REPORT

Urban Briquette Making Pilot

Urban Briquette Making Pilot-Inventory of Raw Materials for making Briquettes (part 5 of 5)

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1 Introduction

1.1 Background

There is no single universal definition of waste, as the definition remains quite subjective. What is considered waste for one process can be a resource for another activity. Different countries adopt different definitions and classifications of waste according to the purpose and message intended to be passed across. The Kenya National Sustainable Waste Management Bill (2018), defines waste as *"any substance, material or object, that is unwanted, rejected, abandoned, discarded or disposed of, or that is intended or required to be discarded or disposed of, by the holder of that substance, material or object, whether or not such substance, material or object can be re-used, recycled or recovered and includes all wastes as municipal waste, domestic waste, waste from agriculture, horticulture waste, aqua culture waste, forestry waste, biomedical, hazardous, industrial waste, pesticide and toxic substances"*. Common classification of waste includes[1]; (i) physical state-solid, liquid or gaseous waste, (ii) source of waste- domestic, industrial, commercial, forestry or agricultural waste and; (iii) impact to the environment-hazardous or non-hazardous waste. Waste generation has always been a concern for countries since the pre-historical period. However, in the recent past population growth and urbanization in developing countries have increased the quantities of waste generated resulting to limited land to absorb the large volumes of waste in cities. Kenya for instance, has recorded rapid population growth, with the total population increasing more than four times over the last 50 years; from 10.9 million in 1969 to 47.6 million in 2019. Kenya is also characterized by rapid urbanization and urban population growth which has an impact on the quantities of waste generated in urban areas. Basing their definition of urban population as the 'core urban' population, Figure 1 summarizes the growth in share of urban population in total population as reported by the World Bank.

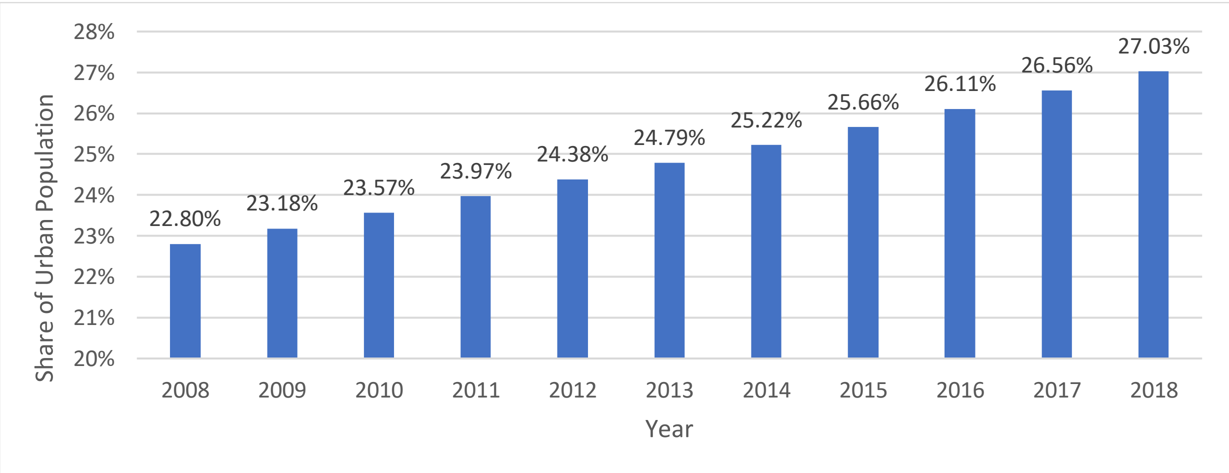

Figure 1: Share of urban population in total population in Kenya (Source: World Bank Data)

The increase in population and the high rate of urbanization in Kenya has resulted in an increase in the waste generated in the ever-growing urban areas. In Nakuru County for example, a 2017

[1]Amasuomo, E and Baird J. (2016). The Concept of Waste and Waste Management. *Journal of Management and Sustainability 6 (4)*. http://dx.doi.org/10.5539/jms.v6n4p88

feasibility report by the World Bank[2] found that the county generates an average of 523 tonnes of waste per day of which 80% is biodegradable material (e.g. organic food, paper, cardboard, and textile). Nairobi County on the other hand is estimated to produce about 2,400 tonnes of municipal waste daily; Kisumu County 500 tonnes daily and Mombasa County 875 tonnes daily. Most urban areas in Kenya are limited in their capacity to collect and dispose of waste[3]. This has given rise to indiscriminate littering and open dumpsites such as the popular *Dandora* dumpsite in Nairobi and *Kachok* dumpsite in Kisumu. These dumpsites pose a significant risk not only to public health but also to the environment. Recognizing that there is an increase in waste generated in urban areas and a challenge in waste management, this report aims to explore the various opportunities for investment in waste management with a focus on waste to energy scenario and specifically the use of waste for production of briquettes. This is geared towards addressing the increasing energy demand driven by population growth and waste management. This report is part of a series of outputs under the CTCN Technical Assistance to Kenya on *Urban Briquette Making Pilot Project*. The report presents an assessment of the different types of waste with the aim of identifying the most suitable raw material for briquette making in Kenya. An overview is provided on the impacts of waste to the environment in a Business as Usual Scenario (BAU), various ways of waste management are discussed and an assessment of the most viable waste for briquette production is conducted. The study focuses on the following categories of waste:

Municipal solid waste (MSW) is defined as all solid domestic refuse, and non-hazardous wastes such as commercial and institutional wastes, street sweepings and construction debris[4]. Typically, the material composition includes organic waste, paper, glass, plastic, metal, charcoal dust and others (hazardous household waste, diapers and textiles, among others). For production of briquettes organic waste is prioritized for this study. The potential of faecal matter as a potential briquetting material is also assessed.

Agricultural waste is waste resulting from rearing of livestock and the production and processing of food and fibre. Examples include; crop residues, animal manure (poultry houses and slaughterhouses), dead animals, harvest waste, and fertilizer runoff that contributes to contamination of the environment[5]. This study focuses on crop residues such as bagasse from sugar cane, rice husks from rice, coffee husks from coffee, maize cobs from maize, etc.

Forestry waste is a by-product of harvesting wood or processing of forest resources e.g. sawdust.

1.2 Impacts of Municipal Solid Waste to the Environment in a BAU Scenario

Due to the non-engineered sanitary landfills, discharge (leachate) and emissions emanating from the waste is released into water, soil and air. The source of pollutants from the commingled waste arises from i) microbial decomposition of organic waste and biomass ii) infiltration of water, iii) heavy metals and iv) open burning of waste. The initial degradation phase of organic waste materials (food residues, paper and biomass), hydrolysis, is aerobic, however, after oxygen depletion the

[2] World Bank. (2017). *Nakuru Integrated Solid Waste Management PPP Project: Feasibility Study Report and PPP Implementation Plan.*
[3] ibid
[4] Magutu P.O and Onsongo C.O. (2011). Operationalizing Municipal Solid Waste Management. Integrated Waste Management – Volume II. *Integrated Waste Management* DOI: 10.5772/16457
[5] OECD. Glossary of Statistical Terms. Retrieved from https://stats.oecd.org/glossary/detail.asp?ID=77

degradation continues anaerobically through acetogenesis and methanogenesis. The latter leads to the production of greenhouse gases (methane and carbon dioxide)[6] and other trace gases (hydrogen sulphide and ammonia) which cause air pollution. Additionally, the chemical, microbiological and physical processes lead to transfer of pollutants to water emanating from groundwater underflow, surface runoff and precipitation, which leads to production of landfill leachate. This is further elaborated in the section below.

1.2.1 Surface Water and Groundwater Contamination

The exact chemical composition of landfill leachate depends on the waste composition, climatic conditions, age and degradation of solid waste. Typical constituent concentrations indicate high ammonia-nitrogen and organic nitrogen, which cause eutrophic conditions in surface waters when in high concentrations[7]. Other pollutants include Chemical Oxygen Demand (COD), Total Organic Carbon (TOC), Biological Oxygen Demand (BOD), specific organic compounds and heavy metals[8]. Currently, the operational open dumpsites in Kenya are not engineered to contain or treat leachate, which percolates to lower soil layers leading to contamination of groundwater, and residual soil. A study of Nairobi River and groundwater around *Dandora* dumpsite indicated high concentrations of COD and heavy metals (Cadmium (Cd), Lead (Pb)) as shown in Table 1.

Table 1: Mean concentration of heavy metals, BOD and COD for Dandora Dumpsite Leachate compared to effluent discharge permissible levels issued through NEMA Water Regulations

Contaminant	Mean Range Concentration of Leachate (mg/l)	Effluent discharge permissible levels (mg/l)
Lead (Pb)*	3 – 4*	1.0
Cadmium (Cd)*	1.5 -2.0*	0.5
Chromium (Cr)	0.5 – 1.5	2.0
Zinc (Zn)	0.5 – 1.5	5.0
Antimony (Sb)	3.5 – 4.0	-
BOD	403	500
COD*	10,700*	1,000

***Concentrations surpassing permissible levels (Data sourced from Odhiambo 2017[9], NEMA Water Quality Regulations)**

Whereas city residents do not depend on the river water for daily use, risk of exposure exists through consumption of livestock reared and vegetables irrigated using contaminated water as well as crops grown on contaminated land. An assessment of the metal extent in blood of livestock from Dandora dumpsite indicated high levels of Cadmium (0.17 – 4.35 μg/kg dry-wt) and lead poisoning (90 – 2710

[6] Bhalla B., Saina M.S., and Jha M.K. (2018). Effect of Age and Seasonal Variations on Leachate Characteristics of Municipal Solid Waste Landfill. *International Journal of Research Engineering and Technology 2(8)*

[7] Stefanakis A., Akratos C., Tsihrintzis V. (2014). *Vertical Flow Constructed Wetlands: Eco-engineering Systems for Wastewater and Sludge Treatment*. (CHAPTER 7: Treatment of Special Wastewaters in VFCWs pp 145-164) ISBN 9780124046122

[8] ibid

[9] Odhiambo H. (2017). *Survey on Environmental Impact caused by Dandora Dumpsite and Proposal of Mitigation Measures.* (Master Thesis).

μg/kg) suggesting human exposure through livestock consumption was likely. Additionally, charcoal dust, which accumulates in the charcoal selling points is disposed to the drains or burnt. This results to blockage of the drainage and emissions from burning[10].

1.2.2 Greenhouse gases and other hazardous gases

According to the Kenya Climate Change Action Plan, greenhouse gas production from the waste sector under a business as usual model was estimated at 2.4 $MtCO_{2}$-eq in 2015 and projected to increase to 4.7 $MtCO_{2}$-eq in 2030[11], of which solid waste accounts for 75% of the emissions[12]. Besides the decomposition of waste additional emissions are released through open burning of waste at landfills and dumpsites, which is one of the main modes of waste volume reduction in Kenya[13]. Open burning is typically a poor combustion process and is a significant source of persistent organic pollutants, (POPs, such as dioxins and furans). It generates 7% of the national releases of persistent organic pollutants[14], particulate matter and heavy metals.

1.2.3 Implications on health

Decomposing organic waste is a rich medium for the growth of numerous microorganisms which are linked to gastro-intestinal infections (gastro-enteritis, typhoid fever, and helminths) if poorly handled. As earlier stated, burning of waste in an open field is a major source of air pollution.
Dioxins, Furans, Mercury and Polychlorinated Biphenyl's are linked to skin lesions such as chloracne, dark patches on the skin, altered or reduced liver capacity. Long-term exposure leads to respiratory diseases including asthma, weakened immune system, central nervous system, endocrine system conceptive capacities and cancers.

Indirect hazards posed by the current disposal methods include environmental contamination due to flooding. Waste disposal sites that are located in lowland areas close to residential areas pose a long-term risk of potential environmental contamination due to inundations. This can potentially increase the transmission of the following communicable diseases such as water-borne diseases such as typhoid fever, cholera, leptospirosis and hepatitis A and Vector-borne diseases such as malaria, dengue hemorrhagic fever, yellow, and West Nile Fever.

1.3 Opportunities for Waste Management

The waste management hierarchy (Figure 2) is premised on reducing the volume of waste produced while allowing for the lowest cost of waste management and the most environmentally friendly option for disposal of waste. Waste prevention (reduce) provides the least amount of generated waste hence the most desired option of disposal while engineered sanitary landfills provide the least preferred option due to the volumes generated and disposed and cost involved. Therefore, waste,

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[10] Njenga,M., Karanja,N.and Iiyama,M. (2013). Implications of Charcoal Briquette Produced by Local Communities on Livelihoods and Environment in Nairobi- Kenya. *International Journal of Research and Development DOI: 10.14710/ijred.2.1.19-29*

[11] Ministry of Environment and Natural Resources (2017). *Kenya's Nationally Determined Contribution (NDC): Update of Kenya's Emission Baseline Projections and Impact on NDC Target*. Nairobi; Kenya

[12] Kenya's Climate Change Action Plan: Mitigation Chapter 9: Waste

[13] MoEWNR (2012). Inventory of Mercury Releases in Kenya. Nairobi; Kenya

[14] MoEWNR (2014). Kenya National Implementation Plan for the Stockholm Convention on Persistent Organic Pollutants 2014 – 2019.Nairobi:Kenya

depending on the treatment and quality, remain viable sources of energy, nutrient recovery and soil conditioners. These options are reviewed below.

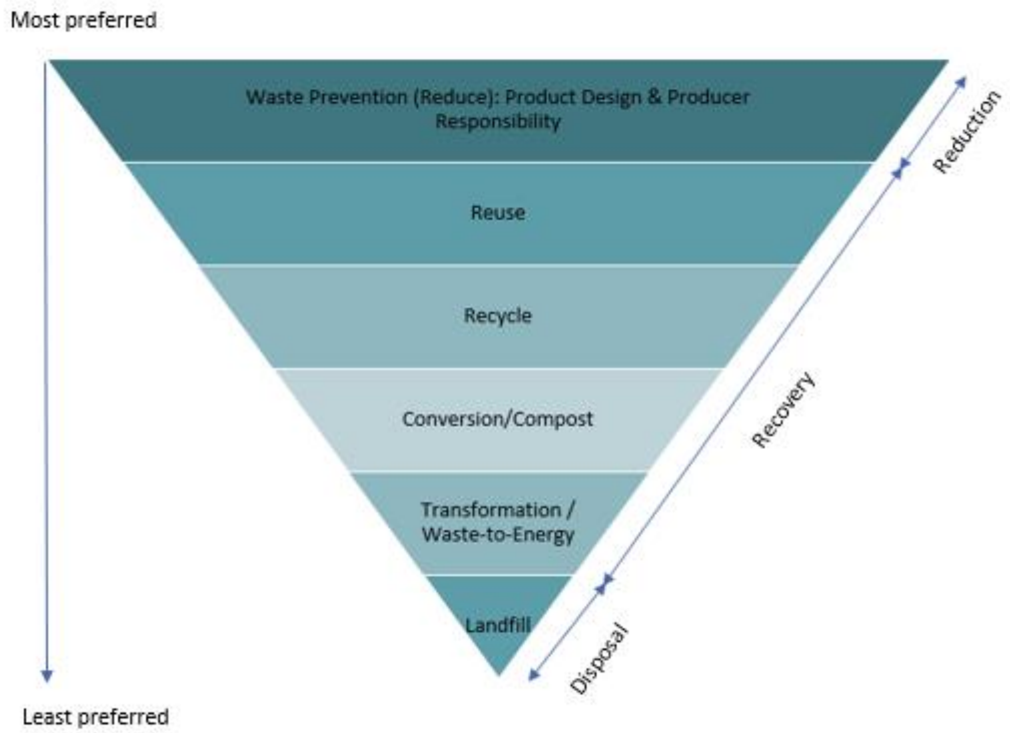

Figure 2: Waste Management Hierarchy

1.3.1 Waste to Energy

Waste to energy (WtE) refers to any process that creates energy in the form of electricity and or heat or processing of fuels from a waste source. There are several pathways of biomass conversion and WtE technologies currently commercialized as shown in **Figure 3**. Ultimately, the technology adopted depends on the amount of waste, local technical expertise, financial implications and the policies available[15].

[15] Coelho S.T., Bouille D.H, Mani S.K., Stafford W.H.L., (2020). *Introduction. Multiple Solid Waste Energy Conversion in Developing Countries, 1 - 7.*

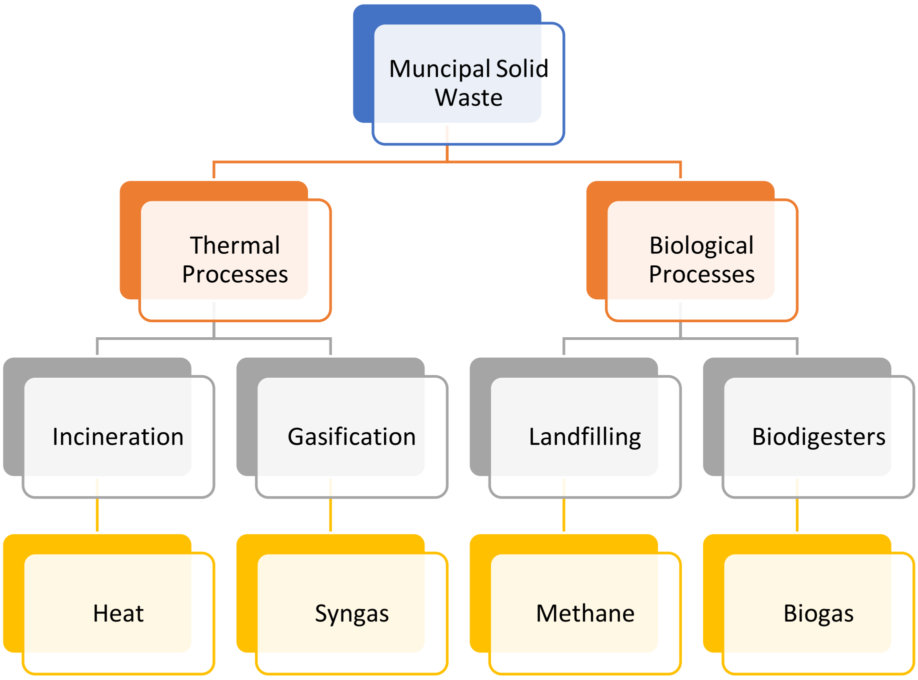

Figure 3: Waste to Energy Technological Options (Adapted from Coelho et al., 2020)[16]

The most commonly used WtE arises from the thermal process of *incineration in a combined heat and power (CHP) plant*. The range of net electric generation depends on the quality and calorific value of the MSW. Typically, the high content of organic waste, high moisture content, low combustible waste such as plastics, and inconsistency of composition due to the lack of sorting for developing countries leads to a lower net electric generation, 300 – 400 kWh per ton compared to 500 – 600 kWh per ton for developed countries[17]. The annual waste generated in Nairobi (approx. 2,400 tonnes/day or 876,000 tonnes / yr) would be suitable for large-scale incinerators[18]. For these volumes of waste, and approximate power production at 30% power generation efficiency is estimated at 177,184 kWh per day (excluding plastics and inorganics)[19]. It should be noted that collection of waste stands at approximately 40% (350,400 tonnes / yr) and the capital investment is high. Technical and legislative frameworks and their subsequent enforcement outlining the emissions standards should also be stringent to avoid pollution through Persistent Organic Pollutants (POPs) such as dioxins and furans which bio accumulate in human tissue and cause adverse health impacts.

Typically, the generation of energy from biological processes arises from the conversion of waste to biogas or bio methane which can be used for powering vehicles, energy for cooking and heating. Biodegradation of the organic fraction, also referred to anaerobic decomposition, leads to the production of biogas (methane and carbon dioxide) for landfilling and biogas / organic compounds for bio digesters. The main factors / parameters influencing anaerobic digestion include the absence of oxygen, substrate composition and temperature. The characterisation of organic matter is of great importance in determining or predicting the efficiency of the anaerobic digestion process. The higher

[16] Coelho S.T., Bouille D.H, Mani S.K., Stafford W.H.L., (2020). *Introduction. Multiple Solid Waste Energy Conversion in Developing Countries, 1 -7.*

[17] Yan M., Waluyo J., and Agamuthu P. (2020). Challenges for Sustainable Development of Waste to Energy in Developing Countries. *Waste Management & Research Vol. 38 (3) 229 – 231.*

[18] Williams P.T., (2005). *Waste Treatment and Disposal (2nd Ed).* John Wiley & Sons, Ltd, England.

[19] Khamala E. M., and Alex. A. A., (2013). Municipal Solid Waste Composition and Characterisation Relevant to the Waste-To-Energy Disposal Method for Nairobi City. *G.J.E.D.T* Vol. 2 (4): 1-6.

the percentage of organic matter presents in the waste, the greater the biogas production potential[20]. The current biological conversion is happening on a small-scale as community projects. According to studies, Skylink Innovators enterprises and SimGas enterprises are a few private sector biogas initiatives where customers are responsible for their own organic waste and which feed into movable biogas digesters[21].

Asticom Kenya with funds from Sustainable Energy for Africa (SEFA), aims to operate WtE facilities in Sub-Sahara Africa including Kenya. The project aims to use municipal solid waste (from urban areas), agricultural crop residues (western counties) and livestock waste or manure for generation of bio methane, ethanol and electricity. They have set up a pilot in Kibera with a capacity of 260 tons/day and 75,000 tons per annum[22].

Organic municipal waste, agricultural residue (e.g. coffee husks, sugarcane bagasse, rice husks, macadamia nuts, wheat straws etc), forestry residue (e.g. sawdust, chips, offcuts) and charcoal dust are used as feedstock for production of briquettes. Briquettes are biomass-based fuels that are considered as alternatives to charcoal and fuelwood.

1.3.2 Composting

Composting is a simple process where optimization efforts are used to increase the rate of decomposition, minimize nuisance potential, and produce a clean and readily marketable finished product, soil conditioners. Composting in Nairobi is observed to happen on a small-scale by private collection companies such as Taka Taka solutions and community-based organisations (CBOs) mostly located in the low-income residential areas and informal settlements[23]. Taka Taka solutions ensures separation of organic waste from the source to improve the quality of product while CBOs source their waste from the markets and farms. The current demand for compost is in excess of 100,000 tons/year while actual production stands at <10,000 tons/year[24]. Sanergy Limited collects, treats and converts faecal matter from low-income areas to organic fertilizer.

[20] Garcilasso V. P., and Oliveir F.C. (2020). *Best Available Technologies (BAT) for WtE in Developing Countries. Multiple Solid Waste Energy Conversion in Developing Countries, 63 - 105.*
[21] Muok Ben (2020). *WtE Project in Kenya. Multiple Solid Waste Energy Conversion in Developing Countries, 208 – 209.*
[22] Asiticom website. https://www.asticom.org/index.php/about-us
[23] Onduru D.D, Waarts Y., Jager A., and Zwart K (2009). Inventory and Analysis of Users, Producers and Markets for Compost, Biogas and Livestock Feeds in Urban and Peri-Urban Areas of Nairobi. Converting City Waste into Compost Pilot Nairobi.
[24] ibid

1.4 Approach and methodology

Information and data used in this report was collected through literature review and primary data collection. This was then collated and synthesised into a unitary report. Figure 4 below summarizes the main approaches and methods used.

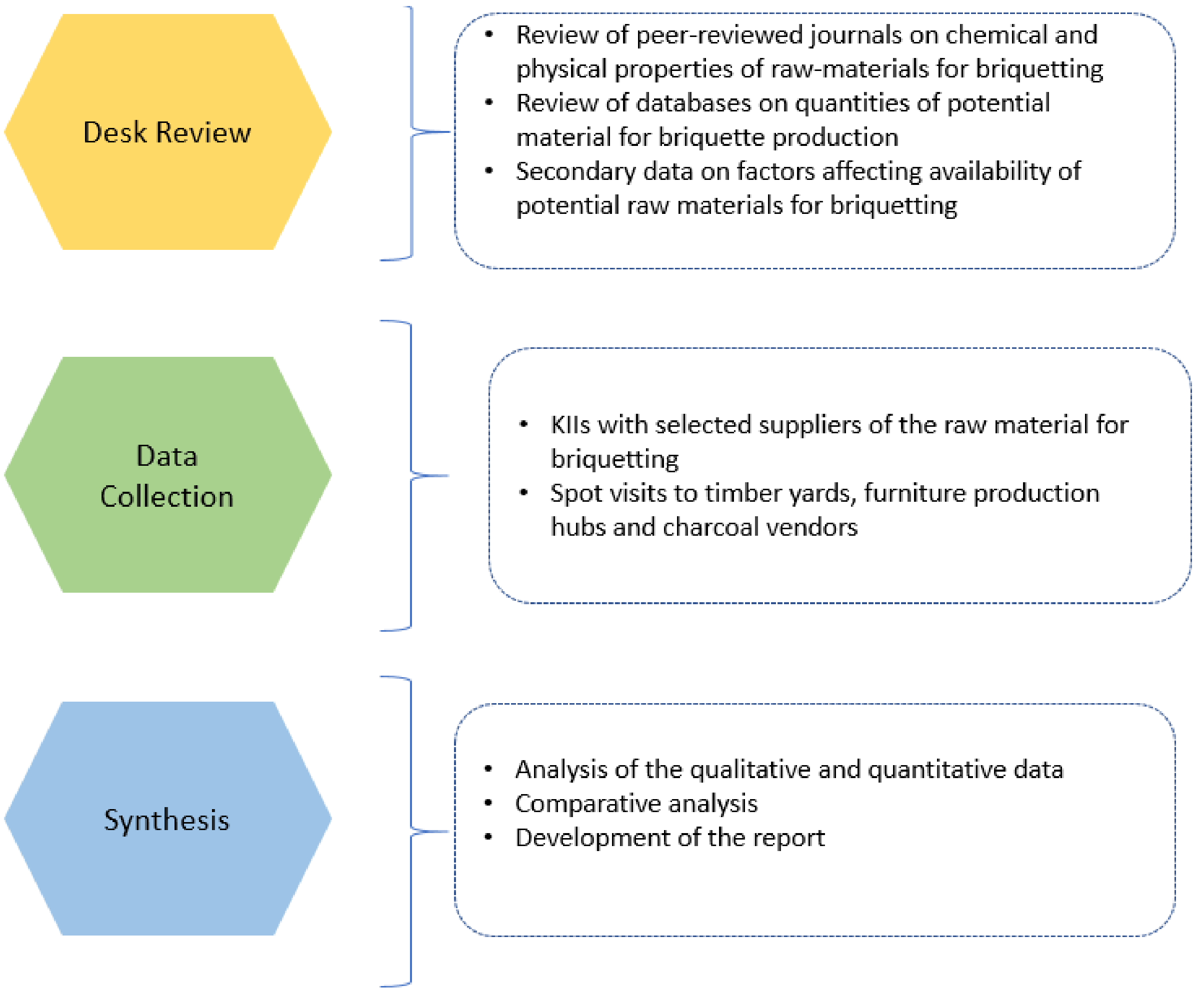

Figure 4: Summary of approach and methodology

i. ***Literature and secondary data review*** included the appraisal of relevant literature on physical and chemical properties of potential raw materials for briquetting from peer-reviewed journals and grey literature. Databases such as the Food and Agriculture organization (FAO), and available secondary materials were reviewed for estimating the quantities of waste available. A summary of the main reports and data sources reviewed is provided below.

Table 2: A list of the main literature reviewed

#	Organization	Year of publication	Report title
1.	European Union	2016	Biomass Use and Potential for Export from Kenya to the European Union 2015 – 2030
2.	FAOSTAT Database	2018	Food and Agriculture Data
3.	Agriculture and Food Authority (AFA)	2019	Year Book of Sugar Statistics 2019
4.	Agriculture, Fisheries and Food Authority	2014	AFFA yearbook of statistics
5.	Government of Kenya	2019	National Solid Waste Management Policy,2019
6.	Chardust Ltd and Spectrum Technical Services	2004	The Use of Biomass to Fabricate Charcoal Substitutes in Kenya. Feasibility Study: Forming Part of the Shell Foundation-Supported Project on Charcoal Briquetting in Kenya.

ii. ***Primary data collection*** involved conducting interviews with selected possible suppliers of the raw materials for briquette production. Spot visits were also conducted within timber yards, furniture production hubs and charcoal vendors in Nairobi County and telephone interviews with saw millers. These include:;
- 2 retail charcoal vendors in Kawangware,
- 2 charcoal wholesalers in parklands area,
- A timber yard in Kawangware
- Furniture production hub along Ngong Road
- 2 saw-millers (1 in Iten and 1 in Nakuru)

iii. ***Report synthesis*** focused on aggregating and analysing qualitative and quantitative data to identify the most suitable raw material for briquette production. Comparative analysis was also conducted to determine the most suitable raw materials.

2 Assessment of Raw Materials for Briquette Manufacturing

There exists an array of raw materials that can be used for briquette production. However, a briquette producer must identify the most suitable raw material for briquette production. Identification of the most suitable raw material was guided by these three main factors: (i) quantities available, (ii) quality of the raw material and (iii) cost of the raw materials. Additionally, national and global trends which may affect availability of suitable raw materials, were also considered. A list of 28 possible sources of raw materials was developed (from literature review and interviews with the briquette producers) and an elimination criterion developed to allow elimination of waste with the least potential for briquette production as summarized in Figure 5.

- Pyrethrum
- Rapeseed
- Sesame
- Beans
- Pigeon Peas
- Sorghum
- Sugarcane
- Cassava
- Coconut
- Cotton
- Groundnut
- Sweet Potatoes
- Irish Potatoes
- Macadamia
- Barley
- Coconut
- Cashew
- Millet
- Coffee husks
- Pineapple
- Rice husk
- Sisal
- Flower waste
- Maize
- Sawdust
- Charcoal dust
- Faecal matter
- Organic waste

The guideline is a funnel-shaped approach beginning with all the potential feedstocks at the top, but as they are subjected to the evaluation criterion the list decreases and only the most suitable raw material is left at the end of the funnel. The elimination process is discussed below.

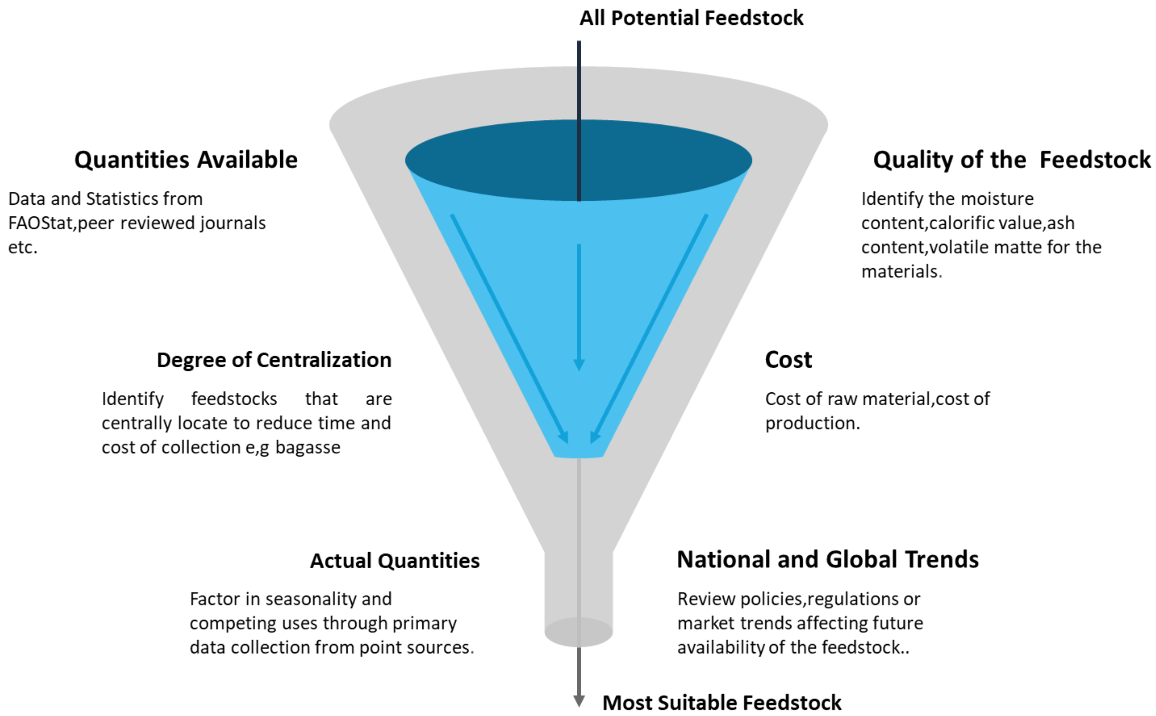

Figure 5: Summary of Feedstock Assessment methodology

2.1 Quantities Available

One of the key factors to consider when choosing a raw material for fuel production is the annual quantities available. Availability of raw material is affected by; (i) seasonality of crop production (for the case of agricultural waste), (ii) competing uses, and (iii) centrality of the raw material. Although, it is difficult to precisely estimate the quantities of biomass residue volumes in Kenya given the informality of trade and the lack of available databases, there exists methodologies that can aid in estimating approximate quantities. For example, agricultural residue (waste) was estimated based on the residue to product ratio (RPR) which describes the amount of residue produced per crop. Using the methodology adopted in the assessment of the available agricultural residues in Kenya by the EU for prominent agricultural products, which was based on production, yield, area of production, and a residue to product ratio (RPR), quantities of waste generated per crop was estimated. This was further supplemented by FAO statistics on the available residues production in Kenya. Literature review was used to estimate the quantities of municipal waste, charcoal dust and sawdust. Table 3 and Table 4 below provides a summary of estimates of waste quantities available before factoring in competing uses.

Table 3: Summary of quantities available for agricultural waste, forestry waste and charcoal dust[25]

Agricultural Residues	Mass of Residue of (Field and Process) (t)
Bananas	2,649,000
Beans	1,122,000
Cashew	15,036
Cassava	518,000
Coconuts	41,763 – 193,000
Coffee	13,357
Irish Potatoes	1,050,000
Macadamia	15,071
Maize	16,063,000
Mangoes	5,564,000
Pigeon & Cow Peas	193,000
Pineapples	109,305
Rice	182,472 – 312,000
Sisal	675,294 – 800,00
Sorghum	692,000
Sugarcane	1,789,748 – 2,416,000
Sweet Potatoes	310,000
Wheat	538,204 – 654,000
Wood waste (off cuts, timber rejects and sawdust[26])	15,600
Charcoal dust (urban areas)[27]	70,000-105,000

Pyrethrum, rapeseed, sesame and cotton were not considered for further analysis because the annual crop production is less than 10,000 tonnes[28].

[25] IIED (2015). *Biomass Use and Potential for Export from Kenya to the European Union 2015 – 20130.* EU
[26] Ministry of Environment, Water and Natural Resources (2013). *Analysis of Demand and Supply of Wood Products in Kenya. Nairobi*. http://www.kenyaforestservice.org/documents/pdf.
[27] 0.7 Mtons of charcoal are consumed in urban areas (MoE,2019). 10-15 % is converted to charcoal dust
[28] FAOSTAT. (2017). Crops. http://www.fao.org/faostat/en/#data/QC

Table 4: Estimates for municipal waste generated for Nairobi, Kisumu and Mombasa

Data Source	Estimated waste generated in Nairobi, Kisumu and Mombasa					
	Nairobi		Kisumu		Mombasa	
	Nairobi (t/day)	Approximate Organic Fraction (t/day)	Kisumu (t/day)	Approximate Organic Fraction (t/day)	Mombasa (t/day)	Approximate Organic Fraction (t/day)
Oyake – Ombis 2017[29]	2,400	1440	500	300	875	525
NAMA 2017[30]	3,030	1818	395	237	602	361.2
MoEF 2019[31]	2,400	1440	1000	600	2000	1200
NCC, 2010[32]	3,200	1920		-	-	-

Centrality of the waste

A raw material can be available in large quantities but highly decentralized in terms of point sources. As a result, there is need to determine the degree of centrality of the raw material. From the list above, there are crops whose processing is done at a farm level and others at an industrial level. Processing of the crops at the farm level results in the waste being highly decentralized and the producer has to source the raw material from multiple suppliers. The procurement process for multiple suppliers is tedious and can at times be costly compared with dealing with one supplier. For this reason, crops like beans, peas, bananas, millet, potatoes, mangoes, sorghum, rice straws, coconut husks, and maize, though have high residue capacities, were dropped from the list of potential crops for consideration because they are not centrally located.

Seasonality of the raw material

For continuous briquette production, the ideal raw material should be available throughout the year. If the raw material has low and peak seasons, it is important that the briquette producer is aware of these periods to plan accordingly. For example, sawdust maybe in limited quantities during the rainy seasons when milling of timber is limited, coffee is a seasonal crop and therefore unavailable in certain times of the year. Although coffee husks have low moisture content and a calorific value of 12.38 MJ/kg, which is within the range of many feedstocks for briquette making, they are unavailable between May-July. Coffee husks are also a source of thermal heat for the Kenya Clay Works and Bidco oils refinery. Other seasonal crops include wheat, maize and beans which may have one or two planting seasons. Even though coffee is seasonal, the waste can be collected at central locations thus it was still considered for further analysis. As for beans, maize, potatoes which are not only decentralized but also seasonal, they were eliminated from the list of potential feedstocks for briquetting.

Competing uses

It is important to establish the existing uses of the waste in determining the actual amounts available for a given crop residue. A feedstock may exist in large amounts but has an alternative use that is more preferred or of a higher economic value than briquette making. For example, wheat straws are

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[29] ibid

[30] UNDP. (2017). *Nationally Appropriate Mitigation Action on a Circular Economy Solid Waste Management Approach for Urban Areas in Kenya.*

[31] Government of Kenya. (2019). *National Sustainable Waste Management Policy 2019 (Revised Draft)*. Nairobi Kenya

[32] I Ngau P, von Harro B. (2020). Integrated Solid Waste Management Plan for Nairobi 2010.

available in large quantities, but most farmers prefer to use them as animal feedstock or as manure for their farms. In such an instance, the price of buying the straws from the farmers would have to offer better economic returns for them to consider it. Sisal waste has the potential of being converted to electricity production[33], however, sisal balls are cut and left in the field as manure. If they were to be utilized in briquetting, there would be need to factor in the expense and logistics involved in collecting the waste into a central location. In addition, sisal fibre has found application in the furniture industry where it is used as a stuffing material. Coconut coir is preferred for weaving of ropes, mats, door mats while coir peat is used as compost. Coconut shells are mainly used in boilers by oil producers and other companies leaving minimal amounts for briquetting. Pineapple waste from one of the largest producers (Delmonte (K) Limited) is utilized by a briquette making company in Kenya (Global Supply Solutions) which has already acquired a patent in Kenya and other countries[34]. Flower waste is currently used by the flower farms as a compost for their farms and as such, no quantities are available for supply. From the analysis on competing uses, waste from pineapples, flowers, coconut and sisal were not considered for further analysis.

Cost of the raw material

The price of the fuel is a key determinant on its rate of adoption at the household level[35]. The cost of briquettes should be more competitive than the other types of fuels in the market that it is replacing. The price at which the briquettes will be sold is in turn determined by the cost of raw material, transport cost for both raw material and the briquettes, processing, packaging etc. As such, the cost of the material is important in determining the economic viability of a given raw material. For example, macadamia nuts and cashew nuts have high calorific value and low moisture content and thus a desirable raw material for briquetting[36]. However, these two raw materials can still provide the required energy content without the need for briquetting. Briquetting of these material is thus not economically viable and as a result thermal intensive industry such as tea factories, Bidco, Clay works, and Bamburi Cement Limited etc. use both in their raw forms. Over the years, there has been a rise in demand for these raw materials by thermal intensive industries such as oil refineries, cement manufacturers, tea factories given their desirable qualities. Some of the costs per tonne identified for this study include; coffee husks costs KES 6,500 + VAT, sawdust KES 3,000- 6,000, charcoal dust KES 6,000[37], macadamia nuts KES 5,000- 20,000 and bagasse KES 0-600. At this point, some of the materials that were already in limited volumes, seasonal and had a high cost were eliminated from the list. For coffee husks, macadamia nuts and cashew nuts, purchasing process is through bidding which is announced in the daily newspaper every end of season and thereafter annual contracts to successful bidders. Briquette start-ups might not be as competitive and in some of the mills, they already have established customers. For this reason, macadamia nuts, cashew nuts and coffee husks were eliminated from the list.

[33] Julia Terrapon-Pfaff, Manfred Fischedick, Heiner Monheim. (2012). Energy potentials and sustainability—the case of sisal residues in Tanzania. Energy for Sustainable Development, (16) 3,312–319: DOI: 10.1016/j.esd.2012.06.001
[34] Global Supplies Limited. Retrieved from https://www.globalsupply.co.ke/about/
[35] Ministry of Energy. (2019). Kenya Household Sector study.
[36] Chardust Ltd and Spectrum Technical Services. (2004).The Use of Biomass to Fabricate Charcoal Substitutes in Kenya. *Feasibility Study; Forming Part of the Shell Foundation-Supported Project on Charcoal Briquetting in Kenya*. Nairobi; Kenya
[37] Calculated from a sack of 50 kg being sold at KES 300.

2.2 Quality of the raw material

The potential raw materials were subjected to a proximate analysis, which assesses the physical characteristics of the feedstock that will affect the combustion characteristics of the resulting briquettes. The following characteristics of the feedstocks were considered:

(i) ***Fixed carbon*** is the remaining residue after subtracting the volatile matter, moisture content and ash content during the heating process[38]. Materials with high levels of fixed carbon are preferred for briquette production. Lower levels of fixed carbon mean that you require high amounts of the material to achieve a given heat output. A high percentage of fixed carbon increases the heat value of the raw material.

(ii) ***Moisture content*** is the percentage of moisture (water) in a sample of raw material in its original state before drying or being subjected to environmental elements such as precipitation. Raw materials with high moisture content must be dried therefore the producer has to invest in drying equipment. Additionally, there is a loss in mass after drying of the raw materials and the cost of transporting wet raw material is high compared to dry raw materials.

(iii) ***Volatile matter*** is the percentage of material that burns in a gaseous state. Lower volatile matter in the biomass is desirable[39] as it improves the efficiency of combustion of the resulting briquette.

(iv) ***Ash content*** is the incombustible residue after the burning of raw material. The higher the ash content in the waste the lower the calorific value of the raw material.

(v) ***Calorific value*** is the heat content of the raw material. The higher the calorific value the higher the heat output during combustion.

(vi) ***Bulk density*** is the weight per unit volume of a material[40]. Biomass with high bulk densities is desirable as the material is able to compact easily. Although the transport of bulk materials is costly.

To determine the optimal quality for feedstock, the following qualities from Asamoah (2016) study[41], were used as a guide (see Table 5).

Table 5: preferred qualities for briquetting materials

Properties	Unit	Requirement
Fixed Carbon	%	9 – 25
Volatile Matter	%	50 – 90
Ash Content	%	Less than 4%
Moisture Content	%	6 – 14%
Bulk Density	kg/m^3	More than 50
Calorific Value	MJ/kg	12 – 20
Particle Size	Mm	1 -10 mm size with 10 -20% powdery

[38] Dipak K.Sarkar.(2015). Fuels and Combustion. *Thermal Power Plant: Design and Operations*. Elsevier,91-137. https://doi.org/10.1016/B978-0-12-801575-9.00003-2

[39] Miller.B. (2013). Fuel considerations and burner design for ultra-supercritical power plants. Ultra-Supercritical Coal Power Plants Materials, Technologies and Optimisation. Woodhead Publishing Series in Energy,57-80. https://doi.org/10.1533/9780857097514.1.57

[40] S. Clarke, P.Eng., and F. Preto. (2011). Biomass Densification for Energy Production. http://www.omafra.gov.on.ca/english/engineer/facts/11-035.pdf

[41]Asamoah, B., Nikiema, J., Gebrezgabher, S., Odonkor, E., and Njenga, M. (2016). A Review on Production, Marketing and Use of Fuel Briquettes. Colombo, Sri Lanka: International Water Management Institute (IWMI). CGIAR Research Program on Water, Land and Ecosystems (WLE).51p. (Resource Recovery and Reuse Series 7). doi: 10.5337/2017.200

Table 6 below provide a summary of the quantities and properties of the key raw materials considered for briquette production.

Table 6: Summary of the quantities and properties of selected waste

Feedstock	Quantities			Properties						
	Quantities available	**Degree of centrality**	**Competing uses that are more viable than briquette production**	**Fixed Carbon (%)**	**Volatile Matter (%)**	**Ash Content (%)**	**Moisture Content (%)**	**Bulk Density (Kg/m³)**	**Calorific Value (MJ/kg)**	**Sources**
Bagasse	1,611,011	Centralized at the sugar milling companies	Cogeneration and other briquette producers	13.6	82.1	4.3	50.0	N/A	13	Lopez (2016)[42]
Cassava stem	1,221,051	Decentralized	Animal feed	30.0	59.0	4.9	7.2	N/A	N/A	Adebisi (2017)[43]
Coconut shells	11,759	Food companies such as Malindi Industries, Navida Natural Foods	Used as fuel in boilers by oil producers	17.0 – 20.7	76.0 – 81.4	0.5 – 7.0	6.9 – 18.1	0.1	15.5 – 23.0	Asamoah et al. (2016), Adeyi (2010)[44]
Cashew nut shells	15,087	Centralized at the processing companies	Used as fuel in thermal intensive industries such as Bamburi, Bidco etc	20.48	72	1.05	6.47	NA	25.9	Muhammad et al (2015)[45]
Groundnut (Shell)	10,612	Centralized at the processing companies	Used as fuel in thermal intensive industries such as Bamburi, Bidco etc	17.1 – 19.5	77.5 – 81.5	1.5 – 1.9	1.6	NA	19.0	Asamoah et al (2016)
Macadamia (Shells)	14,668	Centralized to nut companies	Used as fuel in thermal intensive industries such as Bamburi, Bidco etc	23.7	76.0	0.4	N/A	N/A	21.01	
Coffee husks	13,357	Centralized to coffee milling companies	Used as fuel in thermal intensive industries such as clay works, Bidco etc	15.0 - 20.3	68.8 - 74.4	1.8 - 5.3	14.5	N/A	N/A	Lopez 2016, Chen et al (2012)[46]
Rice Husks	18,715	Centralized to coffee milling companies	Used as fuel in thermal intensive industries. Used as soil conditioners by farmers.	14.2 – 17.5	56.1 – 66.3	7.9 -23.5	5.1 – 15.5	327.0	14.2 – 17.5	Asamoah et al (2016)

[42] Lopez (2016). Biomass utilization for energy purposes in Kenya. Fuel characteristics and thermochemical properties.

[43] Adebisi, J., Agunsoye, J., Bello, S., Kolawole, F., Munyadziwa, M., Daramola, M., and Hassan, S. (2017). Extraction of Silica from Sugarcane Bagasse, Cassava Periderm and Maize Stalk: Proximate Analysis and Physico-Chemical Properties of Wastes. *Waste Biomass Valor*. http://dx.doi.org/10.1007/s12649-017-0089-5

[44] Adeyi, O. (2010). Proximate composition of some agricultural wastes in Nigeria and their potential use in activated carbon production. *J. Appl. Environ. Manage, 14* (1), 55 -58.

[45] Danish, M., Naqvi, M., Farooq, U., and Naqvi, S. (2015). Characterization of South Asian agricultural residues for potential utilization in future 'energy mix'. *Energy Procedia 75*, 2974 – 2980. doi: 10.1016/j.egypro.2015.07.604

[46] Chen, W., Lu, Ke-Miao and Tsai, C. (2012). An experimental analysis on property and structure variations of agricultural wastes undergoing torrefaction. *Applied Energy ,100,* 318 – 325.

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Feedstock	Quantities			Properties						
	Quantities available	**Degree of centrality**	**Competing uses that are more viable than briquette production**	**Fixed Carbon (%)**	**Volatile Matter (%)**	**Ash Content (%)**	**Moisture Content (%)**	**Bulk Density (Kg/m³)**	**Calorific Value (MJ/kg)**	**Sources**
			A board production factory is on the pipeline for production of boards from rice husks as an alternative to timber							
Maize (stover/husk/straw)	16,063,000	Decentralized	Animal feed	6.7- 16.8	72.2 – 84.3	4.6 – 11.8	7.0 – 9.3	1, 017.2	17.1 - 18.4	Asamoah et al (2016), Muhammad et al (2015)
Sawdust	15,600	Centralized at timber yards, furniture shops and saw milling points	Production of boards. Fuel for boilers in companies. Briquette production. Poultry farming as floor cover. Charcoal stove insulator in hotels.	2.2 – 21.6	77.7 – 88.6	0.2 – 5.6	1.8 – 9.8	133.0 - 210.0	2.2 – 21.6	Asamoah et al (2016)
Faecal sludge	N/A	Centralized in sewerage companies	Composting Briquette production	6.9 -8.6	36.1 – 53.0	38.40 – 57.1	80.0 – 97.0	NA	13.0	Asamoah et al (2016)
Paper-Waste	N/A	Centralized in dumpsites and waste collection companies	Recycling	NA	65.5	1.2 – 15.5	7.4 – 12.6	NA	NA	Asamoah et al (2016)
Organic waste (market place)	N/A	Market places	Composting Power generation	12.8	87.2	25.9	22.3			
Organic waste (households)	N/A	Waste collection companies	Composting Power generation	16.9	83.1	37.0	63.1	N/A		
Charcoal dust (urban areas)	70,000-105,000	Charcoal venders	Briquette production			11.3	14.9		28.35	Charcoal properties

The desirable calorific value for the raw material for briquette production falls between 12-20 MJ/Kg. Table 6 above shows all the raw materials under consideration that fall within that range. Cashew nuts, macadamia, groundnuts and coffee husks are among the top materials with high calorific value but they are available in small quantities as they are used as fuel for thermal intensive industries such as cement manufacturers and oil refineries. This makes it difficult for briquette producers to compete with other users who use the raw material in its unprocessed state. As a result, these four raw materials were eliminated from the list. Cassava stem has the highest value for fixed carbon but its production is in small scale and heavily decentralized. Sourcing the raw material from many different suppliers is tedious and may be costly. This also applies to the maize cobs and stovers which, even though they exist in large quantities, are decentralized, seasonal and are preferred as animal feed. As a result, these two raw materials were dropped from the list.

The advantage of using rice husks as a raw material for manufacturing briquettes is that they are dry and they do not require shredding given their small size[47]. However, the husks have high silica content, which wears out briquetting machines, thus increasing maintenance and operation costs. They also produce high ash content, which affect the combustion efficiency of the briquettes. Rice husk has found application in boilers of thermal intensive industries and as soil conditioners for farmers to improve productivity. Additionally, if the plans for setting up the board production factory in Kirinyaga follows through, limited quantities will be available for briquette production. For these reasons, rice husks were dropped from the list.

Bagasse, faecal matter, sawdust, charcoal dust and organic waste were considered for further analysis. The reasons why the five raw materials were selected for further analysis are summarized in Table 7 below.

Table 7: Reasons for selecting the five materials for further analysis

No.	Type of waste	Reason for consideration for further analysis
1.	Bagasse	- High quantities of waste - Can be obtained from central points - Cost is relatively low compared to the other raw materials
2.	Sawdust	- Several point sources in urban areas - A preferred material for production of non-carbonized briquettes because of the high proportion of lignin, which acts as a natural binder during the pressing process resulting to dense briquettes
3.	Charcoal dust	- An urban waste - Already carbonized so preferred for making carbonized briquettes
4.	Organic waste	- An urban waste that may not be well managed
5.	Faecal waste	- Available in large quantities - Unless there are competing uses, the raw material will always be available with the existence of the human race - It's an emerging raw material for briquetting and we have companies piloting the suitability of this raw material for briquette production

Although, baggase and faecal waste have high moisture content of 50% and 98 % they were still included for further analysis as the waste exists in large quantities at central locations and the calorific value falls within the desired range. Faecal sludge also has the lowest fixed carbon and high

[47] S. Suryaningsih, O. Nurhilal, Y. Yuliah and E. Salsabila. Fabrication and Characterization of Rice Husk Charcoal Bio Briquettes. AIP Conference Proceedings 1927, 030044 (2018); https://doi.org/10.1063/1.5021237

ash content but since it is an emerging raw material in Kenya for briquette production, there are companies using it for briquette production, hence it was considered for further analysis.

2.3 Analysis of the selected raw materials

For this section, we focus on the top five raw materials that were considered for further analysis. These are bagasse, faecal matter, sawdust, charcoal dust and organic waste. These raw materials are further discussed below focusing on the cost of raw materials and specific areas to source the feedstocks. Other factors that may affect the availability of the waste were also examined.

2.3.1 Bagasse

Baggase is a waste generated from the processing of sugarcane. Sugarcane in Kenya is mainly grown in western Kenya around Nyando, Migori, Mumias, Busia, Nandi and the Coastal region. It is estimated that there are atleast 250,000 farmers who supply sugarcane to at least 15 sugar manufacturers (government owned and private companies)[48]. Baggase is available in large quantities and is centrally located. It has a calorific value of 13 MJ/Kg, which is within the required value for briquette production. Table 8 below shows quantities of bagasse produced in the last 10 years[49].

[48] Bancy M. Mati1, Michael K. Thomas .(2018). Overview of Sugar Industry in Kenya and Prospects for Production at the Coast. Agricultural Sciences, 10, 1477-1485.Retrieved from https://www.scirp.org/journal/as

[49] Agriculture and Food Authority. (2019). Year Book of Sugar Statistics 2019. Nairobi: Kenya.

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Table 8: Bagasse production for the last 10 years (Source: Agriculture and Food Authority)

Company	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Total (per company)
Chemelil	212,158	147,124	135,463	115,391	192,939	159,289	112,289	84,625	97,834	19,232	1,276,344
Muhoroni	193,369	137,319	172,836	149,914	201,625	158,403	133,060	124,444	89,113	73,166	1,433,249
Mumias	870,462	760,608	751,100	696,525	539,116	511,902	395,343	109,642	35,785	N/A	4,670,483
Nzoia Sugar Company Ltd.	251,975	239,604	269,206	289,439	263,671	266,143	305,921	154,213	135,630	79,265	2,255,067
South Nyanza Company Ltd.	205,122	228,259	181,307	239,439	224,785	264,974	262,029	163,121	180,079	83,094	2,032,209
West Sugar Company Ltd	258,570	229,424	206,658	341,687	295,690	410,869	326,935	305,800	315,699	327,586	3,018,918
Sony Sugar Limited	4,896	4,243	6,763	7,500	--	-	-	-	-		23,402
Kibos Sugar & Allied Industries	140,620	161,517	179,487	251,125	192,815	350,088	338,320	254,125	355,113	255,914	2,479,124
Butali Sugar Company Ltd	-	107,583	147,857	141,760	200,103	182,273	300,862	182,097	262,596	209,659	1,734,790
Transmara Sugar Company Limited	-	-	60,680	129,705	177,023	178,687	282,105	138,800	241,516	244,697	1,453,213
Sukari Industries Ltd	-	-	73,855	108,853	131,838	126,148	166,330	118,151	180,267	217,342	1,122,784
Kwale International Sugar Company	-	-	-	-	-	-	114,720	70,130	61,857	6,141	252,848
Olepito Sugar Company Ltd	-	-	-	-	-	-	-	-	18,086	37,238	55,324
Busia Sugar Company Ltd	-	-	-	-	-	-	-	-	-	57,677	57,677
Total per year	2,137,172	2,015,681	2,185,212	2,471,338	2,419,605	2,608,776	2,737,914	1,705,148	1,973,575	1,611,011	

Data presented in Table 8 above indicate that even though there is a decline in the quantities of bagasse available since 2017, there are still substantial quantities that can be utilized for briquette production. Using 2019 as the base year, the top 5 sugar milling companies with high amounts of bagasse are: West Sugar Company Ltd (327,586 tonnes), Kibos Sugar & Allied Industries (255,914 tonnes), Transmara Sugar Company Limited (244,697 tonnes), Sukari Industries Ltd (217,342 tonnes) and Butali Sugar Company Ltd (209,659 tonnes). These can be the first options to consider as points of purchase for bagasse. In some of these sugar companies, the waste is a nuisance and they would be looking for a way to dispose of the waste, as a result, the producers may get it at a no cost or at a cost of KES 0-600 per tonne.

Factors affecting availability of bagasse

The sugar industry in Kenya has been facing various challenges that have seen a decline in the yields from 66.4 t/ha in 2015 to 55.1 t/ha in 2018. Table 9 below shows the trend of production of sugarcane from 2014 to 2018.

Table 9: Sugar production from 2014-2018[50]

#	Sugarcane Area and production	2014	2015	2016	2017	2018
1	Area under cane ('000 Ha)	211.3	223.6	220.8	191.2	202.4
2	Area harvested ('000 Ha)	72.2	77.8	85.8	67.7	73.1
3	Total Production ('000 tonnes)	6409.9	7164.8	7151.7	4751.6	5262.2
4	Production non-contracted farms ('000 tonnes)	1977.1	1995.8	1816.7	1004.3	1233.1
5	Average yield (tonnes/ha)	61.4	66.4	62.2	55.3	55.1

This has led to the country having to import sugar to meet the deficit in supply from local production. The decline in yields has been attributed to the low quality of sugarcane varieties, high production cost, poor crop management, delayed harvesting (18 months compared to 14 months for varieties in other countries) and disillusionment from the industry[51]. The strained relationship between the farmers and the millers has seen farmers switch to other crops due to delayed payment and the low prices of the sugarcane. This has led to the closure of some of the major state-owned millers in the country such as Miwani (which was closed 20 years ago), Mumias sugar, which was closed for 20 months but was, reopened early 2020 and Chemelil has not been milling for the last 8 months[52]. Another challenge in the sugar sector is the global treaties that Kenya is party to (COMESA, ECA and WTO) which allow the importation of sugar from member countries to have zero or minimum tariffs[53]. Since the production, cost is low in these countries and the sector is greatly subsidized by their governments, the price of locally produced sugar is unable to compete with the imported sugar at local and foreign market.

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[50] Bancy M. Mati1, Michael K. Thomas. (2018). Overview of Sugar Industry in Kenya and Prospects for Production at the Coast. Agricultural Sciences, 10, 1477-1485. https://www.scirp.org/journal/as

[51] Ibid

[52] As reported by the local newspaper

[53]Philip Kariuki. Nd. The Sugar Sub-sector. Challenges and Opportunities.http://www.kenyalink.org/sucam/documents/Sugarsub1.html

The government in a bid to investigate the reforms that can be implemented to revive the sector, created a task force. The task force report was completed and presented to the president in February 2020 with key recommendations being: the re-introduction of the sugar levy, privatization of public sugar mills to enhance their efficiency and the enactment of the Sugar Act[54]. The farmers are however opposed to one of the recommendations that introduces zoning of sugar producing regions. This restricts the farmers from selling their produce to the highest bidder and those who pay promptly. As such, they are threatening to uproot their sugarcane and utilize the land for other economic activities. If these grievances are addressed and the reforms addressed, then the sector may be revived in a few years to come. Otherwise, we will continue to witness a decrease in the land area under sugar production.

Availability of baggase from the state-owned mills is not assured as their operations are on and off due to reasons discussed above. Unlike the state-owned mills, privately owned mills are well managed and may be a point source for baggase. In addition, if the government follows through with the recommendations of the taskforce to privatize the sugar mills, we might see an increase in the amounts of bagasse available.

The competing uses for bagasse include: co-firing in the sugar mills boilers, briquette manufacturers (e.g Tamua Ltd) who sell their briquettes to industries such as tea factories, British American Tobacco Kenya (BAT) and institutions. The daily residue for bagasse contains almost 50% moisture content and to make briquettes, the baggase has to be dried to 12-14% moisture content[55]. This is to mean that, the total amount produced by a mill reduces after drying and this introduces a drying cost. The other challenge with the use of briquettes produced from bagasse is the formation of clinkers (incombustible residue), which block the air, vents of the boilers (for industries) which results in inefficiencies in its operation.

2.3.2 Sawdust

Sawdust is a by-product of wood and timber industries. In Kenya, there are approximately 850 saw millers who are grouped into large-scale mill (process more than 10,000 m^3 of trees annually), medium scale millers (process 2,000 m^3 - 10,000 m^3 of trees annually) and small-scale miller (process less than 2,000m^3 of trees annually). The small-scale millers form the largest group accounting for 77% of the saw millers. The small and medium scale saw millers in the country are spread out within the central, rift and western regions. Most of the millers obtain their trees from government forests in which the Kenya Forest Service provides guidelines for exploitation of the raw material[56]. Briquette producers can source the raw materials from three main points (timber yards, furniture shops and saw-millers). Key informant interviews with the suppliers of saw millers were held and the information gathered discussed below.

[54] Soko Directory. (2020). March Monthly Report. Retrieved from https://sokodirectory.com/wp-content/uploads/2020/03/March-Soko-Monthly-Report-1.pdf

[55] KICIC. (2017). Sugarcane Bagasse as an Alternative Renewable Energy Solution. Retrieved from https://www.kenyacic.org/news/sugarcane-bagasse-alternative-renewable-energy-solution

[56] Ototo., G. and Vlosky.(2018). Overview of the Forest Sector in Kenya. Forest Products Journal 68(1):6-14; DOI: 10.13073/0015-7473.68.1.4

Furniture shop

One source of sawdust is furniture workshops in urban areas. Ngong Road furniture hub in Nairobi County was visited. This is because the sawdust quantities in a furniture hub are higher compared to stand-alone furniture workshops. Four suppliers of sawdust were identified in this production hub. They collect the sawdust from the furniture shop and accumulate it along the road. Figure 6 below shows the sawdust accumulated.

Figure 6: Sawdust from a furniture production hub

They collect two types of waste from furniture workshops: fine sawdust and wood shavings. The wood shavings are more preferred for poultry farming. In a week, they can collect 20 bags of sawdust, each 20 kgs. In a typical week, the 4 suppliers accumulate approximately 1,600 kgs (20 bags x 20 kgs per bag x 4 suppliers) of sawdust. This is sold to customers on a first come basis. Each bag of 20kg is sold for KES 150. The sawdust is sold to briquette producers, hotels within the vicinity to add to the charcoal stoves for heat retention and poultry farmers. These quantities however, are quite low considering large-scale production of briquettes. Availability is also highly uncertain as it is sold on a first come basis. The status and performance of the business also has an impact on the amounts generated i.e. when business is low less furniture will be made and therefore low quantities of the sawdust and vice versa.

Timber Yard

A timber yard in Kawagware area (Nairobi County) was visited. In a week, they can collect 5-10 bags, each 50kgs which sums up to 250-500 kgs in total. A bag goes for KES 150. They sell on a first come basis. Some of their customers include households who use it as a fuel, farmers who use it as mulch and animal bedding and hotels as floor covering and a heat insulator for the charcoal stoves

Saw-millers

Figure 7: Sawdust at a timber yard in Kawagware

In terms of actual amounts available, large and medium scale (e.g. Comply and Raiply) millers are not potential suppliers as they use their sawdust to heat boilers, make plywood, poles and particleboards. The focus is more on the small-scale millers who are spread out within the central, rift and western regions. Key informant interviews with sawdust suppliers were carried out with two suppliers located in Iten (Elgeyo Marakwet County) and Nakuru town. From the information gathered, it is clear that it is difficult to estimate the exact amount of sawdust at a given time. Unlike in the past where the sawdust was abandoned in heaps, currently sawdust has multiple uses and therefore less amounts are readily available. Most of the suppliers have established customers such as Bidco Oil refineries in Nakuru and Thika and briquette producers. Some of these customers pre-pay for the sawdust as a way of securing supply. The available sawdust is sold on a first come basis. Milling in the area has also been affected by the closure of the forests after the government issued a logging ban in 2019 (this is elaborated further in the section below). It is estimated that on a typical day a saw miller can produce up to 30 tonnes of sawdust. However, since the closure of the forests, the highest that can be achieved is 10 tonnes per day. The supplier at Nakuru estimates that there are approximately 50 saw millers in his area of operation with the assumption that each mill 10-30 tonnes a day, the sawdust generated is estimated at 500- 1,500 tonnes per day. The supplier at Iten estimates that in a day he can collect up to 100 tonnes of sawdust. The cost of sawdust is determined by the moisture content of the waste. The typical moisture content for sawdust is 30-40 % immediately after milling. This is sold at KES 3,000 per tonne. If the sawdust is dried, the cost doubles to KES 6,000 per tonnes.

For sourcing of sawdust by the briquette producers, it is recommended that they identify a broker[57] who will be mandated with collecting the sawdust from the various saw millers. This is seen as more efficient approach as the brokers are well versed with the dynamics of sawdust availability in their area of operation. This saves time compared to collecting the sawdust from multiple saw millers. In addition, brokers are able to arrange for transportation of the sawdust that is more affordable (e.g. use of trucks that have no load on their return trip) than if, the producer was to arrange for the transport. It is also advisable that the production site be closer to the sawdust since, the farther you are from the raw materials, the higher the transportation cost. For example, transporting 7- 10 tonnes of sawdust to Nairobi could cost KES 8,000 (if you identify a return truck for transporting goods) and can be as high as KES 20,000 if a truck is hired just to transport the sawdust.

Factors affecting availability of sawdust

The government from time to time issues a ban on logging due to over-exploitation of the forest or in instances when the rate of reforestation is slow. For example, in 1982 a ban was given on the exploitation of Camphor Wood, this was followed by a ban on exportation of indigenous timber in 1984 and in 1985 a ban was extended on exploitation of all timber unless the Office of the President issued special clearance[58]. Another ban on logging was issued from 1999 to 2012 and it resulted in a sharp decline in saw milling in the country. In February 2018, a 90-day ban on logging was imposed on public and community forests to curb the water shortage that the country was experiencing due to decrease in water level in rivers[59]. After expiry of the 90 days, the ban was extended to 6 months and after the 6 months it was further extended for another 12 months. This is aimed to help the country meet the 10% forest cover target by 2022. This on and off bans on harvesting trees from the community and public forests have a great impact on the total amounts of sawdust available. To address the deficit created by the ban, the government removed the 10% import duty imposed on imported raw timber[60]. Another contributor to reduced amounts of sawdust is the push by the government for millers to use wood mizer[61] in their milling process, which is more efficient than the chain saw, and the circular bench saw and therefore produces very little sawdust.

Sawdust is a good briquette material because it contains a high proportion of lignin, which acts as a natural binder during the pressing process resulting to dense briquettes. Sawdust briquettes are preferred to other types of briquettes because they have high energy density, burn for a long time, less costly and produce less ash content[62].

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[57] A broker is an individual or firm that charges a fee or commission for executing buy and sell orders submitted by an investor (definition by investopidia).

[58] George M. Muthike, M., G, Shitanda., D., and Kanali., C., L. and Muisu, F, N. (2010). Chainsaw Milling in Kenya. ETFRN News 52: December 2010.

[59] Ministry of Environment and Forestry. (nd). Government Suspends Logging as Country faces water crisis. http://www.environment.go.ke/?p=4598

[60] ALN.Key highlights of the 2019-2020 National Budget Statement. Retrieved from https://www.africalegalnetwork.com/legal-alert-key-highlights-2019-2020-national-budget-statement/

[61] Government of Kenya. (2016). Forest Conservation and Management Act 2016. Nairobi: Kenya

[62] Ajibade, F., O. Lasisi, H.,K. and Babatola. (2017). Production of Sawdust Briquettes as Alternative Household Fuel Using Water and Cow Dung as Binders. African Journal of Renewable and Alternative Energy.

2.3.3 Charcoal dust

Briquette enterprises in urban and peri-urban areas (mostly small-scale manufacturers with exemption of Chardust Ltd) use this waste as a raw material because it is readily available, it is already carbonized, could complement charcoal if a good quality binder and mixed in the right ration is used[63] and is low cost compared to sawdust and bagasse. To help estimate the quantities available for charcoal dust, charcoal venders in Nairobi were interviewed. One of the charcoal vendors interviewed is based in parklands area where they sell on retail and wholesale (see Figure 8).

Figure 8: Charcoal distributor in Parklands area in Nairobi County

Although, there exists large quantities of charcoal being sold in these locations, charcoal dust quantities remain limited. This is because the charcoal is sold in wholesale and is delivered for distribution when it is already packed in sacks as shown in the figure above. The charcoal dust they collect is from the charcoal sold on retail is not much. They have a briquette producer who collects this waste but would be willing to sell on a first come basis. This is also because the city council fines them if they find the charcoal dust accumulated on their site[64]. A sack of charcoal dust of about 50 Kgs goes for KES 300 or KES 400 depending on the vendor. The maximum they can accumulate in a week is five sacks (50 Kg) of charcoal dust. However, this is not always the case as some charcoal may have limited or no charcoal dust at the point of delivery. Charcoal with low quantities of charcoal dust is preferred by both vendors and final consumers as it has less waste.

[63]Tanui, J.K., Kioni, P.N., Kariuki, P.N. et al. (2018). Influence of processing conditions on the quality of briquettes produced by recycling charcoal dust. *International Journal for Energy Environment and Engineering 9*, 341–350. https://doi.org/10.1007/s40095-018-0275-7

[64] Information gathered from a charcoal vendor in Parkland area in Nairobi

The second type of charcoal vendors visited are the small-scale traders who sell the charcoal on retail (see Figure 9 below). From the information gathered, it is difficult to accumulate one sack of charcoal dust in a week. Each sack is sold at KES 350.

Figure 9: Small-scale vendors of charcoal

Charcoal dust although available, is highly decentralized. While the number of charcoal vendors may be high, the quantities available per charcoal vendor are limited. It would be ideal for small-scale production of briquettes, where the briquette producer identifies the main suppliers of the charcoal dust within the vicinity of the business. Reliability of the raw material is highly uncertain, as there are cases where the charcoal may have limited or no charcoal dust at the point of delivery.

Issues associated with the use of charcoal dust as briquetting material

From an environmental point of view, charcoal briquettes are viewed as additional fuel, which slows down the rate of deforestation and reduces the Greenhouse Gas Emissions (GHGs)[65]. Although this is contrasted with the fact that most of the charcoal dust in Kenya is from unsustainable charcoal production[66]. It can also be argued that in the absence of charcoal (which the charcoal briquettes are aiming to displace) then there will be no raw material for the briquettes. However, if the goal is for the two types of fuel to complement each other, charcoal is produced sustainably and with the expectation that biomass will be the primary source of energy in Sub-Saharan Africa for several years to come[67] then charcoal briquettes could provide additional fuel to the energy mix at a household level. Availability of the waste is affected by the on-and-off bans in the production of charcoal and logging bans. For example, in 2018 there was a ban on charcoal production in the charcoal production hotspot counties due to environmental degradation[68].

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[65]Njenga., M.Yonemitsu.,A. and Karanja.,Nancy. (2014). Implications of Charcoal Briquette Produced by Local Communities on Livelihoods and Environment in Nairobi- Kenya. Journal of Cleaner Production: 10.14710/ijred.2.1.19-29

[66] Ngusale, G. (2014). Briquette making in Kenya: Nairobi and peri-urban areas Renewable and Sustainable Energy Reviews 40:749-759. Retrieved from https://www.researchgate.net/deref/http%3A%2F%2Fdx.doi.org%2F10.1016%2Fj.rser.2014.07.206

[67] Gitau, J.K, Mutune, J., Sundberg, C., Mendum, R., and Njenga, M.(2019). Implications on Livelihoods and the Environment of Uptake of Gasifier Cook Stoves among Kenya's Rural Households. Applied Sciences, 9, 1205.doi:10.3390/app9061205

[68] The conversation. (2018). Banning charcoal isn't the way to go. Kenya should make it sustainable.
https://theconversation.com/banning-charcoal-isnt-the-way-to-go-kenya-should-make-it-sustainable-95610

2.3.4 Municipal Solid Waste

Municipal waste that can be used for the manufacturing of briquette include organic waste (vegetables, legumes, tubers, grains, fruits, and other biodegradable materials), bio-degradable paper, plastic and human waste (faecal matter).The sources of these wastes include households, small food stalls, markets, restaurants, institutions (schools, offices etc) among others. Presently, wastepaper is the most commonly used waste stream for briquetting. However, to maximize the potential of municipal waste for briquetting (wastepaper, organic waste and faecal matter) is blended with other types of biomass wastes in the form of carbonized rice husk, sawdust etc. The mixing of these materials in different ratios will yield briquettes of different quality. Briquettes mixed in the following proportions: Paper Briquette 1 (100%); Briquette 2 Paper (50%) and Sawdust (50%); Briquette 3 Paper (50%); Sawdust (25%) and Carbonized rice husks (25%) yield characteristics as indicated in Table 10[69].

Table 10: Quality of briquettes produced from varied mixture proportions of wastepaper, sawdust and carbonized rice husk

#	Parameters Measured	Briquette 1	Briquette 2	Briquette 3
1	Heating value (MJ/kg)	15.01	16.68	13.69
2	Ash Yield (% dm)	21.0	14.6	31.0
3	Moisture (%)	5.6	7.1	5.8
4	Bulk Density (kg/m^3)	485.41	390.06	459.01

It should be noted that briquettes require a heating value of about 11.66 MJ/kg to sustain combustion.

Other biomass raw materials and mixing ratios currently used in Kenya include: charcoal dust and waste paper (2:1); Sawdust, coffee husks (2:1) with waste paper as the binder; sawdust, char dust, waste paper, wood shavings (no particular ratio) and waste paper, clay, and sawdust (sawdust to clay 4:1) with waste paper as the binder[70].

Vegetable market waste (organic waste) has also been used as a raw material for briquetting. Vegetable market waste has a high initial moisture content and would need drying and size reduction to be suitable for briquetting. Different types of vegetable waste have varying calorific values. A study[71] of briquetting from four food wastes i.e. cauliflower/cabbage leaves, coriander stalks and leaves, field beans and green pea pods indicated calorific values ranging from 10.26 – 16.60 MJ/kg, the calorific value, bulk density and ash content for the individual feedstocks are indicated in **Error! Reference source not found.**. Additionally, the feedstock did not require binding m aterial.

[69] ibid

[70] Ngusale G., Luo Y., and Kiplagat J.K., (2014). Briquette making in Kenya: Nairobi and peri-urban areas. *Renewable and Sustainable Energy Reviews 40 749-759*.

[71]

Table 11: Quality of Briquettes produced from dried and powered vegetable feedstocks

#	Parameters Measured	Cauliflower	Coriander Stalk	Field Beans	Green Pea
1	Heating Value (MJ/kg)	12.39	13.70	16.60	10.26
2	Ash content (% db)*	18.15	3.47	4.22	6.27
3	Bulk Density	509	747	685	557

***physical characteristic of the dried vegetable market wastes powder.**

Plastics may also be used in combination with biomass to increase the calorific value of briquettes. A combination of sawdust, waste from electrical and electronic equipment (WEEE) i.e. halogen free wire and print circuit board (PCB) and automotive shredder residue (ASR) residues from end of life vehicles were used to make briquettes through varied waste proportion, pressure and temperature. The net calorific value of briquettes produced ranged from 16.6 – 18.9 MJ/kg. It was noted the use of sawdust and PCB yielded consistently higher calorific value of 18.9 MJ/kg[72] Table 12.

Table 12: Net Calorific Values of briquettes formed from varying mixtures of sawdust, ASR, and halogen free wire

#	% Biomass	% Waste	Net Calorific Value (MJ/kg)
1	90% sawdust	10% Wire	18.2
2	80% sawdust	20% Wire	17.5
3	70% sawdust	30% Wire	16.8
4	90% sawdust	10% ASR	18.9
5	80% sawdust	20% ASR	18.9
6	70% sawdust	30% ASR	18.9
7	90% sawdust	10% PCB	18.1
8	80% Sawdust	20% PCB	18.9
9	70% Sawdust	30% PCB	16.6

Other studies highlight the potential of mixed plastic waste mixed with corn stover. The mixed plastics were obtained from a dumpsite and the corn stover was obtained from the field after a harvest season. The briquettes from corn stover (100%) were compared to a mixture of plastics (55%) and corn stover (45%), the calorific value of corn stover ranged between 15.64 -16.60 MJ/kg, carbon content 52.17 – 53.72 % and ash content 8 – 9% while the mixture briquettes had a calorific value of 26.4 -28.9 MJ/kg (as high as charcoal Table 4), carbon content 82.83 – 86.65 %, moisture and ash content of 6.10 – 7.02 %[73]. It should however be noted that burning of plastic emits toxic fumes, making them not ideal for briquette production.

[72] Garrido M.A., Conesa J.A., and Garcia M.D. (2017). Characterization and Production of Fuel Briquettes Made from Biomass and Plastic Wastes. *Energies 10,850*.

[73] Auprakul U., Promwungkwa A., Tippayawong N., and Chaiklangumauang S. (2014). Densified Fuels from Mixed Plastic Wastes and Corn Stover. *Advanced Materials Research Vols. 931-932, pp 1117-1121.*

Although both the organic and non-organic fractions of solid waste can be utilized for production of briquettes, the organic fraction, which will be referred to as biowaste, is recommended. Biowaste is mainly comprised of kitchen waste (food scraps and peeling residues), market and yard waste, wood residues and food processing residues. Burning plastic in open systems, where emissions are not captured or treated, as observed during cooking will lead to the increase of household and ambient air pollution for domestic and industrial settings, respectively. For this reason, plastics were not considered as a suitable waste for briquette production.

Challenges in the utilization of municipal waste for briquette production

One of the main challenges at present is obtaining non-contaminated biowaste feedstock from municipal solid waste. Contamination of domestic waste in developing countries arises from the lack of sorting and segregation at source. The use of biowaste from domestic sources for briquetting will therefore need to take into consideration sorting machinery into desirable fractions or training and equipping personnel to separate waste. Additionally, this waste will include both raw and cooked leftovers. The latter is unsuitable for briquetting due to low calorific value. Although the raw material cost is lower than other feedstocks such as macadamia shells or coffee husks, the cost of treatment and processing of waste before use should not be overlooked.

Alternatively, sourcing of organic waste can be done directly from homogenous sources such as open markets such as Marikiti in Nairobi and Kongowea in Mombasa among others. A comparison of the physical-chemical properties of specific fraction biowaste – market / yard waste and organic domestic waste is indicated in Table 13.

Table 13: Physical and Chemical Characteristics of Biowaste Fractions[74]

#	Feedstock	Moisture (wt%)	Ash (wt%)	Volatile (wt%)	Fixed Carbon (wt %)
1	Yard and Market Waste (municipal)	22.3	25.9	87.2	12.8
2	Organic Domestic Waste	63.1	37.0	83.1	16.9

The moisture content of domestic organic waste (63.1%) is almost thrice that of organic fraction from market and yard sources. The higher moisture content will require additional drying to reduce content to an optimum of 10-14%.

It should be noted that the market waste would vary depending on the specific dietary patterns of a region. A report on the retail vegetable vendors in Kenya, indicated that at least 90% of retail vendors experience vegetable waste either while receiving / sorting vegetables from suppliers or waste on the shelf[75]. Therefore, waste can be "intercepted" at different stages of the value chain. Either before sale to a retail seller (from supplier) or waste not purchased by retail customer (from seller). The wastage from shelf was higher than that of receiving and sorting. The retailers highlighted five vegetables with the most wastage: potatoes peelings, tomatoes, snow peas, French beans and sugar snaps. Further assessment of the physical-chemical properties of the individual components of market waste are included in Table 11.

[74] Lohri, C., R., Rajabu, H., Sweeney, D., J., and Zurbrugg, C., (2016). Char fuel production in developing countries – A review of urban biowaste carbonization. Renewable and Sustainable Energy Reviews, 59, 1514 -1530. https://doi.org/10.1016/j.rser.2016.01.088

[75] Ibid

Another hurdle in obtaining adequate resource is other competing uses of the waste. Waste paper has a robust recycling system, which limits the availability of the raw material. Organic waste recovery through composting and gasification is a focal point of implementation in the integrated solid waste management plan of Nairobi. Vegetable waste from markets or groceries *kiosks* in low income areas are used as animal feed (e.g pig food). Large-scale projects on waste management such as that being implemented by ASTICOM K Ltd and the plans by KenGen and Nairobi City Council on generating electricity from garbage pose a threat to availability of municipal solid waste.

2.3.5 Faecal Waste

Faecal matter was assessed as a raw material for briquette production. As highlighted earlier, faecal sludge has moisture content of 80-97 %, ash content of 38.40-57% and a calorific value of 13MJ/kg. The sludge contains high amounts of pathogens such as bacteria and other disease-causing microorganisms including Salmonella, Shigealla, Escherichia coli (E. coli), Ascaris Lumbricoides and Sclustosoma mansonic eggs[76]. Due to the high amounts of pathogens, the sludge has to be pre-treated before briquetting. This is done through carbonization of the dried sludge in temperature of between 450^0C-600^0C[77] (using a carbonization oil drum or furnace). Carbonization is also carried out to increase the fixed carbon of the raw material, which then increases the calorific value of the resulting feedstock. Due to the high moisture content, advanced drying methods such as the use of greenhouse is recommended. The sludge is channelled to the greenhouse drying beds and left for 1-3 days. Due to its high ash content, the faecal sludge is blended with other types of biomass. A study by Nawasscoal concluded that blending faecal sludge with sawdust at a ratio of 50:50 produced a briquette with a calorific value of 18.8 MJ/kg, which is above the minimum recommended value for briquettes (17.5 MJ/kg). The use of the faecal sludge for briquette production is viewed as a solution to the challenge of sanitation in urban areas and a source of alternative cooking solution for low-income households.

The faecal sludge can be obtained from water and sewerage companies in the main cities such as Nairobi City Water and Sewerage Company (NCWSC), which collect faecal sludge from households connected to the company's sewer system. NCWSC strategic plan for 2018/2019 aimed to collect, convey, treat and dispose 400,000 M^3 /day of wastewater in an environmentally friendly manner[78]. Sludge from households is the most suitable as it is not contaminated with heavy metals as is the case for industrial sludge. The sludge can also be collected from septic tanks and pit latrines in urban areas and delivered to the briquette production site using bowsers.

In the recent past, briquette producers have been exploring the use of faecal waste for production of briquettes. Sanivation Limited has been producing briquettes from faecal matter for household uses in Kakuma refugee camp and low-income areas of Naivasha. Nakuru Water and Sanitation Services Company is involved in faecal sludge management through its subsidiary company Nawasscoal that produces carbonized briquettes for household and small enterprises consumption.

Challenges in the use of faecal matter for briquetting

[76] D. M. Nyaanga, P. A. Kabok, J. Mbuba, S. O. Abich., R. Eppinga and J. Irungu. (2018). Faecal matter--saw dust composite briquette and pellet fuels: production and characteristics. Transformation Towards Sustainable and Resilient Wash Services: 41st WEDC International Conference, Egerton University, Nakuru, Kenya, 2018

[77] Ibid

[78] Nairobi City Water and Sewerage Company Limited. (2014). Strategic Plan 2014/15 – 2018/19. Retrieved from https://www.nairobiwater.co.ke/images/strategic_plan/NCWSC_2014-15_to_2018-19_Strategic_Plan.pdf

Faecal sludge must be blended with other carbonized biomass to produce briquettes of desirable quantities. Examples include use of charcoal dust and sawdust whose availability is not reliable due to on-and-off bans on charcoal production and logging in Kenya and the competing uses for the sawdust. However, further research is recommended on conversion of other types of biomass (e.g bagasse) into charcoal dust to be used together with the sludge for briquette production.
Another challenges with the use of faecal sludge for briquette production is people's perception on using briquettes made from faecal matter for cooking. Most communities consider this to be a taboo. However, this can be addressed by extensive awareness creation, demonstrations on the use of the fuel and households sampling the briquettes. Having a KEBs label of quality may also aid in gaining consumer confidence.
In addition to business permits, the briquette producer has to acquire public health permits on handling of faecal matter. The testing of briquettes must also include the testing for pathogens, which is a more elaborate than testing for briquette properties (ash content, moisture content etc). In case the briquette producer decides to acquire the sludge from Water and Sewerage Company then these companies must be willing to form partnerships. If they are unwilling, the raw material may have to be sourced from households.

3 Comparative Analysis of the selected raw materials

This section of the report aims to compare the five types of raw materials discussed above and identify the most suitable raw material for briquetting. Several factors were considered in determining the most suitable raw material. For example, is the aim to produce carbonized or non-carbonized briquettes? Is it large-scale or small-scale production of briquettes? If the aim is to produce carbonized briquettes, then raw materials that are already carbonized rank highest (e.g. charcoal dust). If the material has to be carbonized then the raw materials that are in large quantities and low in cost are preferred as almost 70% of the raw –material will be lost during the carbonization process. In regards to the scale of production, large-scale production of briquettes requires a raw material that is available in large quantities and in a central location.
In comparing the raw materials, it is clear for all the five feedstocks assessed, their calorific value falls within the desired range for briquette production. Additionally, for carbonized briquettes, the calorific value of the raw material is improved through the process of carbonization. Therefore, the calorific value of the raw material was not a key factor for consideration when assessing the most suitable raw material for briquetting. The selection of the suitable material was mainly centred on quantities available and the cost of the raw material. Charcoal dust is a suitable material for producing carbonized briquettes as it is already carbonized. However, its availability to a large extent is decentralized. From the data collected, most of the charcoal vendors are small-scale traders and collecting a sack (50 Kg) of charcoal dust in a week is already a challenge. For the wholesalers of charcoal, the charcoal packed from source and therefore have limited charcoal dust to sell. From the vendors interviewed, the maximum they can gather in a week is five sacks (50 Kgs). This means the producer will have to identify several charcoal vendors for the supply of the charcoal dust.

Sawdust quantities when compared with other raw materials such as bagasse and faecal waste was found to be limited. This is especially the case if it is sourced from timber yards or furniture shops. Moreover, if the aim is to produce carbonized briquettes, then approximately 70% of the waste will be lost through the carbonization process. This is costly for the producer considering the cost of the sawdust per tonne (KES 3,000-6,000). The remaining two raw materials, faecal matter and bagasse are available in large quantities. They can also be sourced from a central location. Bagasse is not only centrally located (from sugar mills), it is also cost-friendly compared to the sawdust. Depending on the supplier and the agreement between the briquette producer and the sugar mill, the bagasse can be obtained at no cost or cost ranging from 100-600 per tonne. Faecal matter is also available in large quantities but other factors such as collecting the sludge from homes or forming a partnerships with the Water and Sewerage Companies come into play. The need to acquire permits to handle the faecal matter and extensive testing can significantly raise the capital requirement for the production of briquettes which maybe a constrain for a start-up. The other challenge with faecal matter is that it has to be blended with another type of biomass. Factors affecting the selected material to be blended with the faecal matter must also be considered when evaluating faecal matter as a potential feedstock. Other factors to consider are competing uses of the faecal waste that might be more economically viable than the production of briquettes, for example, organic fertilizer. Organic waste for briquette production has to be carbonized especially if the aim is to make household briquettes. This reduces the quantities greatly. Organic waste is also a preferred animal feed for pigs, which further reduces the quantities of waste available. For carbonized briquettes, charcoal dust is ranked as the first option but only for small-scale production of briquettes.

For large-scale production of carbonized briquettes, bagasse is ranked as the first option due to the large quantities available and relatively low cost and low investment compared to the use of faecal matter. Faecal matter is ranked as the second option given the need for preparation before use and organic matter is ranked as the last option mainly because the investment required in terms of collection of the waste, sorting and drying of the waste before briquetting may prove to be economically unviable compared to other uses such as animal feed where no processing of the waste is required.

For the production of non-carbonized briquettes, faecal waste and organic waste were not considered. This is mainly because, the faecal matter must be treated (mainly through carbonization) and thus is more suited for carbonized briquettes. Organic waste was omitted due to the reasons discussed above. Two raw materials are considered for the production of non-carbonized briquettes: sawdust and bagasse. The downside of using bagasse to sawdust is the high moisture content of 50% and the formation of the clinkers (incombustible residue resulting from the burning of bagasse briquette). The moisture content of sawdust is between 30-40% at the point of milling. However, in terms of quantities available and cost, bagasse is more preferred. The difference in moisture content is also not a wide range and therefore for both sawdust and bagasse the producer will have to invest in drying techniques. For the formation of clinkers, the boilers can be retrofitted to address this challenge of using bagasse briquettes. The use of bagasse is still ranked as the most preferred raw material for the production of non-carbonized briquettes especially for large-scale production of briquettes. Sawdust is ranked as the second most suitable raw material mainly due to the cost and the quantities available. Table 14 below compares the five raw materials.

Table 14: Comparison of the waste

#	Raw material	Advantages	Disadvantages
1.	Bagasse	- Available in large quantities (for 2019, 1,611,011 tonnes of briquettes were produced) - Available in central locations - Cost is relatively low compared to other types of raw materials (KES 0-600 per tonne)	- High moisture content - Formation of clinkers
2.	Sawdust	- A preferred raw material for non-carbonized briquettes due to high levels of lignin thus allowing proper compacting - It can be used as an additional raw material to other types of feedstock e.g. faecal matter	- High cost ranging between KES 3,000-6,000 per tonne - Requires drying before use - Availability of the raw material is not reliable due to high competing uses and restrictions such as bans on logging.
3.	Charcoal dust	- Recommended for carbonized briquettes as it is already carbonized. - No drying is required unless the charcoal dust has been exposed to environmental elements such as precipitation	- The quantities are to large extent decentralized. A producer would be required to identify multiple charcoal vendors to obtain the desired quantities. - Availability is not reliable as some charcoal maybe delivered with low quantities of charcoal dust

		- Ideal for small scale producers of briquettes	- Availability may be affected by charcoal bans that are issued from time to time
4.	Faecal matter	- Available in large quantities and in centralized locations	- Capital intensive, in regards to drying techniques (98% moisture content), carbonization (treatment of the waste), testing of the briquettes for presence of pathogens - Negative perception from potential users towards use of briquettes made from human waste. - Faecal matter has to be blended with other raw materials such as carbonized sawdust, which also adds to the cost of production.
5.	Organic waste	- Contributes to cleaner environments	- Lack of sorting of waste at the household level makes it difficult to have a homogenous waste, and therefore investment in sorting techniques have to be considered - High moisture content also requires investment into a drying method - Organic waste would require carbonization if the briquettes are for household use, which greatly affects the availability of the quantities available - Use of the waste as compost or as an animal feed may be more economical than the heavy investment required for briquette production

Based on the discussion above, the five raw materials are ranked as shown in Table 15 below. From the most to least suitable material for carbonized briquettes. For non-carbonized briquettes, the choice is between sawdust and bagasse and bagasse ranked first as the most suitable raw material because of its availability in large volumes, low cost and the centrality (large volumes in sugar mills).

Table 15: Ranking of the raw material for production of carbonized briquettes

#	Feedstock	Rank
A	Charcoal dust	1
B	Bagasse	2
C	Faecal matter + sawdust	3
D	Sawdust	4
E	Organic water	5

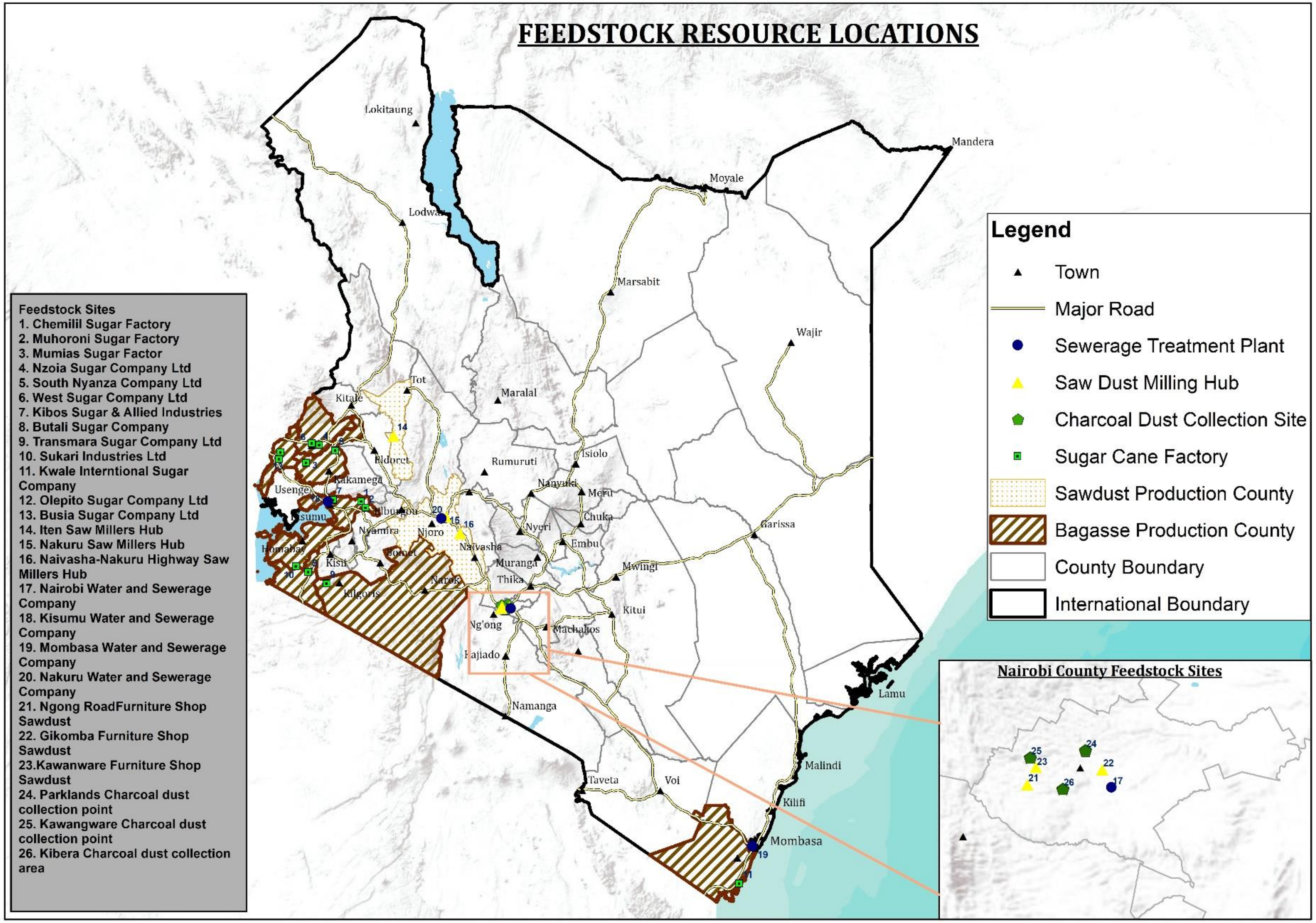

Figure 10: Potential Sources of Briquette Feedstock in Kenya

3.1 Conclusion

Kenya has a considerable number of feedstocks from municipal waste, agricultural residues and forest residue that can be used for briquette production. However, the selection of a suitable feedstock is largely governed by the following key factors: quantities available, quality and cost of raw materials. The process of identifying the most suitable raw material for briquette production commenced with a list of 28 potential wastes for briquette production. Each waste was subjected to an evaluation criterion that was guided by the following factors; (i) quantities available against competing uses, seasonality and ability to congregate the waste in a central location; (ii) quality of waste where the key factors include ash content, moisture content and calorific value and; (iii) cost of the raw material. Using these factors as the guiding principle, five types of waste were considered for further analysis. These are: bagasse, sawdust, organic waste, charcoal dust and faecal matter.

Ideally, the most suitable raw material for briquette production should be available in large quantities, ease of collection i.e. large quantities in a central location, cost of the raw material and level of investment for the waste (cost of the feedstock and pre-processing of the waste). Bagasse was found to tick most of these boxes. Sawdust although a good briquetting material for non-carbonized briquettes, the supply is limited compared to bagasse as well as its cost is relatively high. Use of sawdust for producing carbonized briquettes was found not to be economically viable, because of the losses of the raw material during the carbonization process or thermal decomposition. Charcoal dust is an ideal raw material for the production of carbonized briquettes but it is difficult to obtain large quantities of the waste at a central location. Therefore, it is recommended for small-scale producers of briquettes.

Faecal matter is available in large quantities. The downside is that it has to be blended with another type of raw material; the level of investment is also high. Several challenges would need to be addressed with regard to the use of organic matter. Household waste would be ideal but in Kenya, waste is not sorted at the household level. In that case, the producer must be ready to invest in the sorting of the waste. Market places can be sources of the homogenous waste but factoring in the level of investment required and other competing uses make it not economically viable for briquette production.

ANNEXES

ANNEX 1: KII Guide for potential suppliers of briquetting materials

<table>
<tr><th colspan="3">A. SUPPLIER IDENTIFICATION</th></tr>
<tr><td>1.</td><td>Name of the company(if in an informal location state source of the feedstock e.g Kawagware market)</td><td></td></tr>
<tr><td>2.</td><td>State the location of the main office (Town):</td><td></td></tr>
<tr><td>3.</td><td>Respondent Name:</td><td></td></tr>
<tr><th colspan="3">B. FEEDSTOCK RESOURCE ASSESSMENT</th></tr>
<tr><td>1.</td><td>What are the types of biomass residue produced on your site?</td><td>A. Bagasse
B. Coconut husk/shell
C. Coffee husk
D. Cotton stalk
E. Macadamia nutshell
F. Maize cob/stalk
G. Pineapple pulp
H. Rice husk/straw
I. Sawdust
J. Flower stalk
K. Wheat straw
L. Sisal boles/waste
M. Cassava stalks
N. Cashew nutshell
O. Millet stalks
P. Other</td></tr>
<tr><td>2.</td><td>Please estimate the monthly production for each of the biomass residue identified above (Q 1)</td><td><table><tr><th>Month</th><th>Tonnes</th></tr><tr><td>January</td><td></td></tr><tr><td>Feb</td><td></td></tr><tr><td>March</td><td></td></tr><tr><td>April</td><td></td></tr><tr><td>May</td><td></td></tr><tr><td>June</td><td></td></tr><tr><td>July</td><td></td></tr><tr><td>Aug</td><td></td></tr><tr><td>Sept</td><td></td></tr><tr><td>Oct</td><td></td></tr><tr><td>Nov</td><td></td></tr><tr><td>Dec</td><td></td></tr></table></td></tr>
<tr><th colspan="3">C. BIOMASS SALE ASSESSMENT</th></tr>
<tr><td>1.</td><td>How do you dispose/utilize MOST of the biomass waste generated?</td><td>A. Use it
B. Sell it
C. Dispose through a company/individual (at no cost)
D. Left on growing Sites
E. Burn it</td></tr>
</table>

<table>
<tr><td>2.</td><td>If you use it, how do you use it and the estimated proportions of use?</td><td><table><tr><th>Use</th><th>Percentage (%)</th></tr><tr><td>Composting</td><td></td></tr><tr><td>Animal Feed</td><td></td></tr><tr><td>Burning</td><td></td></tr><tr><td>Energy Production</td><td></td></tr><tr><td>Mulching</td><td></td></tr><tr><td>Others, specify</td><td></td></tr></table></td></tr>
<tr><td>3.</td><td>If you dispose through a company at no cost, which companies/ individuals do the disposal? If yes C for Q C1</td><td></td></tr>
<tr><td>4.</td><td>Who are the buyers (ALL) of the biomass residue and estimated amounts in tonnes per day during the peak and low season?</td><td><table><tr><th>Company</th><th>Amounts at peak season(tonnes)</th><th>Amounts low season(tonnes)</th></tr><tr><td>Briquette manufacturers</td><td></td><td></td></tr><tr><td>Other energy generating companies (waste-energy)</td><td></td><td></td></tr><tr><td>Thermal intensive industries e.g. tea factories</td><td></td><td></td></tr><tr><td>Animal feed producers</td><td></td><td></td></tr><tr><td>Cottage industries (e.g. food kiosk)</td><td></td><td></td></tr><tr><td>Other, specify</td><td></td><td></td></tr></table></td></tr>
<tr><td>5.</td><td>What is the average price of the residue in KES per unit tonne?</td><td></td></tr>
<tr><td>6.</td><td>What is the frequency of collection of the biomass waste for the peak season?</td><td>A. Daily
B. Once a week
C. Twice a week
D. Once a fortnight
E. Once a month
F. Other/specify</td></tr>
<tr><td>7.</td><td>What is the frequency of collection of the biomass waste for the low season?</td><td>A. Daily
B. Once a week
C. Twice a week
D. Once a fortnight
E. Once a month
F. Other/specify</td></tr>
</table>

Inventory of Raw Materials that can be used for making briquettes