CLEAN COOKSTOVES TECHNOLOGY: THE COMING REVOLUTION FOR SUSTAINABLE BIOMASS CARBON AND CLIMATE CHANGE MITIGATION, BOTSWANA

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ABSTRACT
Climate change mitigation through reduction in greenhouse gas emissions via sustainable utilization of biomass carbon requires innovation and technological interventions. Clean cookstoves represent the best substitute for open fire biomass stoves and reduction in greenhouse gas emissions from fuelwood globally. Prospects to transfer this technology to Botswana have not been explored. Therefore, our research objectives were to transfer the clean Institutional Cookstove (IC) technology to ORI as a case study, quantify the amount of fuelwood it consumes in comparison to traditional biomass energy system, and analyze its potential to be used as a substitute for open fire cooking method. The clean IC technology transfer was successfully done within two weeks before testing its energy efficiency and financial viability. It used about two-thirds less fuelwood as compared to the three stone traditional stove. Financial viability analysis of the clean IC as a model to be used in primary schools showed that it has a potential to reduce money spent on fuelwood. Our future work will focus on analyzing carbondioxide gas emissions from using clean IC in comparison to open fire method. The challenge remains on how to rollout the clean IC to schools, and adapting it to the three legged pot.

KEY WORDS
Clean institutional cookstoves, climate change mitigation, energy efficiency, sustainable biomass carbon, forest conservation, clean energy.

1. Introduction
Climate change mitigation through reduction in greenhouse gas emissions via sustainable utilization of biomass carbon requires innovation and technological interventions. Globally, technological interventions geared towards production of clean energy and energy efficient devices provide an opportunity for reducing greenhouse gas emissions. An example of such interventions is the Global Alliance for Clean Cookstoves and Fuels initiative, which aims for the promotion and adoption of clean fuels and cookstoves globally in 100 million homes by 2020 [1]. The global focus on clean fuels and improved cookstoves has increased because of their potential for delivering improved regional climate benefits, local environmental quality and household health [2]. An estimate of 2.4 billion people depend on wood, charcoal, dung and other biomass energy sources for heating and cooking purposes [3], [4]. Burning biomass fuels result in smoke emissions that are an important source of indoor air pollution, especially in rural poor communities in developing countries [5]. The most popular method of food processing and preparation used by these communities is cooking on open fires, which burn poorly thereby resulting in high greenhouse gas emissions and low fuel efficiency [3]. However, opportunities exist through the usage of clean cookstoves on providing solutions to these adverse effects of inefficient cooking devises and methods [1].

Clean cookstoves represent the best substitute for open fire biomass stoves, which cause household air pollution (HAP) that kills 1.5-2 million people in a year [6] and leaves millions more suffering from pneumonia, cancer, lung and heart diseases [1]. Additionally, undesirable social impacts frequently result from using traditional biomass stoves. For example, inefficient stoves require more time to gather fuelwood and cook, a burden customarily borne by children and women, which diverts them from attaining education and participating in income-generating activities [2]. Furthermore, rudimentary cookstoves consume high amounts of fuelwood adding to destruction of carbon pools and land degradation. They also reduce regional and local air quality through emissions of toxic smoke. “Cooking shouldn’t kill, and the Global Alliance for Clean Cookstoves is working to ensure that it doesn’t in part by building bridges between the public and private sectors to make the basic but essential act of cooking safe and healthy worldwide,” said Radha Mutthiah, executive director of the Global Alliance for Clean Cookstoves.
Moreover climate change mitigation as a rational for clean cookstoves interventions benefit creates a platform for their promotion and acceptance [7]. For example, creation of the Safe Access to Firewood and Alternative Energy in Humanitarian Settings (SAFE) stoves initiative was one of the most prominent accomplishments of the 2009 (COP15) United Nations Conference on Climate Change in Copenhagen [4]. Furthermore, rigorous early reductions in greenhouse gas emissions and energy efficiency are key to maintaining the probability for limiting global warming to below 1.5 °C by 2100 [8].

Over the last 30 years, awareness of the environmental and social costs of using traditional fuels and stoves and knowledge about how to reduce emissions from such has grown [5], [9]. Yet the improved stoves currently available to poorer customers do not always represent best practice or an understanding of a design based on modern engineering and some scientific theories as shown in figure 1.

The knowledge required to design cleaner biomass burning stoves exists in centers of excellence in several locations and ORI is networked to one of such around the world, Kwame Nkrumah University of Science and Technology. Providing this knowledge and information to those involved in promoting improved stoves is a necessary first step to aid in reducing indoor air pollution exposure, the quantity of biomass usage, as well as mitigating climate change impacts and enhancing health improvements. The Advanced Studies in Appropriate Technology at KNUST works to develop energy efficient, nonpolluting, renewable technologies that reflect current research, which are designed to fit into the situation in any country. The aim of this research is to adopt and adapt institutional clean cookstoves into the Cubango-Okavango River Basin as an innovative approach to mitigate problems related to health, deforestation, biomass burning smoke and its effect on climate in the basin.

The specific objectives of our research are to:

- Equip participants (cooks, researchers, patrons) with the capacity and capability to manage the IC.
- Quantify the amount of fuelwood consumed by the clean IC as compared to open fire or traditional biomass energy system, and infer implications for climate change mitigation.
- Analyze the potential and cost of using the clean IC as a substitute for open fire or traditional biomass energy system.

2. Background

2.1 Evolution of the Clean Institutional Cookstove Technology

The institutional cookstove (IC) technology has gone through a rigorous research over the years and the product is based on rocket stove science that utilizes heat transfer, selected ceramic materials, thermodynamics, fluid mechanics and high temperature to achieve various desired products [10]. At the turn of the century, an improved and advanced cookstove research program was initiated with the objective of developing a low cost, effective and efficient stove that is clean with less fuel usage, improved health benefits, and environmentally sustainable that can be manufactured and applied in developing countries [11]. This research resulted in the development of a clean IC with insulating bricks to prevent heat loss and enhance maximum heat transfer to the cooking pan. A chimney was introduced for the removal of harmful gasses into the atmosphere and to provide an air draft that allows for complete biomass combustion (Figure 2, 3). Good management of the fuel resulted in clean energy. The IC can reduce firewood usage by up to 85% and has improved clean fuel with up to 95% smoke reduction [10].

It is possible to achieve a new design, cooking pot, energy efficiency and effective clean IC configurations that can be fabricated using local craft skills, existing industrial infrastructure, simple hand tools and readily available materials. These could be realized by employing an integrated design method based on the feedback from users, in combination with social and cultural lessons or inputs.

The clean IC technology consists of ceramic bricks on the outside and insulating bricks on the insides including the fire magazine (Figure 2, 3). The cooking pan sits in the groove completely allowing no smoke or heat to escape except through the chimney. A mortar comprises of a mixture of clay, calcined kaolin and at times fine screened sand and cement mixed with water. It must be noted that there is no fixed materials to achieve such high efficiency. Local indigenous materials work extremely well too with the help of experienced person.
2.2 Clean Institutional Cookstove Design Features

The clean IC design operates via a temperature and heat transfer mechanism through optimum combustion of firewood in order to reduce smoke, enhance efficiency and effectiveness of cooking. With the adopted design at ORI the fire magazine is shifted off the stove centre to the side for enhanced even distribution of heat around the pan (Figure 3). For the even distribution of heat to happen, the chimney is placed at the opposite side of the firewood magazine (Figure 3). A mixture of wood ash, cement and sand are used as insulating materials as well as mortar for filling the gaps between bricks during construction (Figure 3). Addition of wood ash to cement has been proven to results in a mortar of acceptable quality in terms of durability and strength [12].

2.3 Technology Transfer into Botswana

The Okavango Research Institute (ORI) in collaboration with the Technology Consultancy Center (TCC) under College of Engineering (CoE) of Kwame Nkrumah University of Science and Technology (KNUST) initiated a research on investigating the potential to adopt and adapt Institutional Cookstoves (IC) into Botswana. This follows a successful implementation of the IC in Ghana by the TCC in collaboration with the Netherlands Development Organization (SNV), through engaged research and innovation on the potential of (IC) in Ghana at the Applied Industrial Ceramic and Rural Energy and Enterprise Development unit (AIC &REED) of TCC. This IC uses the theory of heat and temperature transfer [13] as the principles for selection of construction materials and design of the stove. The theory will serve as a platform for the potential technological improvement and development of the technologies associated with biomass stoves.

In order to serve as a platform to launch into other biomass stoves projects, i.e. clean IC, Ghana Alliance for Clean Cookstoves and Fuels (GHaCCOF) with Ghs3000.00 financial support in a cost sharing agreement with Kumasi Secondary Technical School (KSTS) and technical support from TCC, KNUST, constructed an improved version of the IC in KSTS kitchen. The aim of this initiative was to demonstrate the importance of clean cooking to other schools and institutions through practical learning exhibitions. It was also to allow for students to further research into commercialization of the product and study modalities that will help improve, maintain and sustain the technology.

Although improved and advanced biomass cookstove technology is relatively new in the Ghanaian market, its widespread usage in Ghana and Africa can be promoted through technology transfer and engagement of organizations like GHaCCOF, Government Ministries, policy makers, and Higher Education Institutions. The project was partly funded by GhaCCOF, whilst the cost of construction of the clean IC, facilities and housing were provided by KSTS. A similar approach is deemed necessary to ensure technology transfer from Ghana to Botswana. This will also allow for conduction of comparative research in the two countries by involved researchers. The researchers observed wasteful usage of fuelwood through open fire cooking method at a primary school in Maun where clean IC could be introduced and promoted (Figure 4).
3. Materials and Methods

3.1 Study area

The clean IC technology transfer was done at the Okavango Research Institute (ORI) in Maun (Figure 5).

![Figure 5. Map Showing ORI location in the Cubango-Okavango River Basin, Southern Africa.](image)

3.2 Materials

Most of the materials needed to construct the clean IC were available locally although not as prescribed in the original design document albeit as substitute materials, which were suitable to do the work and achieve comparable results. The materials were purchased at the local market and some were available at the metal shops in Maun. The term “approtech and appromat” which means appropriate technology and appropriate materials respectively were mostly used during the process because quite a number of tools that were perfect for the task had to be made at the workshop effortlessly.

Major components purchased for construction of the clean IC were as follows:

- 10cm square Galvanize 1.0 mm thick Chimney pipe
- 75ltr aluminum cooking pot with lid
- 18 cm2 metal grate
- Burnt clay bricks
- Cement
- Sand
- 0.5cm Granite gravels
- Mild Steel Metals 55cm diameter disc
- Water
- Refractory mortar (locally prepared with wood ash)
- Iron rods
- Corrugated iron sheets
- Fuelwood

3.3 Construction

Constructing the clean IC started with having the plan on the ground or floor with bricks (Figure 6), laying the air inlet and firewood magazine positions, which served as a framework for the foundation. The next activity was laying the bricks with cement mortar seven to eight layers of bricks at a time. Refractory cement consisting of a mixture of cement, ash and sand was used for laying bricks in high temperature areas like fire magazine and the cooking pan cavity. And insulating bricks were used for construction of the IC.

![Figure 6. Laying the foundation for the clean IC.](image)

3.4 Performance test

A performance test was carried out to boil water and determine the amount of fuelwood used. Fire was prepared using Mopane wood to operate the clean IC. The weight, length and circumference of fuelwood pieces used for the test were measured and recorded. After the fire was ready a 75liters stainless steel pan was filled with water and placed inside the pot cavity. The amount of time taken and fuelwood used to boil the water was recorded. Seven replicate tests were performed. A control experiment was conducted using open fire method to boil 75litres of water.

4. Results and Discussions

4.1 Technology transfer

The clean institutional cookstove technology transfer was successfully done within a period of two weeks at ORI before testing its efficiency and financial viability. This section covers results and discussions on the performance and potential financial viability of rolling out the technology to schools in Botswana. Figures 7 and 8 show the completed clean institutional cookstove at ORI.
4.2 Water boiling test results

Our results indicate that the IC performances are consistent with the previously reported information by [10]. For example, the new IC at ORI can boil 75 litres of water within 55 minutes using 3.0kg-4.5kg firewood. A control experiment using open fire to boil 75 litres of water took about 83 minutes. The amount of firewood used was 10.5-14.7kg. Therefore, the institutional cookstove used about two-thirds less firewood as compared to the three stone traditional stove. This can be reduced by using some innovative ideas like skirting the pot cavity and lowering the cooking pot to 2cm gap from the base of the pot cavity. A 3.5cm gap was attained for our ORI design and there was no skirting.

4.3 Fuelwood and fire management

The fuelwood that was used to test/run the clean IC consisted of Mopane tree wood pieces. It was purchased from the common market along Shorobe Road to ORI. The fuelwood pieces were derived from dry dead trees of unknown sizes. Table 1 shows descriptions of the fuelwood pieces in terms of weight, length and circumference. The average biomass weight for fuelwood pieces was 1.04kg. Fuelwood size and quality play a significant role in providing satisfactory performance during operation of the clean IC. Wood biomass pieces with an average length of 47cm and 19cm circumference are preferable. Pieces that do not fall within this category produce smoke and reduce fire temperature.

After two weeks of sun drying, the average dry biomass weight of fuelwood pieces was 0.94kg. Therefore, water content of fuelwood directly from the market is estimated at 9.5%. This has an effect on fuelwood combustion efficiency and fire temperature. Direct combustion of biomass technology accounts for about 97% of bioenergy production globally [14]. The same technology is applied for the clean IC; hence the use of wood with low water content could improve our results.

<table>
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<th>Descriptive Statistics</th>
<th>Weight (kg)</th>
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<td>Total N</td>
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4.4 Implication for climate change mitigation

Carbondioxide is absorbed or sequestered during biomass growth and emitted during combustion [14]. Furthermore, high water content in wood is associated with an increase in carbondioxide evolution during combustion or decomposition [15]. Therefore, using fuelwood with low water content could increase combustion efficiency,
reduce carbon dioxide emissions and time taken to boil water. In addition it will improve energy efficiency of the clean IC and reduce the amount of wood needed to boil water. Our results indicate that open fire method consumes more fuelwood as compared to the Clean IC; thereby the former significantly contributes to fuelwood associated greenhouse gas emissions. A study by Johnson et al. (2008) [16] found a reduction in organic carbon within the aerosols fraction emitted from improved cookstoves as compared to open fire. Therefore, reductions in greenhouse gas emissions from fuelwood combustion via usage of clean IC technology provide opportunities for climate change mitigation in Botswana.

Generally, biomass has relatively less carbon compared to coal [14]. Thus, a decision to use fuelwood for cooking in schools in a semi-arid country such as Botswana where coal is abundant is creditable. Mopane and miombo woodlands vegetation form part of the savanna woodland ecosystem in Southern Africa [17] that is deforested for fibre and fuelwood by local communities [18]. The challenge remains on how to ensure sustainable utilization of biomass carbon pools through reduced deforestation, afforestation and enhanced conservation of forest and woodland resources. Adoption of the clean IC for cooking in schools that use open fire cooking method coupled with afforestation program offers a potential solution to address this challenge.

4.5 Observations

There was less heat and smoke in the clean IC fireplace in comparison to open fire where the researchers were exposed to scorching heat and smoke. The slant firewood chamber allowed for flexibility in fire management since the fuelwood could slide down by gravity into the fire chamber. Or it is easy and comfortable to manage fire in the clean IC. In contrast, for open fire method the fuelwood had to be manually pushed towards the center underneath the pot to allow for maximum combustion and heat transfer. It was also conceptualized that the stove can be adopted and adapted to the three legged traditional pot used for cooking in schools.

4.6 Safety operation points

No poisoning from carbon monoxide and other gases occurred when testing the stove. Researchers could lean on the stove without slightest discomfort from the heat. However, safety glasses should be worn when stoking firewood inside the firewood chamber to protect the eyes from fire. Protective clothing (insulated hand-cloves, closed shoes, overall pants and hat) should also be worn during operation of the stove.

4.7 Financial viability analysis of the clean IC

The cost of one Hilux truck of firewood is BWP250-300 (2015 cost). An institution such as a primary school with 120 students uses a maximum of 12 Hilux trucks per term, that is, when open fire cooking method is used. This arrives at a total amount of BWP9 900 for an academic year. Financial analysis of the clean IC showed a potentially marked reduction in money spent on firewood with savings of about BWP6, 600, and payback time of two years and 5.5 months as expressed in the following:

\[ \text{Pay Back} = \text{days, months, year} \times \text{initial Investment/Total Investment} \]

A detailed comparative analysis of the cost of using a clean IC instead of open fire will be determined once the stoves are constructed in at least 3 primary schools as a pilot project.

4.8 Sociocultural barriers for adoption of the clean IC

Although our results indicate that the clean IC has a potential to reduce the amount of fuelwood consumed and greenhouse gas emissions during food processing as compared to traditional open fire method at an institutional level, there are some sociocultural barriers that might make the technology socially unacceptable at a household level. The following responses were obtained during presentations of our results at seminars and workshops in Maun:

- “Youths are encouraged to uphold traditional norms and culture. Collecting fuelwood and making fire is part of our culture. Is this stove not contradicting our norms and culture, which are passed from generations to generation”?
- “Culturally, people like to see fire and be around it, now the stove is going to occupy the fireplaces and interfere with traditional norms of having such sacred spaces in homes”.
- “Smoke is essential for cooking as it makes food smell nice, especially traditional meat dishes. The stove will not allow for such natural spicing to occur”.
- “Women like going out to collect fuelwood as it gives them a space to socially interact and discuss their problems; this stove is going to interfere with such social gatherings”.
- “The three legged cast iron pot is our tradition, we should not be distracted by new technologies and lose our culture in pursuit of living in a globalized world”.

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Nevertheless, the clean IC technology was demonstrated to primary schools cooks and teachers who showed keen interest in having the technology transferred to their schools for cooking purposes. As a result three clean institutional cookstoves will be built in primary schools to pilot the technology there. This would provide a platform to do a detailed comparative energy efficiency test and carbon dioxide emissions estimates with the existing traditional cooking system in schools. The future outlook is to have the technology reproduced in all schools that use fuelwood for cooking in Botswana and SADC.

5. Conclusion and Future Work

The clean institutional cookstove technology transfer was successfully done within two weeks at ORI before testing it. It was found that the clean IC consumes two thirds less firewood as compared to open fire method. Financial viability analysis of the clean IC showed a potential for marked reduction in money spent on fuelwood by primary schools. The clean IC technology was demonstrated to primary schools cooks and teachers who showed keen interest in having the technology transferred to their schools for cooking purposes. As a result three clean institutional cookstoves would be built in primary schools to pilot the technology there. This will provide a platform to do a detailed energy efficiency test and analysis of greenhouse gas emissions from using the clean IC in comparison with existing traditional cooking system in schools. The future outlook is to have the technology reproduced in all schools that use fuelwood for cooking in Botswana and SADC coupled with afforestation program. Of course the IC efficiency can be further improved through addition of skirting, new pot designs, lowering the cooking pot to 2cm gap from the base of the pot cavity and better fuel management. Adoption of the technology to the three legged pot used for open fire cooking in primary schools will also be explored in order to consider existing traditional practices in the country.

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