XV WORLD FORESTRY CONGRESS
Building a Green, Healthy and Resilient Future with Forests
2–6 May 2022 | Coex, Seoul, Republic of Korea

An innovative approach of developing agro-industrial waste to biofuel value Chain to avoid charcoal driven deforestation in Kenya

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Abstract

We present an innovative value chain on upscaling and commercial production of carbonized bio-briquettes from agro-industrial waste (mainly a sugarcane bagasse), that aims at substituting a forest-based charcoal for household consumption and thus reduce deforestation. We demonstrate the three main pillars of the value-chain: (1). Empowering and capacity building of members of the cooperatives (mainly women), through developing technical skills, using and maintaining technologies and tools, ergonomics and safety, businesses, and marketing. (2). Innovative locally built biowaste to biofuel conversion technologies. This are technologies for raw material (biowaste) preparation (transport, drying and storage), locally developing carbonization kilns of high efficiency and commercial volume, biochar production, selection of bio-based binders, local fabrication of briquetting machines, production of briquettes, drying and storage of briquettes. This section demonstrates (using videos and pictures) on how a daily briquettes production of 3-tonnes is achieved, with briquette qualities comparable to that of wood-based charcoal. We also demonstrate production of custom-made cookstoves for briquettes by modifying existing local cookstoves. Further, we demonstrate the amount of avoided deforestation through such innovative local approaches. (3). Business and market development: This aims at bringing green-jobs to villages in sustainable supply, distribution, and sales of clean locally produced bio-briquettes. The program enables capacity building of members of the cooperatives in business and marketing, building partnership with key market segments and cooperation with private sector such as distributors, consumers, lenders, and banks. The complete value-chain is a result of a successful development and partnership program (2018-2021) supported by the government of Norway that involved Kenyan national institutions, local community cooperatives and international partners.

Keywords: Bagasse, Kenya, Briquette, Deforestation, value chain

1. Introduction, scope and main objectives

Charcoal remains the major energy source for millions of Kenyans, meeting close to 70% of household energy demand. Charcoal, although produced mainly in rural areas, is consumed in peri-urban and urban areas, involving numerous actors (wood providers, charcoal producers, transporters, wholesalers, retailers) to form a value chain. The charcoal value chain is one of the most important sources of employment, and a major source of livelihood for an estimated well over half a million people in Kenya (Kiruki et al., 2020). Consequently, charcoal production became among the major drivers of deforestation in Kenya (Kiruki et al., 2017), where annual deforestation between 2014–2017 was estimated at 10,459 ha per year (Rodriguez-Veiga et al., 2020). National as well as international efforts to reducing forest loss (UNFCCC, 2015), will not be successful unless the actual drivers of deforestation are addressed, and alternative household energy sources is made available.

On the other hand, Kenya has a large agro-industrial waste particularly sugarcane bagasse from the its network of sugar industries, which can be a potential biomass-based energy resource (Yuko, 2005). Annual bagasse production in Kenya has been between 1.5 - 2 million tonnes per year during 1990 -2017 (Kenya Statistics Bureau, 2018). Up to 60% of the bagasse produced annually is being used as a fuel within the sugar milling industry, but the remining 40% is often left to decay around the sugar factories or taken to dumping sites.

Converting sugarcane bagasse into carbonized briquettes, a value-added solid biofuel product, is a promising opportunity for increasing access to renewable energy options for rural populations, while potentially reducing unemployment. Given the availability of large amount of sugarcane bagasse, since recently there are community-based micro-and small enterprises (MSEs) in in western Kenya. Majority of the MSEs produce non-carbonized briquettes for industrial applications targeting large factories. However, the non-carbonized briquettes run in inefficient cook stoves emit smoke and are less preferable for household applications. Carbonized briquettes if produced using efficient carbonization and briquetting technologies may provide a suitable alternative to charcoal from wood for direct application as a substitute to wood charcoal for households, local enterprises, and institutions such as schools and hospitals (Brunerov et al., 2020; Lubwama and Yiga, 2017). However, there are still operational, technical, market, financial and policy barriers to develop profitable biofuel enterprises converting bagasse to carbonized briquettes.

A project, "Biofuel4Kenya" supported by the Norwegian Agency for Development Cooperation (Norad) was designed and became operational since 2017 in western Kenya. The project aims at developing a bagasse-based briquette value chain through upscaling the production of carbonized bagasse briquettes. The expected impacts were to contribute to (1) the renewable energy sector in Kenya with direct effects on the domestic energy supply to households by providing bio-briquettes for household consumption, and (2) reducing deforestation by substituting natural forest-based wood fuel and charcoal. The major challenges were lack of appropriate technology, technical skills, and markets for biochar-based briquettes. The project activities have been slowed down mainly due to COVID-19 during 2020 and parts of the year 2021. Consequently, data/information on the some of the elements in the production value chain are on preparation. Therefore, discussions presented here are based on preliminary results, pending a more detailed quantitative description to later.

2. Approach

The approach followed here is description of technical procedure and specific technical elements for a complete production line for a bagasse-based briquettes is represented by the diagram (Fig. 1). The overall value chain consists of three main packages of activities: a) capacity building of local partners and village cooperative members, b) access to production technologies, raw material, and skills, and c) business development and access to markets. This paper, however, focusses on- access to production technologies- particularly, designing and locally fabricating technologies for biomass feedstock drying, carbonization, briquetting machine, and briquette-fired cookstoves. The paper describes preliminary findings of the optimized low-tech technologies from bagasse handling to production of carbonized briquettes, to adapting charcoal cookstoves to bagasse-based briquettes. Further, a brief account will be provided on the potential socio-economic and environmental significance of the value chain if fully implemented and upscaled.

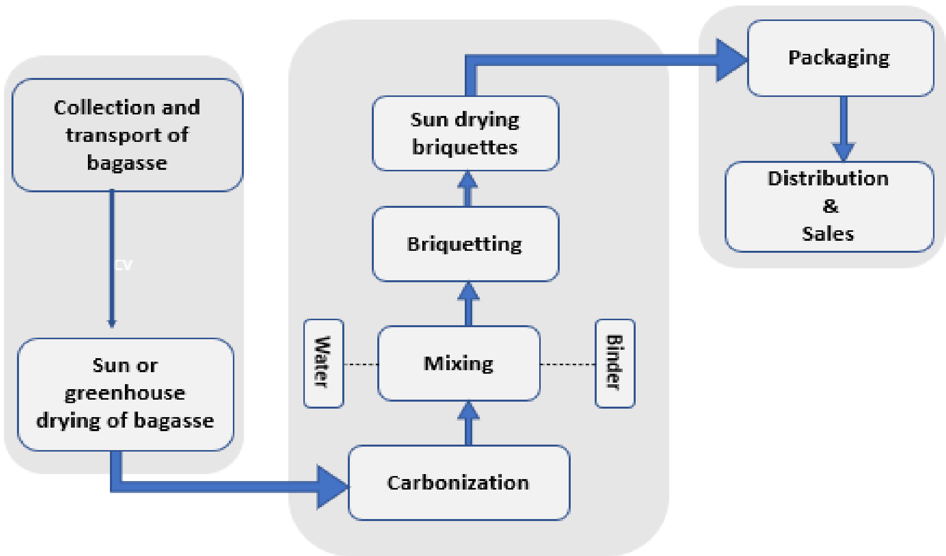

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Fig 1. Workflow diagram of for the technical activities involved in the value chain of carbonized bagasse- briquettes.

3. Results and discussion

3.1 Bagasse resources and bagasse drying

Bagasse yield per year in Kenya amounts to 1.5-2 million tonnes since 1990s (Kenya Statistics Bureau, 2018). In the sugar cane industries of Kenya, for each unit of crushed sugarcane, 0.27 tonnes of bagasse is used to produce process energy (steam and electricity) in the sugar industries (UNFCCC, 2013). This leaves a surplus of millions of tonnes of bagasse annually, which is left in the yards of the factories or dumped to landfills to decompose. We receive freshly produced bagasse at the bagasse extrusion point of the Sukari Industries LTD- the sugar milling factory. The wet bagasse at the point of collection has a moisture content of 50-60%. But biochar production requires the moisture reduced to 10 -15% (Lubwama and Yiga, 2017). In an open sun. reducing the moisture content to an optimum takes 3 - 5 days, depending on the season. To facilitate faster drying. We constructed a greenhouse provided with a wind drawn ventilators on rooftop (Fig. 1) to expel moisture.

Fig 2. Bagasse delivery near a greenhouse (left) and drying in a greenhouse (5 m x 30 m long) supplied with wind drown ventilators (Photo by Jack Ochieng).

The preliminary result shows that using greenhouse requires one full day to reduce the MC to an optimum of 10-15%. However, if a large-scale commercial production is anticipated, a much larger size greenhouse is required, which requires an additional resource (land and cost). Therefore, where sufficient land for drying is available, and if a large volume of commercial production is anticipated, an open sun drying followed by immediate carbonization is generally less costly, particularly during dry seasons. In our context, the green house is often used for the rainy days, while and open-air drying is being practiced for dry seasons.

3.2 Bagasse carbonization kilns and biochar

The purpose of carbonization is to convert waste bagasse into a carbon-rich char through a process of a slow pyrolysis. Under carbonization, the bagasse is heated in an inert atmosphere to high temperatures until volatiles are expelled, thus enriching the heating value and energy content of the resulting biproduct- biochar. For carbonization, we designed steel kilns (Fig. 1) and perform several runs of preliminary tests. We modified the traditional Top-lit Updraft Kilns (TLUD) gasifier, originally designed for wood charcoal, by Thomas Reed and the Norwegian architect Paal Wendelbo, during 1985-1988 (Anderson, 2009). A modification was needed as the bagasse requires design reconsiderations given the density and surface area that is different from that of wood. Using experience, trials and errors as well as basic scientific principles of carbonization, we incorporated an internal perforated chimney to facilitate air movement from the primary air inlets at the bottom. In the Modified TLUD (M-TLUD), bagasse will be filled from the top, just below the secondary air inlet holes. Ignition will be from the top for the carbonization to start. Air then flows in through the internal perforated chimney from primary to the secondary air inlets. We further incorporated a mechanism for easy bagasse loading from the top and char-harvesting steel box at the bottom. The technical and economic considerations in the construction of the kilns included- cost, availability of local construction material, ease of construction, speed of carbonization, ease of operation and maintenance. The result is construction of 25 units M-TLUD (Fig. 3), with a capacity of producing 120 kg of biochar each pr day using 3-4 batches of operation and bagasse to biochar efficiency of 18 - 22%. The M-TLUD kilns are easy to operate manually after a short training and easy to maintain by local workshops. The dry bagasse is then subjected to carbonization at a temperature of 250-300 ºC. The resulting biochar (see fig 4) has physical structure similar to that of dry bagasse, with a feathery dust-like structure.

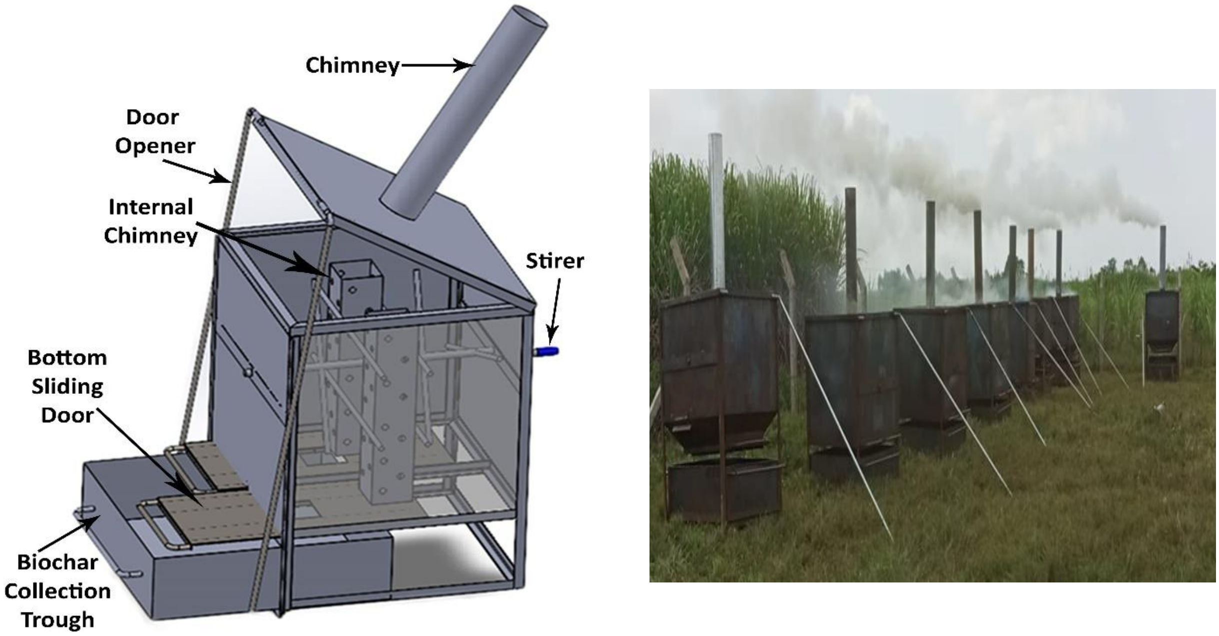

Fig.3. The schematic diagram of the modified TLUD (M-TLUD) carbonization Kiln (left panel) and series of M-TLUDS under operation (right panel). (Design and Photo by Jack Ochieng).

Fig 4. Bagasse biochar (left) and the resulting briquettes (right). (Photo: Jack Ochieng)

3.3 Briquetting machine and the briquettes

Briquetting biowaste (molding and densifying a biochar mixed with a binder into a briquette) is a common technology (Brunerov et al., 2020; Lubwama and Yiga, 2017). However, adapting to different types of raw material, biochar-binder mix and improving capacity as well as efficiency require series of testing. Furthermore, there are technical and economic considerations including cost and availability of construction material, ease of construction and maintenance by local artisans, and speed or efficiency of pressing for small scale commercial production.

We designed, constructed, and tested an extrusion screw-press type briquetting machine (Fig. 4), suitable for a small-scale commercial production, with the technical and economic considerations. The machine is provided with a slanting manual feed (hopper), switch box, a screw conveyor, bearings, couplers, gearbox, motor, pulleys and belts, screw, barrel, and extruder (see Fig 5, left panel). Power is transmitted through pulleys and belts from the motor to the gearbox which then transmits the torque to the screw. The preferred binder is a low-grade gum Arabic with an optimum ratio of 1:24 (1 Kg of gum Arabic mixed with 24 Kgs of biochar). The mix is fed manually into the slanting feeder (hopper) which feeds to a powered screw, rotating at 300 rpm using a 15-kW electric motor. the rotating screw takes the mix from the hopper and compacts it against a die which assists the build-up of a pressure gradient along the screw and extrudes a wet freshly pressed cylindrical briquette (Fig. 5 right panel). Finally, 3- of briquetting machines, with a capacity of 150-200 kgs pr hour each, were fabricated locally.

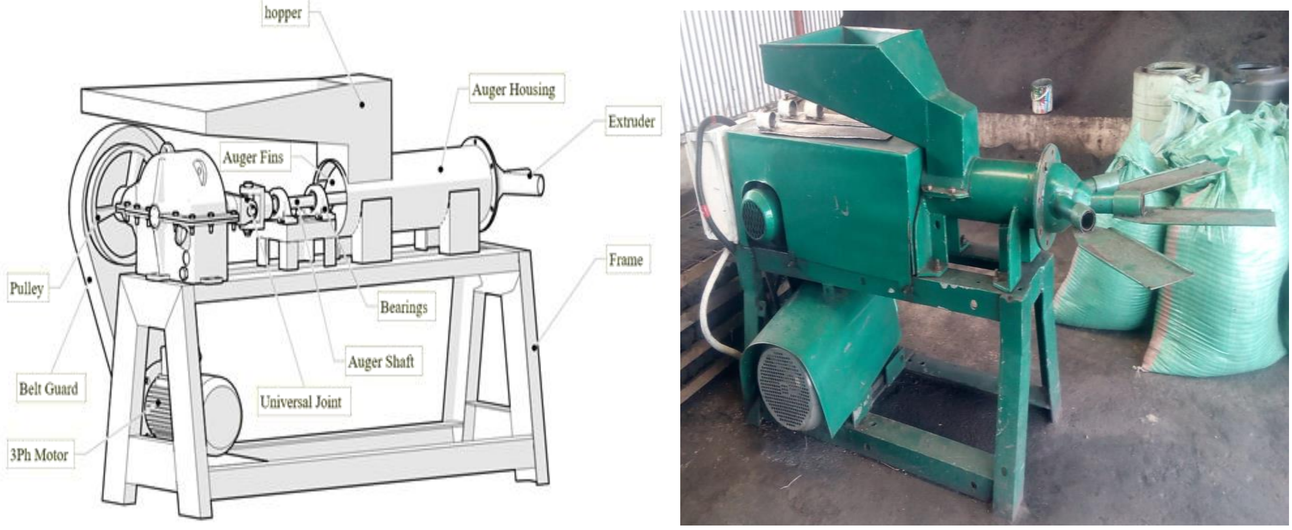

Fig 5. The schematic diagram of the basic screw-type char briquetting machine (Design and Photo by Jack Ochieng)

The produced briquettes are sun dried for a period of up to 7 days to remove the moisture, and thus to enhance ignition and the burning time. The physical and thermal properties of briquettes influence its characteristics as a fuel. The resulting carbonized briquettes produced have the average physical properties of- Fixed Carbon = 36.3%; Volatile Matter = 21%; Ash Content = 35 %; Moisture Content = 7.13%, and heating value of 16 MJ/kg. The volatile matter and moisture content are lower or comparable to the results from recent tests of briquettes originating from bagasse (Lubwama and Yiga, 2017). The ash content however is rather high, thus lowering the heating value. Increasing the carbonization temperatures and the use of mixtures of various binder proportions are among the approaches to improve the fuel quality of biochar (Manyuchi et al., 2019). These tests to reduce the ash content and improve heating values are ongoing but results not reported here.

3.4 Briquette-fired cookstoves

Wood charcoal consuming homes in Kenya commonly use the Kenya Ceramic Jiko cookstoves, most of which are designed for wood charcoal, and thus could not be used directly, because of the different physical properties such as density, ash content and calorific value of the briquettes. We modified the wood-charcoal based cookstoves and produced the first set of 20 cookstoves (Fig. 5) of which 10 were designed for households and 10 large-sized for schools and restaurants considering these characteristics. The cookstoves were distributed among rural users, along with the briquettes, both near the project sites and up-markets in western Kenya. User's opinions and rankings were collected to further modify according to opinions. Re-design and modifications were considered based on consumer ratings and opinions including briquette loading and lighting, ash storage and removal, increased air movement, and prices compared to existing wood based cookstoves. The modified stoves provided with a better air flow and ash deposit at the base were recommended for further production and distribution. Scaling up of manufacturing the modified cookstoves will follow further testing of the re-designed cookstoves, which is ongoing by the time of this report.

Fig. 5. Improved small-scale household cookstove (left) (Design and Photo by Jack Ochieng), and larger sized cookstoves for schools and restaurants, right (Design and Photo: Peter Ogutu,).

4. The socio-economic and environmental significance

Members of three independent cooperatives, with 40-60 members each were, were involved from project inception to the progress thus far. Short term, practical, technical, and business management training were conducted in cooperative governance and management, feed stock handling and carbonization, techniques of biomass briquette production, marketing of briquettes, basic bookkeeping, as well as ergonomics and safety. Furthermore, partnerships with key market segments and cooperation with private sector such as distributors, consumers, lenders, and banks were introduced. The value chain is not yet in a full-scale operation but has already created a number of jobs within the cooperatives and a few outside the cooperatives. At the current stage of the pilot production and distribution of bio briquettes, every stage in the value chain generated jobs for the locals. However, when full scale production is achieved, and the domestic energy value of carbonized briquettes are realized, we anticipate a considerable potential for jobs and improved livelihoods associated with, processing of raw material, production, transport and distribution and sales of briquettes.

5. The potential for reducing deforestation

In Kenya, wood charcoal has been an important source of energy for decades and continued today. With increased population and urbanization, demand will continue to increase. Consequently, charcoal production is one of the substantial drivers of deforestation in Kenya. Furthermore, a new regulation, since 2018 of banning logging and charcoal production in Kenya has left consumers with few alternatives. Briquettes produced using resources such as sugarcane bagasse, which otherwise are considered waste, with improved technologies can have the potential to reduce deforestation. We demonstrate the potential avoided deforestation based on the following assumptions: (a) the cooperatives will be able to operate at the maximum capacity and produce at least 600 tonnes of briquets per year; (b) deforestation of Kenyan Forests (dense forests and Open woodlands) continues at an annual rate of ca 11 000 ha per year, if not abated, as estimated by (Rodriguez-Veiga et al., 2020), and(C) woody biomass conversion to charcoal is at a ratio of 7:1 as estimated by (FAO, 2020).

Given these assumptions, along with a projected annual briquette production of 600 tonnes pr year (projected from current daily production rate), 60-350 ha of forests could be saved per year (Table 1.). Sugar cane is a short rotation plant, which can be produced on a much shorter rotation and higher frequency than trees. Thus, the use of bagasse waste as an energy source can be considered a renewable, and an alternative to reduce deforestation through reducing the dependence on wood-based charcoal for domestic energy. However, a large-scale effort is needed to substitute a forest-based charcoal for household consumption and thus reduce deforestation.

Table 1. Potential avoided deforestation in ha per year assuming a production of 600 tonnes per year of bagasse-based briquettes, within the established value chain.

Forest types of Kenya	AGB (t/ha) (Rodriguez-Veiga et al., 2020)	Charcoal pr ha using Biomass to Charcoal ratio FAO estimates: (7:1)(FAO, 2020)	Avoided deforestation (ha/yr) Due to briquet (600 t/yr)
Open to Dense Forests	72 (+/- 34)	10 t/ha	60 ha/yr
Wooded Grass Land (60% of forest)	12 (+/-6)	1.7 t/ha	352 ha/yr

Conclusions

We presented an overview and a preliminary finding of the process, the optimized low-tech technology for production of carbonized briquettes from sugarcane bagasse. The main outcomes are availability of low-tech locally fabricated briquette production infrastructure as well as demonstrated possibility of locally producing biochar-based carbonized briquettes of acceptable quality, with room for further improvement. We showed that technically this is achievable using only locally accessible construction material, and locally available workshops and skills. We also see that it's of paramount importance to strengthen technical skills and organizational capacity among the rural producers for an effective large scale commercial production and marketing of carbonized briquettes. This may motivate a large-scale effort that aims at substituting a forest-based charcoal for household consumption and thus reduce deforestation significantly.

As an additional benefit, converting bagasse into briquettes can greatly help in waste management, which has become a major issue in the sugar cane sector. Currently, only about half of the generated bagasse is used for electricity or heat generation within the sugar milling system. The rest is left as waste occupying a large space and as a source of methane emission and pollutant to the environment. The pilot briquette production presented here clearly showed ways to re-use waste as an important contribution to waste management. Since carbonization is a more carbon-efficient way to capture bioenergy compared to other bioenergy systems, production and storage of biochar would add significant benefits to soil health as well as carbon storage in agricultural soils. While biochar applications to agricultural soils is currently most widely practiced, other land uses including forests can benefit from addition of biochar to soils.

Despite all these potentials, we also see that commercial scale production of carbonized briquettes in the current rural settings of countries such as Kenya is challenging in terms of logistics and finance. The resource requirements including land, electricity, and water as well as establishment costs for the construction and operation can be daunting. This can make briquette production at commercial scale expensive or inaccessible to rural households or small business start-ups. This may therefore hinder local communities to engage in the production component of the biowaste to biofuel value chain. Therefore, there is a need for a financing mechanism through for example private sector engagement to scale up and replication of production and marketing of carbonized briquettes at commercial scale.

Acknowledgements

Funding and partnership: The project is part of a program "Development and partnership program" (2018-2021) Funded by the government of Norway through the Norwegian Agency for Development Cooperation (Norad). Biofuel4Kenya QZA-0746 KEN — 17/0009 (1700734). Project implementers are the Norwegian Institute of Bioeconomy Research (NIBIO), Royal Norwegian Society for Development (Norges Vel); Kenyan Forestry Research Institute (KEFRI), The Sugar Directorate, Agriculture and Food Authority (AFA-SD) of Kenya, Fine Aromas, community cooperatives at Ligodho and Sinoka in Homa Bay County, Kenya. The views expressed in this information product are those of the author(s) and do not necessarily reflect the views or policies of the funding or implementing institutions.

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