketing of charcoal briquettes is easy as users are familiar with this type of briquette because its color and features resemble conventional charcoal. The disadvantage is that it may be more difficult to start the fire than non-carbonized briquettes (Kaliyan and Vance Morey 2009). The other qualities in terms of durability, strength and density vary with the raw materials used and production parameters. For charcoal briquettes to be classified as durable, crushing strength, impact resistance index and water resistance must be at least 375 kN/m^2, 50 and 95%, respectively (Prasityousil and Muenjina 2013; Coates 2000).

3.2.5. Costs of Production

The costs involved in the production of charcoal briquettes include raw material preparation, operational cost (energy

TABLE 14. TIME TAKEN FOR THE BRIQUETTE TO IGNITE, BOIL AND EXTINGUISH, AND THE BURNING CHARACTERISTICS.

RAW MATERIALS/ *BINDERS*	TIME TAKEN TO* (MINUTES)			WEIGHT OF ASH (g)	BURNING CHARACTERISTICS	SOURCE
	IGNITE	BOIL	EXTINGUISH			
Bagasse *Molasses and clay*	6.4-15.2	9.6-18.2	25.5-49.4	420.7-518.7	• No smoke, no sparks and no irritating smell • Burns with blue glowing flame • No loss of ash on cooling • Releases sweet smelling smoke	Onchieku et al. 2012
Eucalyptus grandis charcoal[1]	3.3-5.5	6.3-11.2	49.1-56.2	45.3-86.6	• No smoke, no irritating smell and no sparks • Burns with orange glowing flame and no loss of ash on cooling	
Wood charcoal[1]	11	Not available		117	Very little smoke and burns with yellow glowing flame	Njenga et al. 2009

Note: * This is based on a standardized method, i.e., using 2 kg of charcoal-based briquettes to boil 2 liters of water (Onchieku et al. 2012).
[1] This is a conventional charcoal product.

consumption) during carbonization, densification and maintenance cost of the machines used in the briquetting process (Stolarski et al. 2013). The cost of producing charcoal briquettes generated from vegetable market waste ranged between USD 24.7 to USD 28.9 per tonne in India (Srivastava et al. 2014). In Uganda, the cost of producing briquettes with charcoal dust by a company and a private individual ranged between USD 200 and USD 400 and between USD 100 and USD 300 per tonne, respectively, as compared to that of charcoal, which costs USD 600 per tonne (Ferguson 2012).

3.3. Roles and Technology Preferences of Men, Women and Youth in Community-based Small-scale Briquette Production

Women in poor communities produce briquettes using different raw materials, e.g., MSW, fecal sludge and industrial waste. Being a woman or man plays a role in determining people's involvement in briquette production. In low-scale briquette production, most women (especially those of middle age and above) prefer to use familiar equipment (e.g., mounding briquettes using recycled tins) as opposed to using mechanized tools (Figure 7[A]). While the younger women are very much at ease with using manual presses, young men prefer both manual and automated systems. This highlights that physical strength among youth is not the only factor that influences the choice of pressing equipment used. Studies in Kenya, for example, where local communities run small-scale briquette enterprises, showed that women preferred using recycled nets to sieve the charcoal dust while men use wire mesh fitted with timber flames. Older women mound the mixture, for example, of charcoal dust plus soil using their bare hands or recycled plastic tins while men and young women prefer using manual wooden or metal presses (Njenga et al. 2013b). Young women seem less eager to be involved in practices that make their hands dirty and possibly prefer activities that are considered modern. In large-scale briquette production, men prefer being involved in grinding, mixing and compacting briquettes using the automated machines (Figure 7[B]), while women find it easy spreading the briquettes in the drying beds (Figure 7[C]) and collecting the dry pieces and packing them. It is important to note that the raw materials used and mixing ratio are important factors that determine heating quality, while the pressing methods influence the physical characteristics.

3.4. Disproportionate Health Impacts from Cooking with Biomass

Women and young children are the most affected by the negative health impacts from the use of briquettes as fuel for cooking. Globally, women spend 3-7 hours per day near stoves, preparing food, with young children around (WHO 2005). Compared to men, they are more consistently exposed to the negative health effects of smoke from the firewood and other solid fuels that are used for cooking. A recent factsheet from the World Health Organization (WHO) on indoor pollution (WHO 2016) states that around 3 billion people cook and heat their homes using open fires and simple stoves burning biomass (wood, animal dung and crop waste) and coal. This leads to over 4 million people dying prematurely from illnesses attributed to household air pollution as a result of cooking with solid fuels. Further, indoor smoke exposure has been found to be responsible for 39% of annual deaths due to chronic pulmonary diseases in women, while only 12% in men (Rehfuess 2006; Smith et al. 2004).

Smoke generation and concentration in the kitchen is a result of four factors, which include fuel, cook stove, ventilation and user behavior (Roth 2013). As such,

FIGURE 7. BRIQUETTE PRODUCTION IN NAIROBI, KENYA. LOW-SCALE PRODUCTION: (A) WOMEN MOUNDING BRIQUETTES USING RECYCLED TINS, AND LARGE-SCALE PRODUCTION: (B) MEN PRODUCING BRIQUETTES USING AUTOMATED PRESSES, AND (C) WOMEN SPREADING BRIQUETTES IN THE DRYING BEDS.

(A) (B) (C)

Photos: Mary Njenga, ICRAF.

cooking with wet fuel, such as fuelwood, in poorly ventilated kitchens and using inefficient cook stoves exacerbates the risks of illnesses associated with smoke in the kitchen. Burning biomass releases harmful pollutants which produce extremely high levels of indoor air pollution. For instance, levels of particulate matter (PM_{10}) released in 24 hours in homes using biomass in Africa, Asia or Latin America range from 300 to 3,000 micrograms per cubic meter ($\mu g/m^3$). Biomass fuels also release 1,500-2,000 $\mu g/m^3$ of respirable particle indoor pollution, while kerosene and gas produce 76 $\mu g/m^3$ and 101 $\mu g/m^3$, respectively (Rehfuess 2006).

“Women exposed to indoor smoke are three times more likely to suffer from chronic obstructive pulmonary disease (COPD), such as chronic bronchitis or emphysema, than women who cooked with electricity, gas or other cleaner fuels” (Rehfuess 2006). They are also more prone to pneumonia and other acute respiratory infections. Similar respiratory effects were noted for their young children, since women care for children while cooking. Cataracts represent another health problem that can be caused by exposure to smoke, including smoke from biomass (Pokhrel et al. 2005), as demonstrated by a study in Nepal and India. Smith and Mehta (2003) also noted links between solid fuel use and blindness.

Concern about gas emissions from briquettes in respect to public health differ with application. Cleaner burning is more important if briquettes are intended for household use rather than industrial use, such as drying tea or curing tobacco. Depending on the type, fuel briquettes emit less smoke and hence reduce air pollution compared to using biomass fuel. For household use, charcoal briquettes should be the preferred briquette type. In general, they emit less fine particulate matter as compared to non-carbonized briquettes (Njenga et al. 2013a; Jenkins et al. 1998; Bhattacharya et al. 1989). For example, briquettes comprised of charcoal dust (80%) combined with soil (20%) produce three and nine times lower emissions of carbon monoxide (CO) and fine particulate matter ($PM_{2.5}$), respectively, than charcoal (Njenga et al. 2013a).

Women and young children, who spend several hours in the kitchen, would benefit the most from a cleaner cooking fuel such as briquettes. For instance, the use of charcoal briquettes would contribute to reducing over 50% of deaths of children below 5 years due to pneumonia (WHO 2016). The impacts of emissions on health during production or use of briquettes can be reduced further by ensuring proper ventilation and providing chimneys during production or combustion of briquettes.

3.5. Positive Environmental Impacts of Briquette use

Briquette production has been identified as contributing to improved waste management. Domestic waste, waste from schools and other institutions, fecal sludge and agricultural waste can be converted to briquettes. Most urban centers in sub-Saharan Africa face the challenge of managing waste. In Nairobi, for example, only 40% of the waste generated in the city was collected and disposed of according to the 2010 UN-Habitat report (Njenga et al. 2012). Women and youth groups and large companies collecting waste from cities for producing briquettes contribute to cleaning of neighborhoods. Chardust Limited in Nairobi works with youth groups who collect charcoal dust from informal settlements and sell it to the company for briquette production. If uncollected, the charcoal dust is burned in situ, causing environmental pollution and clogging open drainages. The management of waste through briquette production supports a clean and healthy society.

Briquettes could contribute to mitigating the negative impacts of fuelwood. Studies at the regional level indicate that as much as two-thirds of the fuelwood used for cooking worldwide comes from non-forest sources such as agricultural land and roadsides. In Kenya, for example, 85% of charcoal is produced from trees and shrubs sourced from private farms outside protected forest areas. However, over 40% of the fuelwood is produced unsustainably and this is a big concern in the face of climate change (Drigo et al. 2015). Unsustainable production of charcoal in response to urban demand, particularly in sub-Saharan Africa, places a strain on biomass resources. Charcoal production is often inefficient, and can lead to localized deforestation and land degradation around urban centers. The raw materials used protect the environment as trees need not be cut for the production of briquettes. Therefore, the use of briquettes contributes to reduced deforestation, landfill degradation and waste generation.

When using charcoal briquettes for cooking, soot is not formed under pots as when using charcoal and kerosene. Lack of soot means less time in washing pans after cooking and reduction in the use of water. Water for urban household use has been a problem in most sub-Saharan countries due to scarcity, which can be attributed to urbanization to hitherto un-urbanized communities. Women are charged with the responsibility of finding water for household use. The less water used in cleaning after cooking as a result of using briquettes is time saved on finding water for other chores.

4. BRIQUETTE MARKETS

The opportunity to utilize agricultural residues and the organic fractions of MSW more efficiently with a potential reduction in pollution levels has aroused the interest of developing as well as developed countries in briquetting. The viability and sustainability of the briquetting business, in addition to suitable technological options, depend on a number of key factors, including the prices of alternative products such as firewood and charcoal as compared to briquettes, the acceptance of briquettes by potential users, and existing policy and institutional frameworks. Different types of briquettes exist to cater to a variety of applications. In Europe and North America, briquettes in the form of fuel pellets or briquette logs are major sources of energy and are commonly used as fuel in industrial and biomass cogeneration plants (Ferguson 2012). Sweden leads in the production of pellets and utilizes briquettes in excess of 1 million tonnes per year (Young and Khennas 2003). In developing countries, the briquette industry is not yet mature, but this is changing in certain regions. In East Africa, declining wood resources (due to over-exploitation of forest resources) coupled with rising prices of charcoal (due to a decline in wood resources) has resulted in the briquetting business gaining momentum (Ferguson 2012).

4.1. Market Segments for Briquettes

The market segments for briquettes can be differentiated into domestic, institutional and industrial use, and for export. The majority of briquette businesses in developing countries supply briquettes to a regional/local market, and only a few briquette businesses are export oriented. The most accessible markets for briquettes produced from non-carbonized waste are energy-intensive industries which use fuelwood for their operations, such as brick-making, cement factories and other similar industries. Other markets for non-carbonized briquettes are institutional kitchens, such as restaurants, schools and hospitals. Charcoal briquettes are mostly targeted to households and institutional kitchens in rural and urban areas. Although briquettes are common in informal settlements in East Africa, globally, there is still low adoption of briquettes in developing countries which is partly due to lack of awareness, and the availability of cheaper and accessible firewood to many users (Ferguson 2012).

A study conducted by the Energy and Environment Partnership in Southern and Eastern Africa (Barasa et al. 2013) on the briquette industry in East Africa argued that the substitution of traditional cooking fuels is one of the reasons for the modest successes of the briquette business. This is not only because of the price, but also due to multiple factors such as compatibility with cooking appliances, availability of the fuel, consistency in the quality of briquettes or the type of food prepared influencing energy choices at the household level. The type of cooking practices and the existing stoves determine the acceptability of briquettes by households, as cooking requires certain properties of the fuel used. In a number of sub-Saharan African countries, the food prepared requires extensive boiling, thus a fuel that can last long is required. In Asian countries, the main dishes are stir-fried, thus requiring a fuel with a high heating output for a short time, such as charcoal or LPG. In countries such as India, many dishes are simmered, thus requiring a fuel with a low heating output (Hulscher 1991). Barasa et al. (2013) further concluded that, as several factors influence the preferred use of cooking fuel, reducing the price of briquettes may not necessarily lead to higher demand. On briquette use in Asia, Hulscher (1991) concluded that households that use briquettes do not completely shift to using briquettes, but they prefer stocking multiple fuels, i.e., using briquettes for certain purposes and traditional fuel for others.

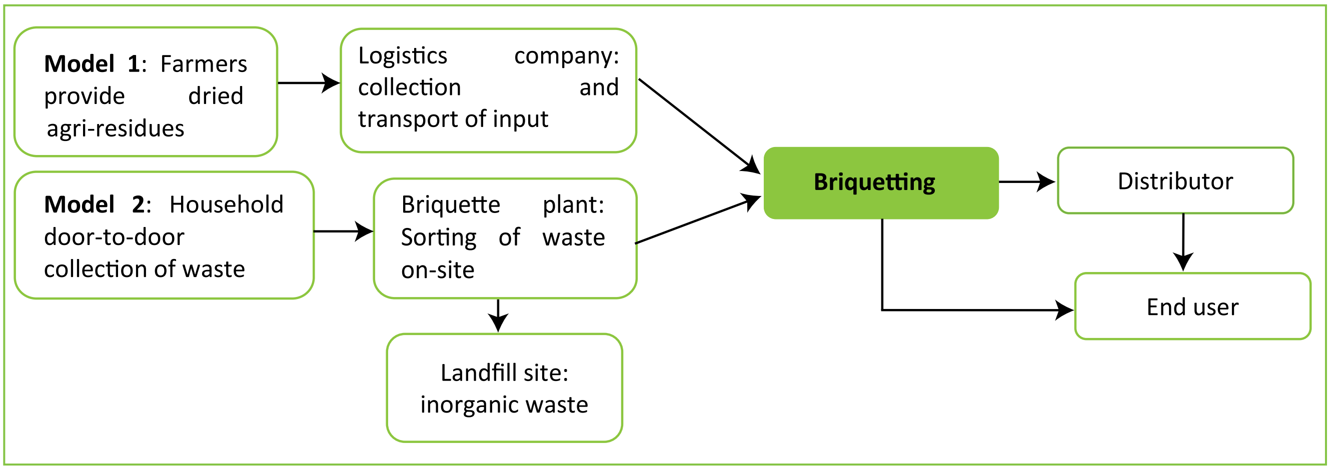
For the institutional and industrial users of briquettes, the major factors that influence their energy choices are price per unit of energy output, availability in large quantities, reliability of supply, consistency in the quality of briquettes and the choice of sustainable energy solutions (Barasa et al. 2013). Compared to small-scale users, such as households, the energy choices of institutional and industrial users are influenced by existing regulations which may promote the use of sustainable energy solutions. Existing stoves in institutional kitchens also determine the uptake of briquettes by institutions. Institutional users are likely to be more encouraged to use the briquette, if the briquette can be used in existing stoves. In instances where the briquettes are not compatible with the existing stoves, the briquette business can also provide its clients with efficient briquette-burning stoves.

4.2. Briquette Sector - Examples from East Africa

4.2.1. Briquette Value Chain

The value chain for briquettes varies depending on the scale of the business, input material used, type of briquette produced and the target market segment. Non-carbonized briquettes produced from MSW or agricultural residue have different value chains depending on how inputs are sourced and outputs are sold. A briquette business in Rwanda, Coopérative pour la Conservation de l'Environnement (COOCEN), for example, collects MSW from households, processes it and produces briquettes through the implementation of a PPP with the Kigali City Council. The PPP is based on the provision of waste collection services by COOCEN. As a component of the partnership, the Kigali City Council provides a site (7 ha of land) to COOCEN where the primary waste sorting and briquette production take place. The briquettes are sold directly to clients, mainly to prisons in Rwanda, on a three-month rolling contract. In Kampala, Uganda, Jellitone Suppliers Ltd. (KJS) sources its agricultural residues from farmers, and hires a logistics company to collect and transport its raw materials. KJS helps to organize farmers into groups and trains them in drying the agricultural residues to attain a moisture content of at least 15%. This could enable a saving on transportation costs as some of the farmers are located more than 300 km away from the factory. The briquettes are sold to institutional and commercial users directly and through distributors. Figure 8 shows the value chain for briquette businesses that outsource the collection and transportation of dried agricultural residue (Model 1), and for a vertically integrated model where the collection

FIGURE 8. SCHEMATIC OF THE VALUE CHAIN FOR BRIQUETTES.



of domestic waste from households is carried out by the briquette business entity (Model 2).

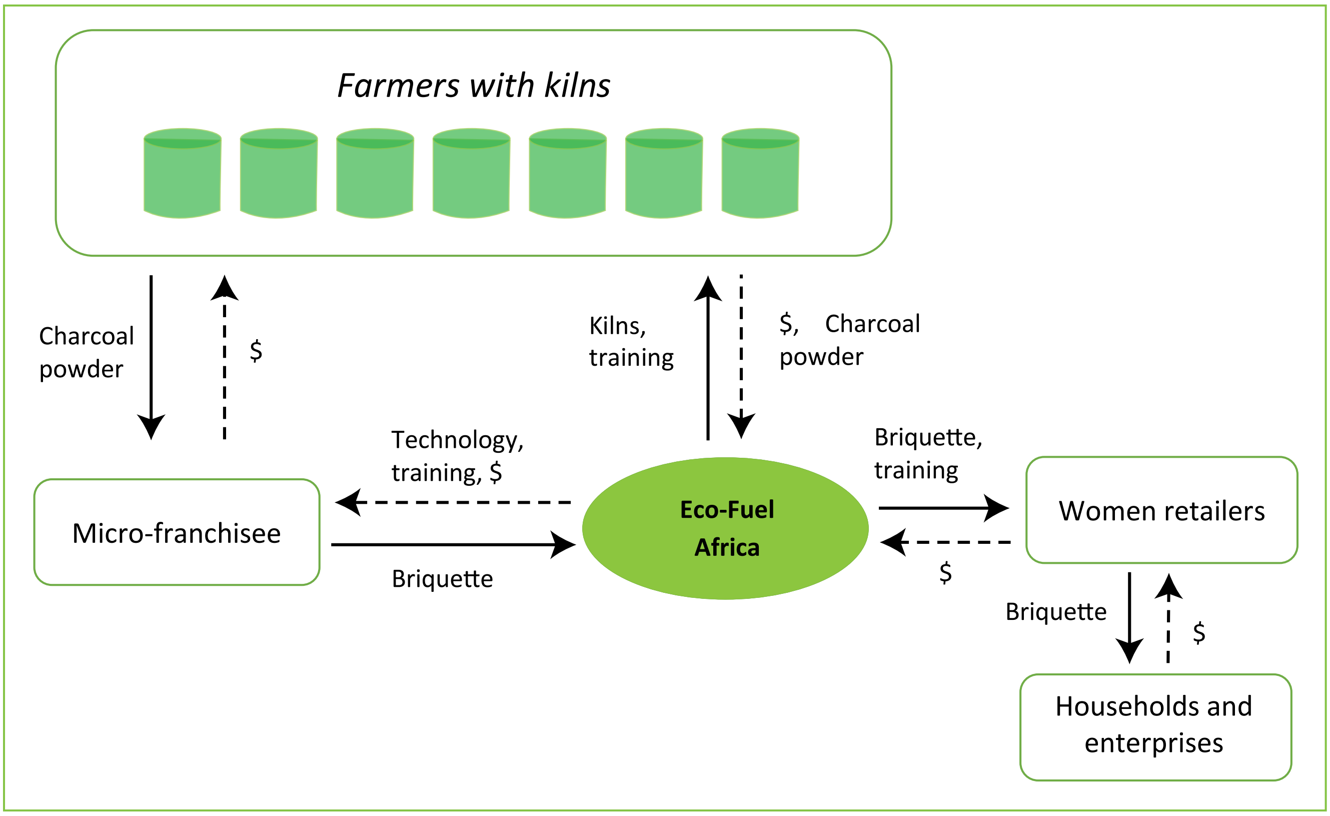
In East Africa, charcoal briquettes are mostly produced by several informal small-scale businesses which directly distribute to households. However, there are also formal medium-scale briquette businesses which produce charcoal briquettes. Green Heat, a youth social entrepreneurship company, works with farmers. The company sell kilns to farmers and buys the carbonized crop residues, such as banana leaves and peelings, at a fee to be used as charcoal dust for briquette production. Eco-Fuel Africa (EFA) has a similar model. It produces and distributes briquettes through a micro-franchising model to its clients, which mainly comprises households in rural and urban areas (Otoo and Drechsel Forthcoming). Figure 9 shows the value chain for EFA. The briquette value chain involves three important actors: farmers, micro-franchisee and women retailers. Farmers are trained and provided with kilns on a lease basis to carbonize their agricultural residues, which are then supplied to the local micro-franchisee. The franchisees are trained and provided with a briquetting machine to produce briquettes, which are sold to households through women retailers.

In such cases, women are involved in the briquette supply chain through the supply of agro-residues, charcoal dust/fines, corn cob, oil palm, palm kernel shells, rice husk, rice straw and vegetable waste to industries and enterprises involved in briquette production for a fee.

4.2.2. Technical and Financial Overview of Briquette Businesses

Table 15 presents the technical and financial overview of operating briquette businesses in Uganda and Rwanda, two countries in Africa with extensive experience in briquette production and use. The two cases from Uganda vary in their scale, their process, type of briquette produced and the target market. KJS is a large-scale briquette plant in

FIGURE 9. ECO-FUEL AFRICA BRIQUETTE VALUE CHAIN.



Source: Otoo and Drechsel Forthcoming.

Uganda producing non-carbonized briquettes targeted for institutional users, while EFA in the same country is a medium-scale plant producing charcoal briquettes targeted for domestic use. COOCEN is a large-scale plant in Rwanda producing non-carbonized briquettes targeted for institutional users. Both KJS and COOCEN reach their major clients directly while EFA sells its briquette through a network of retailers.

The investment cost, land required and production cost vary depending on the technology used/process followed, source and type of raw material used and the local context. The investment cost for the large-scale briquette plants vary from USD 108/tonne to about USD 350/tonne, while production costs vary from USD 61/tonne to USD 237/tonne. The investment cost of KJS is high compared to that of COOCEN, which is partly due to the fact that KJS uses imported machines to produce the briquettes and flush driers to dry its raw materials, while COOCEN uses locally made machines and sun drying to dry its raw materials and the briquettes. Moreover, the investment cost of KJS is inclusive of land, while land was granted by the Kigali City Council in the case of COOCEN. In terms of land size, it varies from 2.4-7 ha with COOCEN having a large land area. All pre-processing, including sorting of MSW collected from households, is carried out on-site in the case of COOCEN, thus requiring a large land area.

Looking at the total production cost, input cost accounts for 46-54% of the total production cost for the large-scale briquette businesses. Looking at the absolute value of total production cost, the amount is high in the case of KJS compared to COOCEN, because KJS sources its agricultural residue from farmers who are located as far as 300 km from the plant and uses electricity during the production process thus increasing production cost, while COOCEN collects and processes MSW using locally made machines which require no electricity.

TABLE 15. OVERVIEW OF BRIQUETTE BUSINESSES – CASES FROM EAST AFRICA.

BRIQUETTE BUSINESS CASE	KJS, UGANDA	COOCEN, RWANDA	EFA, UGANDA
Technical/general data			
Scale (tonnes per year)	2,000	1,500	200
Briquette type produced	Non-carbonized	Non-carbonized	Carbonized
Number of full-time workers	50	60	19
Land area (ha)	2.4	7	1.2 (in two sites)
Equipment used/process followed	• Imported machines • Flush driers	• Locally made • Sun drying	• Locally made • Sun drying
Input	Agricultural residue	MSW	Agricultural residue and MSW
Supply of input	• Milled and dried farm residues from farmers • Collection and transportation outsourced	Direct collection from households	Franchise model: • Farmers supply carbonized agricultural residue • Franchisee produces briquettes
Distribution of output	Directly to clients and through distributors	Directly to clients	Retail outlets – women retailers
Main clients	• Institutions (schools) • commercial users (restaurants, bakeries)	Institutions (prisons)	Households
Other outputs/offers	Institutional briquette-burning stoves	• Waste collection service to households • Compost sold to Kigali City Council	• Leasing of kilns to farmers • Leasing of briquette machine to franchisee
Key partners	• Farmers • Logistics company	• Kigali City Council (granted land)	• Farmers • Franchisee • Women retailers
Financial data			
Source of financing	85% owner's equity 15% donor funding	• Major funding from donors • Land granted	• Major funding from donors (Uganda government and other donors)
Investment cost per unit (USD/tonne)	349.5	108-150	52.5
Input cost (USD/tonne)	129	28	Not available
Total production cost (USD/tonne)	237	61	155
Price of briquette (USD/tonne)	283	122	170

Source: Based on Otoo and Drechsel Forthcoming.

4.3. Drivers for Success of Briquette Businesses – Lessons from East Africa

A number of factors contribute to the success of briquette businesses as discussed below:

- *Cost and availability of competing fuel*: Fuelwood has historically been a cheap and accessible source of fuel for small- and medium-scale industries in many countries. For many years, it has been sourced from forests at no cost or for a very small fee.
- *Policy regulations*: Regulations on charcoal have had an influence on increasing the cost of the commodity. In Uganda, for example, the government is implementing regulations on charcoal production, which includes control on cutting down trees and levies on charcoal by the National Forestry Authority. The levies have increased the cost of charcoal, creating an opportunity for briquettes as a competitive fuel. In contrast, briquette businesses in Kenya, such as Chardust Ltd., were unable to sell their briquettes during their start-up due to low prices of charcoal (Barasa et al. 2013). Thus, it is not only regulations directly related to briquettes that can have an impact on the success of briquette businesses, but regulations related to alternative products can also have a substantial impact.
- *Partnerships*: Strong partnership with key stakeholders such as the municipality, financiers and other actors within the briquette value chain is important for the success of briquette businesses. For instance, lack of access to financial capital is a major bottleneck during start-up and operation of briquette businesses. Some examples of successful partnerships are presented below:
    - Kigali City Council supported COOCEN by providing land for the briquette business. Further, COOCEN secured funding from international donors which contributed to the start-up and operation of the business.
    - Eco-Fuel Africa secured funding from the Government of Uganda during start-up of the business, which enabled the business to run a franchise model. Eco-Fuel Africa further partnered with input suppliers and franchisees in building capacity in carbonizing raw materials and processing briquettes, respectively.
    - KJS provided a price incentive to encourage input suppliers to dry their farm residues to attain a moisture content of at least 15% to reduce transportation cost.
- *Consistency in the quality and supply of briquettes*: Users are sensitive to changes in quality or burning efficiency of their cooking fuel. Thus, it is essential to maintain both quality and consistency of supply.
- *Appropriate targeting of consumers:* For instance, large-scale producers of non-carbonized briquettes target restaurants and institutions, which require large quantities of fuel and this type of briquette is well suited for their cooking requirements.
- *Securing contracts with partners:* For example, with raw material suppliers and bulk buyers of briquettes. To secure an offtake contract, ensuring consistency of supply and quality of briquettes is essential if buyers are to trust briquettes as a replacement for their current source of fuel.
- *An effective marketing strategy coupled with a good distribution system*. A case example is Eco-Fuel Africa, who have successfully implemented a decentralized production and distribution system through a franchise model.

4.4. Challenges Faced by Briquette Businesses

Briquette businesses have the potential to supply a commercially viable source of fuel in developing countries. However, there are a number of challenges and barriers that hinder the advancement of the sector. These challenges can be grouped into regulatory, financial, operational and market-related barriers as detailed below:

4.4.1. Regulatory Barriers

Regulations that support the production of cleaner energy solutions are important in facilitating private and public investment in cleaner cooking fuels. Although many developing countries have renewable energy strategies, briquettes are seldom mentioned in the strategies or policies of these countries and are classified under the broad biomass energy category. Thus, important aspects of the briquettes are not regulated. Product certification or standardization of briquettes is missing in many countries, thus resulting in substandard briquettes being produced by many small- and medium-scale businesses. Lack of consistency in quality due to inconsistent mixing ratios by small and medium enterprises creates a negative reputation for briquettes, consequently affecting their use. Another challenge related to government regulations is the prevailing poor reinforcement of regulations against the indiscriminate cutting down of trees for fuelwood. Charcoal production is still unregulated despite its environmental effects.

4.4.2. Financial Barriers

The investment and operational costs of briquette businesses vary widely depending on scale, and technology and types of raw materials used. Access to finance is a major bottleneck for the advancement of the briquette sector and is part of the reason why there are a limited number of briquette businesses operating purely on a commercial basis. The majority of briquette businesses operating in the Eastern Africa region access finances mainly in the form of grants from local government or international donors, and are faced with difficulties in sustaining themselves after the end of the funding period. Barasa et al. (2013) showed that, of all the briquette producers considered in its study, 67% have received a grant to support their project while the local financial institutions are inactive in the sector.

4.4.3. Operational and Market-related Barriers

Briquettes and/or their benefits are unknown to many biomass fuel users, which makes tapping into the potential market challenging and costly. Without sufficient marketing and distribution strategies, the product is not likely to sell. Further, medium- and large-scale briquette operations face input-related risks which increase the cost of production. For instance, procuring a consistent supply of raw materials in appropriate quantities and desired quality is a bottleneck for briquette businesses. In the case of KJS, a large-scale briquette business in Uganda, high transportation cost and high moisture content of raw materials that required more drying increased production costs. Thus, the company is incentivizing farmers to supply milled and sun-dried residues to transport in large quantities and reduce the cost of drying.

4.5. Impact of Briquette Use and Sales on Women and the Poor

4.5.1. Source of Income

Several studies conducted in East Africa and Asia, where briquette production is on the rise, have shown that briquette production and use is a novel intervention that not only supports efficient use of biomass energy, but also improves the livelihoods of men and women, including the young and old.

Briquettes are made from recycled waste and in many cases where the business is not well established the raw materials are collected for free. However, once the people having the waste materials realize that it is being turned into a sellable product, they sell the waste at a low price. In Kampala (Uganda), for example, the Green Heat company buys carbonized on-farm residues, such as banana peelings and leaves, at UGX 58 (USD 0.004) per kilogram. In Nairobi (Kenya), Chardust Limited, one of the largest briquette producing companies in the country, has a working relationship with youth groups from informal settlements, who collect charcoal dust and sell it to the company for briquette production.

Briquette production and marketing have been recognized as another important source of income to many families in urban Kenya. In this country, 50% of briquette-making enterprises are community-based organizations, comprising women and youth (Terra Nuova and AMREF Kenya 2007). Briquette production provides several income benefits for these groups. A community group of about 24 members generates a monthly income between USD 7 and USD 1,771 from the sale of briquettes during the dry season, and between USD 7 and USD 2,240 during the wet season (Njenga et al. 2013b). The briquette-making groups comprised of 68 females and 101 males, with 78% of the members being youth below 35 years of age. The main customers include households, food kiosks, institutions such as schools and chicken hatcheries.

4.5.2. Direct Cost Savings

Women often bear the burden of cooking food and consequently sourcing cooking fuel. For instance, in East Africa, about 10% of household income is spent on fuel for cooking among the low-income households (Bacon et al. 2010). Over half of the expenditure is on biomass energy mainly constituting charcoal and firewood, which can be easily substituted with fuel briquettes as both have similar cooking practices. Briquettes provide a cheaper source of energy for cooking. Typically, cooking a traditional meal of dry beans (*Phaseolus vulgaris*) and green maize (*Zea mays*) for a standard Kenyan household of five people costs KES 3 (USD 0.03) with 850 g of charcoal briquettes, while it is KES 26 (USD 0.26) with 890 g of charcoal and KES 45 (USD 0.45) with 0.36 liters of kerosene (Njenga et al. 2013b). Therefore, cooking the meal with charcoal briquettes costs 88% and 93% less than cooking the meal with charcoal and kerosene, respectively. This would, for instance, benefit the over 80% of households using charcoal in urban areas in sub-Saharan Africa.

A study conducted among 199 households in the Kibera informal settlement in Nairobi showed that people that produce charcoal briquettes for household use (Figure 10) and those that purchase them save about 70% and 30%, respectively, of money spent on energy for cooking (Njenga et al. 2013b). A preference survey carried out among the same households in the study indicated that consumers in the Kibera informal settlement preferred fuel briquettes over conventional wood charcoal due to their low price (Yonemitsu et al. 2015). According to the participants engaged in the study, not only is fuel briquette cheaper, it also burns longer than charcoal and other wood fuels, hence they see its use as cost-effective. The households in the study stated that they could consider cooking dry grains at a cheaper cost because these food types consume a lot of fuel and this increases the cost of fuel used for cooking (Yonemitsu et al. 2015).

FIGURE 10. A WOMAN SELLING BRIQUETTES IN NAIROBI, KENYA.

Photo: Mary Njenga, ICRAF.

5. CONCLUSIONS

Recycling MSW and other organic waste for briquette production is gaining momentum in sub-Saharan Africa, due to increased costs and other challenges in accessing affordable biomass fuel for domestic, institutional, commercial and industrial use. It has a far-reaching consequence in improving the livelihoods of men and women, including the young and old, since recycling of MSW in sub-Saharan Africa presents a great opportunity for fuel production as a large proportion of it is organic. Recycling MSW saves countries' income that is otherwise spent on its disposal and this also contributes to environmental management. A lot of concerns have been raised on the unsustainable production and use of fuelwood in sub-Saharan Africa, necessitating the development of cleaner and affordable biomass fuels as viable enterprises.

Fuel briquettes come in different qualities and dimensions based on raw materials used and technologies applied in production, and require appropriate targeting of different market segments. For instance, the different types of raw materials used and technologies applied have an implication on combustion and emission qualities. For example, briquettes produced from coconut shells/husks have higher calorific value than those made from grass or paper. Briquettes produced from fresh raw materials, such as sawdust, causes higher gas emissions than those produced using carbonized sawdust. Sawdust requires a less amount of binder as carbonizing material breaks down lignin and reduces the binding capacity of the material. It is also important to dry the raw materials as well as the end product for better combustion and emission properties. As such, the target users of the briquettes influence the selection of the type and processing technologies. Drying the briquettes well and applying an adequate amount of pressure and binder improves the bulk density and durability of the briquettes. These are important parameters, especially if the briquettes are to be transported long distances. Use of presses with high pressure reduces the amount of binder required. It is important to follow guidelines on good quality of biomass energy, such as charcoal, so as to produce competitive briquettes.

Men, women and youth have varied preferences on briquette production technologies, where elder women prefer using techniques that are simple and require a less amount of physical energy. Youth, both male and female, prefer using manual machines. In large-scale production, where electric presses are used in compacting raw materials into briquettes, women are more involved in spreading the briquettes on drying beds and packing them in sacks, while men are involved in running the mixing and compacting machines. It is, therefore, important to understand the roles and preferences among different gender categories for appropriate technology development. Women are also involved in the briquette supply chain through the supply of agro-residues and charcoal dust/fines, and retailing of the briquettes produced.

Fuel briquettes could present multiple benefits: It could (a) be a cheap and sometimes cleaner source of cooking fuel, (b) generate income through sales, and (c) reduce household expenditure on energy for cooking. Generating income and reducing household expenditure are critical to achieving poverty reduction, and the money can be invested in other productive activities such as agriculture and commercial enterprises. The low emissions produced by briquettes contribute to a reduction of illnesses and premature deaths associated with smoke in the kitchen, hence improving the welfare of women and children as they spend a lot of time cooking food for the family. Since briquettes are affordable, it can contribute to food and nutrition security. Families are able to cook food types of their choice, especially traditional food, that take long to prepare and consume a lot of fuel. Families can also cook as many times as they need, cook the amount of food they need and cook food properly. They also support commercial enterprises such as food processing, poultry farming, brick making, and drying of fish, tea, tobacco and several other products. Both small- and large-scale production of briquettes contributes to MSW management, hence cleaning cities and neighborhoods.

Fuel briquette enterprises require a consistent supply of raw materials with good energy qualities, appropriate technologies for processing, consistency in the quality and supply of the product, and market opportunities. Fuel briquette enterprise development also requires workable partnerships for resource mobilization, technological support, establishment of linkages among stakeholders and enabling policy. Partnership with the private sector for waste pre-processing and delivery, for instance, significantly reduces the cost of production, which can also be reduced by partnering with municipalities or other organizations for obtaining the required land area. As such, research is a prerequisite to successful fuel briquette enterprises that consistently produce quality products with a viable market under an enabling policy framework.

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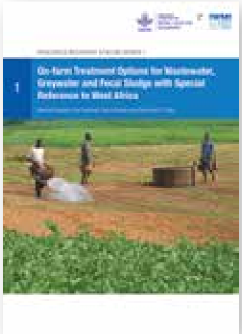
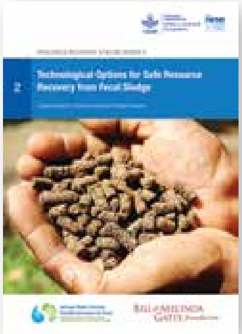


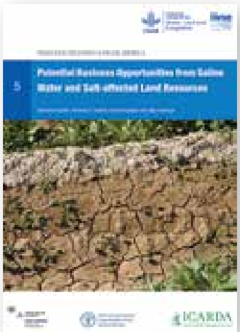

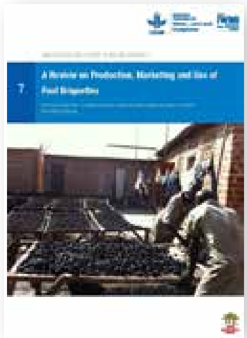
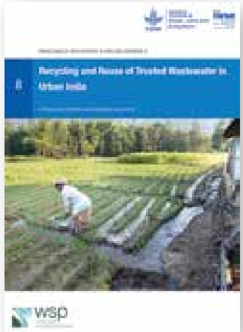
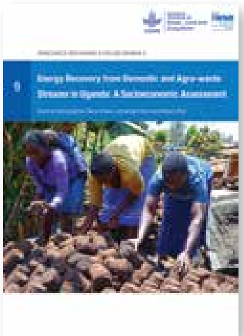
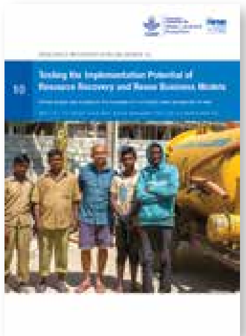

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RESEARCH PROGRAM ON Water, Land and Ecosystems

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