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Article

Charcoal briquetting: Alternative energy sources and waste management solution for sustainable cities in Tanzania

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Abstract: This paper presents a report as part of a comprehensive study on the utilization of some forms of solid waste (SW) to make charcoal briquettes (CB) as an alternative fuel source in communities that are reliant upon traditional charcoal (TC) and wood as the primary cooking fuels. The study coincides with the Tanzanian government's efforts to diminish reliance on wood and charcoal as a primary fuel source, particularly for large-scale consumers. Nevertheless, the government restriction on TC usage comes with little or no presentation of alternative sources that are both eco-friendly and economically sustainable. Introducing the mechanism that meets both environmental and economic criteria, the study employs a cross-sectional approach to collect the required data and uses experimental methods to evaluate the performance of the produced CB. Such tests focused on cooking duration, burning rate (BR), specific fuel consumption (SFC), and the general efficiency expressed by the percentage of heat utilized (PHU). In most cases, CB performs by far or less well than TC. Such results make the study important as it develops clean cooking technologies to solve the existing fuel crisis and improve health and environmental conditions from SW pollution while reducing deforestation, subsequent desertification, and climate change for sustainable environmental conservation.

Keywords: charcoal briquettes; solid waste; fuel sources; traditional charcoal; climate change; sustainable cities

1. Introduction

The global rate of forest loss is said to have decreased since 2010 to 3.3 million hectares, equivalent to 0.08% annually. This gives reasons to be optimistic about the global future of forests and forest resources [1]. However, at the local level, especially in low- and middle-income countries where the dependability on forests and forest resources as the dominant means of livelihood is still high, the situation is typically different [2,3]. In Tanzania, the sustainability of forests and woodlands is excessively threatened by increasing forest degradation. The major causes of degradation include the mass conversion of forested land to agricultural land, forest fires, the need for building materials, and most importantly, the increasing demand for charcoal and wood fuel, which are currently vital sources of energy for domestic cooking. Because of such increasing demand for forests and their resources, a considerable volume of this important resource is lost every year. According to Heist [4], Tanzania currently constitutes approximately 39.9% of forest cover, but it has an annual deforestation rate of about 1%, which is twice the world rate of 0.5% per annum. The country, therefore, loses around 400,000 hectares of forests every year. It is estimated that between 1990 and 2010, the country lost over 19.4% (about 8 million hectares) of its forested land. Thus, despite a relatively high volume of forest standing in the country, there are very few primary forests remaining. If not checked, the high deforestation rate will quickly lead to widespread forest clearing, resulting in climate change [5]. The environmental burden of such forest loss will include air pollution characterized by a total emission of 49, 1, 9, and 12 million tonnes of CO_2, SO_2, NO_x, and CH_4, respectively, by the year 2030 [6]. It is because of such looming dangers and the potential to save so much at-risk land, that conversational internationals placed the East African coastal forests among the top 10 on the list of endangered forests around the world [4].

Together with other major uses, the rate of forest degradation in Tanzania is triggered by the increasing demand for wood and biomass as the primary source of cooking energy. Of the total energy consumption in the country, over 90% is estimated to originate from fuel wood and charcoal [4]. Studies indicate that many households in large cities in developing countries—Kenya and Tanzania, for instance—are primarily using traditional charcoal for cooking stoves [6–9]. The reason for relying on traditional charcoal (TC) fuel is the fact that its preparation requires very little skill and low capital for investment. The TC is just prepared in rural areas through traditional earth kilns [6,7] by using logs and wood, largely collected from local forests, oftentimes illegally [10]. It is estimated that nearly 70% of the total charcoal produced across the country is consumed in Dar es Salaam, the largest commercial capital of the country [11]. A survey within the city of Dar es Salaam and adjacent areas including some rural areas particularly between Kibaha and Chalinze, as well as some other areas in the Coast and Morogoro regions indicates that the sources of wood-energy supply are increasingly becoming critical [12,13]. Degradation of Miombo Woodlands within a 2–3 km distance on either side of the main road of these areas suggests that wood-energy shortages are becoming serious and could result in a cooking energy crisis all over the country, the problem of which may exceed that of food supply [12,14,15]. Generally, the use of charcoal and firewood poses several environmental, social, and economic challenges. Apart from the ecological impacts of deforestation and resource destruction, each year, close to 4 million people die prematurely from illness attributable to household air pollution from inefficient cooking practices using polluting stoves paired with traditional charcoal (TC) fuels and kerosene [16].

The government of Tanzania is aware of all these impacts and is exercising significant efforts to diminish the reliance on wood and charcoal as primary fuel sources. This includes a recent declaration to phase out the use of wood and charcoal for large-scale consumers. Nevertheless, no alternative source has been presented that is both eco-friendly and economically sustainable. Therefore, it is of utmost importance to introduce an alternative fuel source that meets both environmental and economic criteria.

While the demand for cooking energy is rapidly increasing, adding to the energy crises across the country and much awful forest destruction, there is also a significant increase in volumes of materials discarded as municipal solid waste (MSW). The rise in volumes of MSW is mainly caused by various factors, including increases in the human population, urbanization, economic growth, and associated consumption patterns [17,18]. As postulated by Kazuva and Zhang [19], two perspectives are used in dealing with waste in the environment, namely, pessimistic and optimistic perspectives. The pessimistic perspective considers MSW as a problem causing pollution and other related environmental hazards. In this perspective, any addition to waste volumes jeopardizes the sustainability of the ecological environment and human health [20,21]. The perspective is most evident in developing countries, where waste management resources are more limited than in developed countries [22]. On the other hand, an optimistic perspective considers additional waste volumes, not as a problem [23], but rather as free resources and employment opportunities, especially for the poor and marginalized communities [2,24–26]. The perspective essentially focuses on improving infrastructure, applying modern technologies, and using the best management approaches from a list of scientifically derived options to ensure sustainable management of MSW [27–30]. Focusing on the second perspective the current study investigates the best means of using discarded waste material, treating them in a way that not only helps to get rid of the potential ecological environment and health risk from haphazardly dumped waste but also minimizes energy crises while solving the major environmental challenges facing forests and woodlands in the region.

In recent years, the use of fuels and energy sources with less pollution (biodiesel and ethyl alcohol) in the environment has emerged as an alternative to fossil fuels. Brazil, the world's largest producer of alcohol from sugarcane, is using advanced technology to replace sawdust for domestic cooking [31]. A good number of studies that investigate waste as an alternative source of energy for domestic use are available. However, literature that investigates the application of common MSW for charcoal making in developing countries is hard to find, while the applicability of such studies, which are mostly practised in the developed countries in the region, is limited. The study conducted in Tanzania by Gladstone and others [7] with a target of charcoal briquettes as an alternative source of energy suggests the use of sawdust agricultural waste, and other forms of bindering by using experience from local knowledge already existing. The idea is challenged by various scholars, including the WHO, in their report on the potential health-related illness attributable to household air pollution from inefficient cooking practices using polluting stoves [16,32]. It is in this regard, that the need for further studies on fuels with minimal negative environmental impacts is important. The current study employed waste material for charcoal briquette (CB) after a critical investigation of various studies on waste streams the amount constituted by each stream, and the environmental risk from haphazardly discarded waste [19,33–35]. It considers the CB technology that results in briquettes with minimum emissions to account for the aforementioned environmental and health concerns. To do so, the study went through a series of experiments to identify the most suitable and efficient fuel. It tests the residual humidity, density, mechanical resistance, residual ash, and caloric value, leading to the final products as an alternative energy source to traditional charcoal (TC) and firewood.

Thus, the objective of this study is to provide scientifically tested means of solving waste management challenges in developing countries, which in Dar es Salaam is currently haphazardly dumped, leading to the rapid increase of the environmental risk index [34]. By developing from it, a clean cooking technology that also improves environmental and health conditions in communities traditionally reliant upon wood as the primary fuel source will be developed. The move will reduce dependence on forest resources, resulting in reduced environmental degradation and climate change impacts [36]. Acceptance of this technology will likely reduce up to 40% of the total budget used in MSW collection and general management approaches under the current treatment option [19], employing in the waste and fuel industries while reducing the total volumes of forests and woodland cleaned for fuels.

2. Materials and methods

For ease of analysis, both basic and technical data were collected for the study. In this case, the study methodology was divided into two major stages, namely the basic data acquisition stage, and the experimental design and analysis stage.

2.1. Basic data/material acquisition and categorization

In the first stage of data acquisition, the study took into account the quantification of MSW generation and composition by identifying different waste streams, generation levels, and management status as documented in previous works [19,34]. The stage focused on the designed waste treatment scenario (defined according to physical, chemical, and biological characteristics) in the period from 2006 to 2017, and later from 2018 to 2022, which was considered an acceptable "environmental pollution risk assessment period" [37–40]. Other important data are those related to risk prevention, protection, and mitigation measures such as waste management systems, population density, settlement patterns, urbanization level and trends, and human factors like waste management experience and worker skill sets, all of which provide basic information on the current generation rate and future prediction [34].

On the other hand, data acquisition also includes information on TC production, i.e., procedures, demand and supply [41,42], the cost involved, and its impacts on forest and vegetation cover across the country, on which there is plenty of literature on forest data from which the study focused on the subject matter of this study [43–55].

For population projection, which was also an important parameter for determining the per capita waste generation rates (PGR), projecting generation trends, and the rising demand for charcoal, which has direct impacts on the degradation of the forest, the study used national population data from the National Bureau of Statistics (NBS) [56], as reported in the previous survey [34].

For the determination of PGR and the subsequent projections, the study used data obtained from four sampled wards, Mikocheni, Oyster-Bay, Mwananyamala, and Buguruni, with over 250,000 inhabitants. These wards were selected based on the socioeconomic characteristics and settlement patterns of their inhabitants. For instance, while the former two wards represent the suburbs–areas with properly planned and serviced locations (including the homes of some major political figures, government officials, and some merchants), the latter two are among the low-income neighborhoods characterized by poor settlement planning, low-quality housing, and limited social services including access to waste collections [57]. In this case, the stratified random sample technique was used, choosing two wards randomly in each social group. The computation of average waste generated per day and population data helped to determine the overall PGR of MSW in the city as 0.84 kg/capita/day. This figure is consistent with the previous study by the expert mission on integrated solid waste management (ISWM) from Dar es Salaam, which estimated the PGR of waste to be 0.82 kg/capita/day [58].

Investigating the composition of MSW was an important aspect of defining waste treatment and management scenarios, and was useful for briquette making [19]. However, it was not an easy task to have such data in a city where waste segregation is limited and recycling systems are quite limited. The available literature indicates that the composition of MSW varies greatly from one municipality to another and changes significantly over time [59–62].

Thus, based on data from the surveyed areas, the study managed to estimate the composition of MSW generated in the city. To do this, the SW samples were collected from various sources, including domestic sources, market/commercial sources, institutional sources, industrial sources, and other major sources as identified in the previous study by Kazuva et al. [34]. Since most of the collected samples were unsegregated, they were first sorted out into different streams and weighed independently to obtain the actual quantity for each stream. The result from this survey showed that, despite the that the sources of waste are primarily the determinant of the quantity of each stream, on average, MSW in Dar es Salaam is composed of 57.21% organic waste, 13.08% plastic waste, 6.12% paper-related waste, 2.32% glass, 1.02% ferrous metal (Steel and Aluminium), and 20.25% of other waste components put together. These figures are consistent with the results from the studies by Kazuva and Zhang [19] and by Huisman and others [58], so they were accepted as relevant for this study. However, only organic and paper-related waste, 57.21% and 6.12%, respectively, are relevant and recommendable for briquette making [63–66]. Thus, from the total sample collected, organic and paper-related wastes were considered for further screening.

The screening involved further segregation of the two waste streams (organic and paper-related waste), from which various components with different physical and chemical properties were found. Such components include paper, paper/cardboard, wood, sawdust, bagasse, various food starch (cassava, corn, banana, etc.), and many other waste items from various aforementioned sources. For this work, the items were divided into two categories based on their use in briquette making. The first category involved items like paper, paper/cardboard, sawdust, bagasse, and other organic and inorganic items termed “briquettes major material” (BMM). The second category is waste materials with binding components, which must be used for strengthening by holding together the BMM particles for adequate briquettes [67–69]. The study termed this category “briquettes binding material” (BBM) and was importantly used.

2.2. Experimental design and analysis

At this stage, all the required samples and materials were collected, ready to prepare the two major ingredients (BMM and BBM). On the one hand, the BMM was prepared by passing them through a 0.128 mm (120 mesh) sieve to prepare the fly ash particles to be taken to an adequate gross fraction for briquettesher preparation. The laboratory oven and balance helped to obtain the amount of moisture and organic and/or inorganic ash frictions in all four samples used. The major distinguishing factors for the collected samples were the sources from which they were brought, showing differences in physical composition [70,71]. For instance, in the first sample coded SI as domestic-based waste, food waste comprised the highest percentage

(>58.52%) among other components. The second sample (SII) was market/commercial-based waste, of which the major constitutes is generally dependent on the type of market they sourced. In this study, the researcher used the foodstuffs and vegetable market sources, from which food waste constituted the highest percentage (>75.05%) among other components. The third sample (SIII) was built from institutional waste, considering the sampled education institution as the target. In this case, paper waste was noted to constitute the highest percentage (>80.02%). The last sample (SIV) was an industrial-based waste. The major waste depends mainly on the type of industry referred to. Since the study focused on the sawmill industry, sawdust contributed the highest percentage of other waste components (>85.75%). The percentage composition of all considered samples is summarized in **Table 1**.

Table 1. Percentage composition of samples used.

Sample code	Waste source	Waste categories/components	Percentage composition (%)
		Food waste	58.52
SI	Domestic source	Paper & cardboard	16.05
		Coconut shells & other waste	25.43
		Food waste	75.05
SII	Market/commercial source	Bagasse waste	12.15
		Coconut shells & other waste	12.8
		Paper & cardboard	80.02
SIII	Institutional source	Garden waste	9.46
		Others waste	10.52
		Sawdust waste	85.75
SIV	Industrial source	Wood waste	6.3
		Others waste	7.95

For laboratory tests, each sample was made of 10 g, and after the process, it was dried at 115 °C for 18 h, and fired at 700 °C. The thermogravimetric analysis (TGA) and differential scanning calorimetry (DSC) (TA Instruments model SDT-Q600) were used to characterize the particles (ashes) and the briquettes to see humidity, organic and/or inorganic concentrations, and the homogeneity of the BMM/charcoal powder. After experimental work, a sufficient amount of each sample was taken and passed through the required process to change the biomass into charcoal powder. This is done by heating the material at a temperature above 400 °F (>204.44 °C) in a low-oxygen environment to complete the pyrolysis [7]. To do this, a pyrolyzer is a burning chamber designed with a controlled airflow to allow partial combustion, as opposed to burning into the ash of the BMM material to remain with charcoal powder.

On the other hand, the BBM was prepared in a standard manner using relevant materials. Studies suggest that binding material can range from pulped paper to thrashed grass [72,73]. However, recent experiences in Tanzania indicate that starch-based binders such as cassava flour gels provide a much more reliable level of cohesion [7]. This study used a combination of banana, cassava, and corn starch to prepare binders. As studies suggest, the mixture was added to the boiling water

(100 °C) until the polymer molecules in porridge/gum form were molded [73–75].

Depending on the circumstances and material used, various methods can be used to prepare the briquettes. In the current study, briquettes were prepared in two different ways. The first was by mixing the charcoal powder with the gum at a ratio ranging from 6%−10% of the total weight used until a homogeneous paste was formed. The second was by mixing the charcoal powder with starch in the same ratio as above (6%−10% of a binder), then adding water before heating to boiling the mixture until a paste is formed.

After this step, a manual honeycomb briquette press machine with 4 steel cylindrical moulds of 4 cm− internal diameters each (**Figure 1a**) was used to compress the paste, forming the cylindrical briquettes with a diameter of 4 cm and a height of 12−15 cm (**Figure 1b**). For compression, an adequate compression force was applied for at least 45 s on each sample.

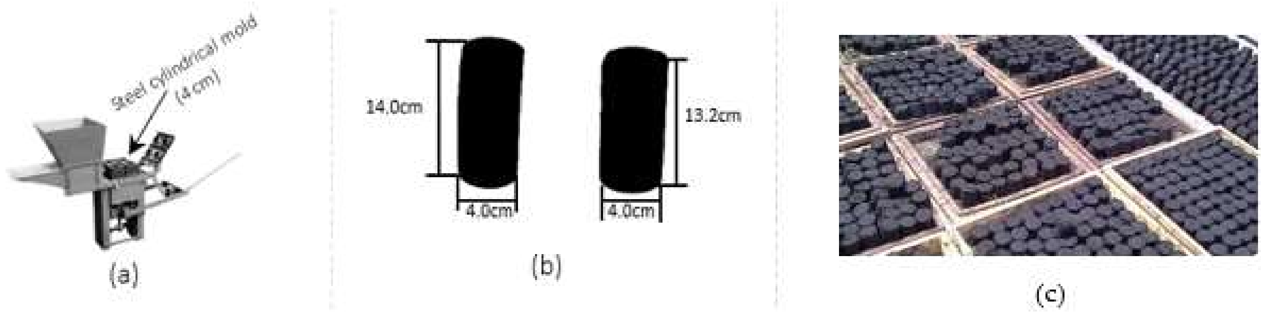

Figure 1. Charcoal briquette making: **(a)** Picture of a manual honeycomb briquette pressing machine; **(b, c)** Pictures of the briquettes in different dimensions.

Finally, the obtained briquettes were subjected to a temperature of 752 °F (400 °C) until they were dried. For local use, the temperature is the same as exposing the briquettes to the sunlight for 3 to 5 days, depending on whether it is sunny or partially sunny, respectively. After the drying process, the briquettes were taken for the combustion test, while recording the type of each sample, weight, time taken for complete combustion, and the amount of energy released.

2.3. Performance evaluation and analysis

The produced charcoal briquettes (CB) were from four samples considered, each representing a particular waste source, i.e., domestic, market/commercial, institutional, and industrial sources; coded SI, SII, SIII, and SIV, respectively (ref. **Table 1**). Four groups of CB (one from each sample) were set, and several tests, including the ignition point, burning time, smoke produced, burning rate, etc., were carried out, as summarized below. The reason for testing each sample as an independent entity was to examine the potential differences in CB based on waste type/sources.

For all tests, the stove was loaded with the CB of a particular code (SI, SII, SIII, or SIV), while recording the CB weight, time taken to catch fire (ignition point), burning rate (BR), time spent in cooking/boiling, time taken for complete combustion, and the specific fuel consumption. To do all these tests, several tests, including water boiling tests, and controlled cooking tests were run. For comparison purposes, similar tests were repeated using four different samples of traditional charcoal (TC) taken from various market centres within the city. The involved procedures are summarized as follows:

2.3.1. Burning rate of the charcoal briquettes

After loading the charcoal in different es for each of the four groups of CB and TC, the burning rates (BR) were carried out using Equation (1):

$$BR = \frac{Mass\ of\ consumed\ fuel}{Time\ taken} \tag{1}$$

2.3.2. Water boiling test

Water boiling tests (WBTs) can simply be performed by simulating standard cooking/boiling procedures. It measures the fuel consumed and the time required for the simulated cooking. WBTs are usually performed to explore the performance and/or efficiency of the fuel or stove used under different circumstances. The technique is used by the stove designer, field workers, fuel manufacturers, or researchers for a quick comparison of the performance of the target aspect [76]. In this test, fuel-efficiency is expressed by the percentage of heat utilized (PHU) in Equation (2):

$$PHU = \frac{Net\ Heat\ Utilized}{Net\ Heat\ Supplied} \times 100\% \tag{2}$$

2.3.3. Controlled cooking test

The controlled cooking test (CCT) is designed to assess the performance of the improved stove and/or fuel type relative to the traditionally used one that the improved model is meant to replace. The test enables the determination of the specific consumption, which expresses the amount of fuel required to obtain 1 kg of cooked food [77]. The tests were carried out with two food items, ‘‘wali-maharage’’ in the local language, meaning rice and beans. For each test carried out, the cooking pots were first weighed, and then 0.38 kg of food was placed in a respective pot containing 1.4 L of water each. The food was cooked on different ports representing each sample considered. The weights of the fuel used in each stove were recorded before and after the test. The data collected in this test were useful in computing the specific fuel consumption (SFC) in Equations (3) and (4):

$$SFC = \frac{Mass\ of\ consumed\ fuel}{Total\ mass\ of\ cooked\ food\ item} \tag{3}$$

Algorithmically,

$$SFC = \frac{M_w(1 - Z) - 1.4X}{\sum(M_{pf} - M_p)} \tag{4}$$

where, M_w = Mass of fuel before the test (kg), Z = Fuel moisture contents (%), X = Mass of fuel after the test (kg), M_p = Mass of the empty pot (kg), M_{pf} = Mass of the pot with cooked food (kg).

2.3.4. Time spent in cooking

Finally, the time spent (TS) in cooking per unit of cooked food item was computed using Equation (5):

$$TS = {}^{T_c}\!/_{M_f} \tag{5}$$

where T_c = Total time spent in cooking, M_f = Total mass of cooked food.

All these procedures were followed, and the results are summarized in the following section.

3. Results and discussion

The study results indicate differences in the burning rate among different briquette samples. The type of parent material used in making a particular briquette plays a significant role in making differences. Using Equation (1) to calculate the burning rate [78], it was noted that, CB made from materials with a high percentage of food contents are hard to catch fire (high ignition point), but their low burning rate is different from those with a low percentage of food contents. For instance, while the BR for CB with 58% and 75% of food contents and an ignition time of 3.55 min and 4.15 min is 0.0024 kg/min and 0.0021 kg/min, respectively, it is 0.0032 kg/min and 0.0030 kg/min for CB dominated with other waste components (paper and sawdust) with an ignition time of 3.20 min and 3.10 min, respectively (see **Tables 1** and **2**).

On the other hand, the comparative analysis of the average BR between CB and traditional charcoal (TC) found CB to have a lower BR (0.0027 kg/min) compared to TC, which is 0.0030 kg/min. The average BR for CB found in this study is not only lower than the TC but also for many other briquettes from various materials [79–81].

Table 2. Burning rate of CB and TC.

Type	Sample code	Material source	Weight (kg)	Ignition time (min)	Time to complete burning (min)	Burning rate (kg/min)
CB	SI	Domestic waste	0.144	3.55	59.43	0.0024
	SII	Market/commercial waste	0.144	4.15	66.12	0.0022
	SIII	Institutional waste	0.145	3.20	43.44	0.0033
	SIV	Industrial waste	0.145	3.10	45.31	0.0032
TC	TC	Traditional charcoal (market)	0.15	3.51	50.22	0.0030

Since the burning rate determines the life span of the fuel during combustion, this means that the higher the burning rate, the shorter the life span of the fuel. In this case, it is often costly and disadvantageous to use fuel with a high burning rate. Therefore, despite the fact that they are hard to catch fire (high ignition point), the briquettes of material with a high percentage of food and other related organic waste contents could handle fuel consumption more economically.

From the water boiling test, the comparative analysis that was made to measure the fuel efficiency between the produced briquettes (CB) and traditional charcoal (TC) shows that CB is more efficient and has more potential than TC. On average, a maximum of 0.25 kg of CB is sufficient to boil 4 L of water within 27 min, while it needs about 0.27 kg of TC for approximately 32 min to boil the same amount of water. Similarly, the fuel efficiency expressed by percent heat utilized (PHU) from Equation (2) demonstrates that the CB is more economically sound (33.5%) than the TC, which is 31.30% (**Table 3**).

Table 3. Differences in fuel efficiency.

Type of fuel	Weight	Quantity of water	Time spent in boiling	Percentage heat utilized (PHU)
CB	0.25 kg	4 L	27.20 min	33.50%
TC	0.27 kg	4 L	31.57 min	31.30%

From a controlled food test, the average time taken to cook 0.38 kg of rice and beans by using CB stoves was 36.40 min and 49.11 min, respectively. Conversely, the average time used to cook the same amount of food using TC is 39.13 min and 53.05 min for rice and beans, respectively. Such results confirm a significant difference in the time taken to cook by using CB and TC stoves. That is to say, the CB stove cooks food faster than the TC stove.

Furthermore, there is also a slight difference in the specific fuel consumption (SFC) between the two fuel types considered, which the CB found superior to TC. As from Equation (4), the SFC of CB for cooking rice and beans was 0.23 kg/kg of cooked food and 0.29 kg/kg of cooked food, respectively, while for TC, the SFC was 0.25 kg/kg of cooked food and 0.31 kg/kg of cooked food, for rice and beans, respectively (**Table 4**).

Table 4. Results of controlled cooking test.

Type of fuel	Time spent in cooking 0.38 kg of food (min)		Time spent in cooking (min/kg-of-cooked food)		Specific fuel consumption (SFC) (kg-of-fuel/kg-of-cooked food)	
	Rice	Beans	Rice	Beans	Rice	Beans
CB	36.40	49.11	95.79	129.24	0.23	0.29
TC	39.13	53.05	102.97	139.61	0.25	0.31

Generally, as the results show, the use of CB made from SW for domestic cooking reduces deforestation and severe degradation of the environment due to the bulk need for energy used for domestic cooking. Results from the analysis of efficiency and effectiveness favour the use of CB over TC made from forests and related resources. However, the use of CB for TC is associated with some problems, including, but not limited to:

Smoking problem: Some kind of smoke was detected, especially during the start-up time, however, it tends to decrease as the briquette catches fire and continues to burn. To solve this problem, it is suggested to control the process more comprehensively. This can be achieved by effectively drying the material waste to remove all moisture and allowing more oxygen during the heating process to let the material waste turn completely into carbon from its original organic nature. It is also suggested that the smoke produced can largely be minimized by mixing various types of waste and processing them together [82,83].

The ignition problem is among the major problems, unlike fuels like kerosene, gas, etc., which require just a spark of fire to start on and continue burning, CB requires more intense heat to ignite (ref. **Table 2**). To deal with this problem, there should be other easily inflammable materials, like charcoal sparkling sticks (provided they are proven to have no side effects), to reduce the time taken to reach the ignition point.

4. Conclusion

As shown by various studies, over 50% of the total MSW produced in the city of Dar es Salaam has the potential to make CB [9,19,63]. The current study uses discarded waste materials to produce CB, which, upon adoption for mass production, will essentially reduce the dependability of TC and firewood for domestic cooking. As aforementioned, high dependence on TC and firewood is said to be among the leading causes of deforestation and severe degradation of the environment. Thus, this study provides solutions to the existing fuel crisis by suggesting a new convenient, and clean energy source in the study area and others with similar conditions. It also reduces the potential ecological and health risks associated with inadequate management of SW. Such basic knowledge of the usability of MSW to reduce excessive use of TC was the knowledge gap that the study anticipated filling.

From various experiments carried out, evaluation of the performance of the sampled fuels shows that the CB has better performance than the TC. It is evident from the study results that the use of CB is more efficient and has less negative impact on the environment and human health compared to traditional wood charcoal. On average, the burning rate of a well-made CB is 0.0027 kg/min, which is approximately 11% less than TC (0.0030 kg/min). The better performance for CB was also confirmed by the efficiency test expressed by the percentage of heat utilized (PHU), which for CB is 33.5% while it is 31.3% for the TC. Generally, CB was found to be more efficient and effective in terms of cooking duration, quantity used (costs), and environmental consequences for individual households, municipalities, and the country at large.

Based on these findings, it is recommended that policy options be explored to promote the use of these briquettes. The study recommends that the government, through environmental management policy, develop incentive schemes that encourage more manufacturing of these briquettes, introduce regulations to limit the use of traditional wood charcoal and educate the public on the benefits of using alternative briquettes. These policy options must be implemented if there is to be an overall decrease in reliance on traditional wood charcoal, which is harmful to both the environment and public health.

It is concluded that the CB fuel is not only cheaper, readily available, and takes less time and quantity to cook than TC, but also that its adoption for use will solve the long-standing ecological and human health problems associated with inadequate SWM. Equally, it will reduce between 35% and 55% of the current forests and woodlands cleaned for domestic cooking. Therefore, the study recommends mass production and use of CB to enhance the utilization of MSW, which is currently a burden to municipal authorities, while reducing pressure on already depleted forests and woodlands and preserving the still-existing forests and woodlands for sustainable resource conservation and climate change reduction.

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