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Case study

Clean Cookstove Technology Use for Energy Efficiency in the School System

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Abstract

Globally, clean cookstoves represent the best substitute for open fire biomass stoves in order to reduce greenhouse gas emissions from fuelwood. Prospects to transfer this technology to Botswana are being explored. Our research objectives were to transfer the clean Institutional Cookstove (IC) technology to Okavango Research Institute (ORI), quantify the amount of mopane (Colophospermum mopane) fuelwood it consumes in comparison to the traditional biomass energy system, and analyze its potential to be used as a substitute for the open fire cooking method. The clean IC technology transfer to ORI was successfully completed before testing its energy efficiency and financial viability. It consumed approximately two-thirds less fuelwood than the traditional three stone stove. This presents an opportunity for a reduction in greenhouse gas emissions from fuelwood consumption in Botswana. This is a critical consideration in an environment where there is limited readily available fuelwood. The use of clean cookstoves allows enhanced carbon sequestration by live mopane woodland resources. A financial viability analysis of implementing the clean IC in primary schools showed that it has the potential to save money spent on fuelwood. Our case study provides essential pertinent results on the energy efficiency of the developed prototype, which forms a basis for further research on the use of clean cookstoves for mitigating greenhouse gas emissions from fuelwood consumption in Botswana and the entire Cubango-Okavango River Basin. A comprehensive analysis of cultural barriers to adoption of the technology will be carried out through piloting the construction of the clean cookstove.

1. Introduction

Climate change mitigation through reduction in greenhouse gas emissions via the sustainable utilization of biomass carbon requires innovation and technological interventions. Globally, technological interventions geared towards the production of clean energy and energy efficient devices provide an opportunity for reducing greenhouse gas emissions. An example of such interventions is work done by the Global Alliance for Clean Cookstoves, which aims for the promotion and adoption of clean fuels and cookstoves in 100 million homes globally by 2020 (Global Alliance for Clean Cookstoves, 2015). The global focus on clean fuels and improved cookstoves has increased because of their potential to deliver improved regional climate benefits, local environmental quality and levels of household health (Lewis & Pattanayak, 2012). An estimated 3 billion people are dependent on wood, charcoal, dung, farm waste, kerosene and other biomass energy sources for heating and cooking purposes (Ruiz-Mercado, Masera, Zamora, & Smith, 2011), (Simon, Bumpus, & Mann, 2012).

Burning biomass fuels results in smoke emissions that are sources of indoor air pollution, especially in poor rural communities in developing countries (de Koning, Smith, & Last, 1985). These smoke emissions kill 4 million people every year in poorly ventilated kitchens through noncommunicable diseases including pneumonia and asthmatic conditions, and heart conditions such as ischaemic heart diseases, chronic obstructive pulmonary diseases (COPD) and lung cancer. The most popular method of food processing and preparation in these communities is cooking on open fires, which burn poorly, thereby resulting in close-proximity air pollution, high greenhouse gas emissions and low fuel efficiency (Ruiz-Mercado et al., 2011). Opportunities for change exist through the use of clean cookstoves which provide solutions to these adverse effects of inefficient cooking devices and cooking methods (Global Alliance for Clean Cookstoves, 2015).

Clean cookstoves represent the best substitute for open fire biomass stoves that forms a basis for our case study, gas and charcoal; they can have fuel usage savings of up to 75 % (Barstow, Millinger, Nyer, & Saade, 2010), lower emissions by 90 % (Lucon et al., 2014) and increase levels of comfort through cooler ambient temperatures. Poor air conditions that presently exist from open fire biomass stoves cause household air pollution that kills 1.5-2 million people per year (WHO, 2006) and leaves millions more suffering from pneumonia and other respiratory conditions (especially among children under the age of five years), lung cancer and heart diseases (Global Alliance for Clean Cookstoves, 2015). All these conditions are caused by particulate matter PM10 and PM2.5 (soot) inhaled from household air pollution (Kim, Kabir, & Kabir, 2015).

There are additional undesirable social impacts that frequently result from using traditional biomass stoves. For example, more time is required to gather fuelwood and prepare food over the fire when using inefficient stoves. This is a burden customarily borne by women, including girls. When the women and girls are out collecting the fire wood, they can also be bitten by snakes or attacked by wildlife. Women, and especially children, are therefore diverted from attaining education and participating in income-generating activities (Lewis & Pattanayak, 2012).

Furthermore, rudimentary cookstoves consume high amounts of fuelwood, contributing to the destruction of the local carbon pool, potentially causing substantial land degradation. This all contributes to the reduction of 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 Muthiah, executive director of the Global Alliance for Clean Cookstoves (CEMEX and the UN Foundation, 2013). Moreover, climate change mitigation as a rationale for interventions of clean cookstoves creates a platform for the promotion and acceptance of the cookstoves (Grieshop, Marshall, & Kandlikar, 2011). For example, the 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 (Simon, Bumpus, & Mann, 2012). Rigorous early reductions in greenhouse gas emissions and energy efficiency are key to maintaining global warming to below 1.5 °C by 2100 (Rogelj et al., 2015).

Over the last 30 years, awareness has grown concerning the environmental and social costs of using traditional fuels and stoves as well as knowledge about how to reduce emissions from such fuels (de Koning, Smith, & Last, 1985), (Omer, 2008). Despite this, the improved stoves currently available to customers do not always conform to best practice or are not designed based on modern engineering and scientific theories. **Figure 1** represents a design based on modern engineering and scientific theories.

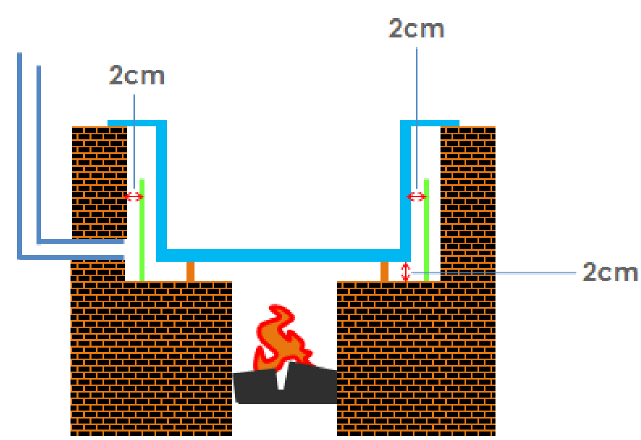

Figure 1: Clean institutional cookstove (IC) design.

The knowledge required to design cleaner biomass burning stoves exists in centers of excellence in several locations. Providing this knowledge and information to those involved in promoting improved stoves is a necessary first step to aid in the reduction of indoor air pollution occurrence and exposure, the quantity of biomass usage, as well as mitigating climate change impacts, and enhancing improvements in work conditions, which in turn will enhance health conditions. The aim of this research was 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 objectives of our research are to transfer the clean IC technology to ORI as a case study 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 compared to open fire or traditional biomass energy systems, infer implications for climate change mitigation, and analyze the potential and costs of using the clean IC as a substitute for open fire or traditional biomass energy systems.

2. Background

2.1 Evolution of the clean institutional cookstove technology

IC technology has undergone 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 temperatures (Commeh, 2014). At the turn of the century, an improved and advanced cookstove research program was initiated with the objective of developing a clean, low cost, effective and efficient stove with less fuel usage, improved health benefits, that is environmentally sustainable, and can be manufactured and applied in developing countries (Jacobsen, 2012). 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 gases into the atmosphere and to provide a draft that allows for complete biomass combustion (**Figure 2**, **Figure 3**). Good management of the fuel results in the generation of clean energy. The IC has the potential to reduce firewood usage by up to 85 % according to previous experimentations as compared to open fire. It has improved clean fuel operations with a possible reduction of up to 95 % in smoke generation (Commeh, 2014).

Previous work proved that it is possible to achieve new design, cooking pot, energy efficiency and effective clean IC configurations that can be fabricated using local craft skills, existing industrial infrastructure, readily available simple hand tools and local materials (Commeh, 2014). These can be achieved by employing an integrated design method based on feedback from users in combination with social and cultural lessons or inputs.

The clean IC technology consists of ceramic bricks on the exterior and insulating bricks on the interior, including the fire magazine (**Figure 2**, **Figure 3**). The cooking pan sits completely in the cavity, not allowing smoke or heat to escape except up the chimney. A mortar comprises of a mixture of clay, calcined kaolin and sometimes fine screened sand and cement mixed with water.

2.2 Clean institutional cookstove design features

The clean IC design operates via a temperature and heat transfer mechanism through the optimal combustion of firewood in order to reduce smoke and enhance the efficiency and effectiveness of the cooking. With the adopted design at ORI, the fire magazine is shifted off the stove centre to the side for 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. 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. The addition of wood ash to cement has been proven to result in a mortar of acceptable quality in terms of durability and strength (Cheah & Ramli, 2011).

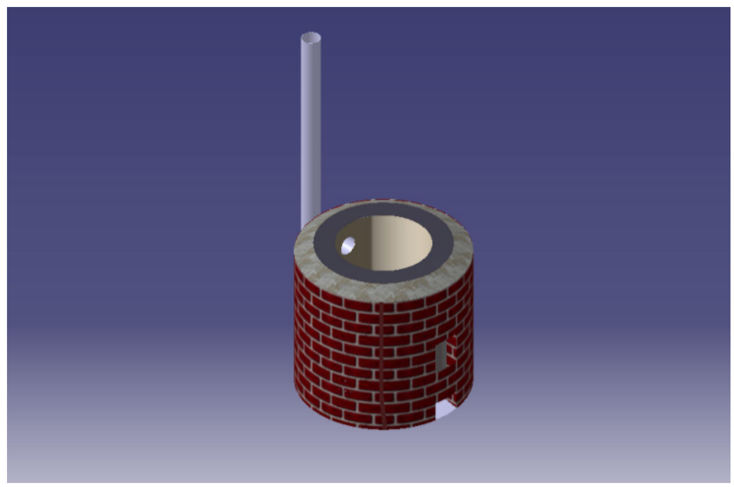

Figure 2: Pictorial view of the clean IC (Commeh, 2014).

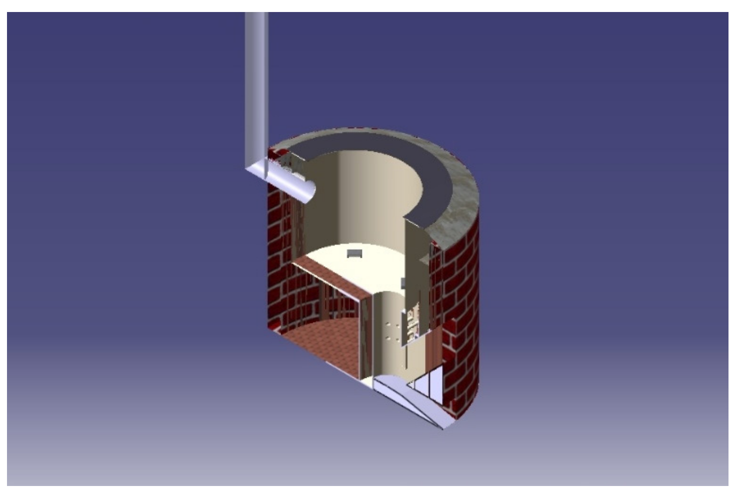

Figure 3: Cross sectional view of the clean IC design (Commeh, 2014).

2.3 Technology transfer into Botswana

ORI, in collaboration with the Technology Consultancy Center (TCC) at the College of Engineering of KNUST, initiated research investigating the potential of adopting and adapting ICs into Botswana. This follows a successful implementation of the IC in Ghana by the TCC in collaboration with SNV Netherlands Development Organisation, through engaged research and innovation of the potential of IC in Ghana at the Applied Industrial Ceramic and Rural Energy and Enterprise Development Unit (AIC - RED) of TCC. This IC uses the theory of heat and temperature transfer (Lienhard & Lienhard, 2008) as the principle for selection of the construction materials and design of the stove. The theory serves as a platform for potential technological improvements and the development of new technologies associated with biomass stoves.

In order to serve as a platform to launch into other biomass stoves projects, eg. clean ICs, Ghana Alliance for Clean Cookstoves and Fuels (GHaCCOF) arranged for a financial cost sharing agreement with Kumasi Secondary Technical School (KSTS) with technical support from TCC, to construct an improved IC at the KSTS kitchen. The aim of this initiative was to demonstrate the importance of clean cooking to other schools and institutions through practical learning exhibitions. The initiative also allows students to conduct further research into the commercialization of the product and led to the development of study strategies that will help improve, maintain and sustain the technology.

Although improved and advanced biomass cookstove technology is relatively new on the Ghanaian market, its dissemination across the African continent can be promoted through technology transfer and engagement of non-government organizations (NGOs) such as the Turkson Foundation, government ministries, policy makers, and higher education institutions. The project was self-financed with the construction costs for the clean IC covered by researchers; facilities and housing were provided by the University of Botswana. A similar approach is deemed necessary to ensure technology transfer from Ghana to Botswana. This will also allow for collaborative research by all the involved researchers. The researchers observed wastage of fuelwood through the open fire cooking method at a primary school in Maun (Botswana), where the clean IC could be introduced and promoted to other institutes (**Figure 4**).

Figure 4: Cooking method at a primary school in Maun (Botswana), showing the wastage of fuelwood Source: authors.

3. Materials and Methods

3.1 Study area

The clean IC technology transfer was performed at ORI in Maun (**Figure 5**). The study area is located in the Cubango-Okavango River Basin, where a high percentage of people live in poverty. The use of firewood as an affordable means of cooking is preferred by the majority of people in this region who live in rural areas. Institutions such as government schools in the area rely on firewood for cooking purposes. Therefore, technological interventions such as the transfer of clean cookstoves are of paramount importance.

3.2 Materials

Most of the materials needed to construct the clean IC were available locally similar to the case in (Commeh, 2014), though not as prescribed in the original design documents. They were however suitable for achieving comparable results. The materials were purchased at a local market and some were available at the metal shops in Maun. Major components purchased for construction of the clean IC were: 10 cm square galvanize 1.0 mm thick chimney pipe; 75 L aluminum cooking pot with lid; 18 cm^2 metal grate; burnt clay bricks; cement; sand; 0.5 cm granite gravels; mild steel metal 55 cm diameter disc; water; refractory mortar (locally prepared with wood ash); iron rods; corrugated iron sheets; and fuelwood.

3.3 Construction

Construction of the clean IC started with setting the plan on the ground with bricks, and laying the air inlet and firewood magazine positions, which serve as a framework for the foundation. The next step was bricklaying, with cement mortar comprising seven to eight layers of bricks at a time. Refractory cement made of a mixture of cement, ash and sand was used for laying bricks in high temperature areas. Insulating bricks were used for construction of the IC.

3.4 Performance test

A performance test consisted of boiling water and determining the amount of fuelwood consumed. The fire was prepared using mopane wood to operate the clean IC. The weight, length and circumference of fuelwood pieces used were measured. After the fire was ready, a 75 L stainless steel pan was filled with water and placed inside the pot cavity. The time required and fuelwood used to boil the water was recorded. Seven replicate tests were performed. A control experiment was conducted using the open fire method to boil 75 L of water.

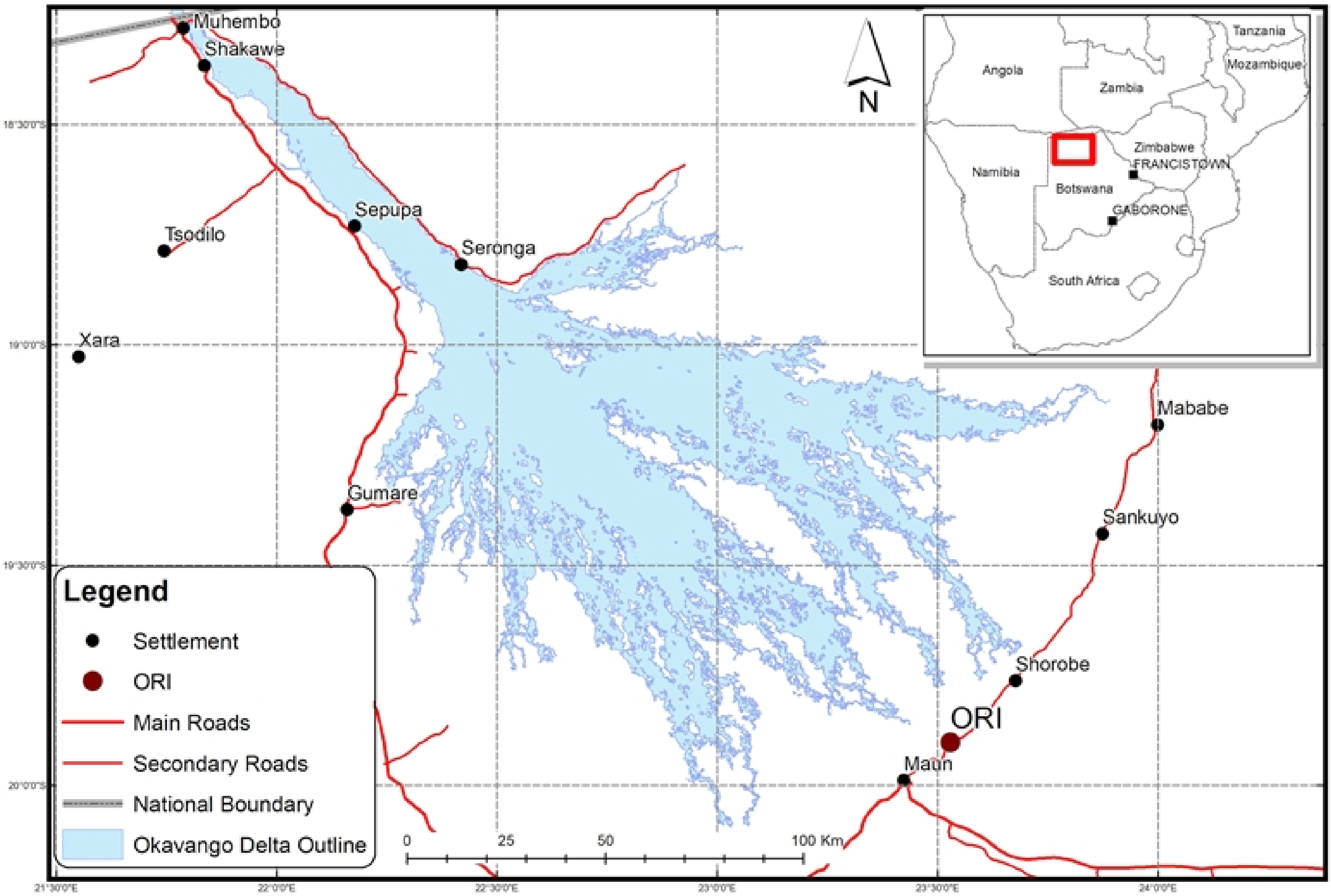

Figure 5: Map showing the location of ORI within the Cubango-Okavango River Basin, Southern Africa.

4. Results and Discussion

4.1 Technology transfer

The clean IC technology transfer was successfully performed at ORI, before testing its efficiency and assessing the financial viability. This section includes results and discussions on the performance and potential financial viability of deploying the technology in schools in Botswana. Figures 6a and Figure 6b show the completed clean IC at ORI.

4.2 Water boiling test results

Our results indicate that the IC performances are consistent with the previously reported information (Commeh, 2014). For example, the new IC at ORI can boil 75 L of water in 55 min using 3.0 kg - 4.5 kg of firewood. A control experiment using an open fire to boil 75 L of water took 83 min. The boiling of water was achieved in two-thirds of the time taken by the control experiment. The amount of firewood used was 10.5 - 14.7 kg in the control experiment. The IC used only 30 % of the firewood in two-thirds of the time. Therefore, the IC is far more efficient when compared to the three stone traditional stove. This efficiency could be enhanced further through the implementation of innovative ideas such as skirting the pot cavity and lowering the cooking pot to a 2 cm gap from the base of the pot cavity. A 3.5 cm gap was used for our ORI design.

4.3 Fuelwood and fire management

The fuelwood that was used to test and run the clean IC consisted of mopane tree wood pieces. They were purchased from the common market. The fuelwood pieces were came from dry dead trees of unknown sizes. Table 1 shows information regarding the weight, length and circumference of the fuelwood pieces. The average biomass weight for fuelwood pieces was 1.04 kg. 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 47 cm and circumference of 19 cm are optimal for our case. Pieces that do not fall within this category produce more smoke and reduce fire temperature.

Figure 6a: A completed clean IC at ORI.

Figure 6b: A close-up of completed clean IC at ORI.

After two weeks of sun drying a sample of fuelwood used for testing the stove; the average dry biomass weight of fuelwood pieces was 0.94 kg. Therefore, the water content of the fuelwood sourced directly from the market was calculated at 9.5 %. Water content affects fuelwood combustion efficiency and fire temperature. Direct combustion of biomass technology accounts for about 97 % of global bioenergy production (Cheah & Ramli, 2011). The same technology is applied in the clean IC; hence the use of wood with low water content would improve our results.

Table 1: Fuelwood size descriptions (number of pieces = 44)

Descriptive Statistics	Weight (kg)	Length (cm)	Circumference (cm)
Mean	1.041	57.3	18.9
Minimum	0.467	43.0	14.5
Std. Dev.	0.314	6.3	2.7

4.4 Implications for climate change mitigation

Carbon dioxide is absorbed or sequestered during biomass growth and emitted during combustion (Demirbas, 2004). Furthermore, high water content in wood is associated with an increase in carbon dioxide evolution during combustion or decomposition (Boddy, 1983). Therefore, using fuelwood with low water content would increase combustion efficiency, reduce carbon dioxide emissions and reduce the time taken to boil water. In addition, it would improve the energy efficiency of the clean IC and reduce the amount of wood needed to boil water. Our results indicate that the open fire method consumes more fuelwood than the clean IC; hence the open fire method significantly contributes to greenhouse gas emissions associated with fuelwood. A study by Johnson, Edwards, Alatorre Frenk and Masera (2008) found a reduction in organic carbon within the aerosols fraction emitted from improved cookstoves compared to open fires. Therefore, the reduction in greenhouse gas emissions from fuelwood combustion via the use of clean IC technology provides opportunities for climate change mitigation in Botswana.

Generally, biomass has less carbon than coal (Demirbas, 2004). Thus, there is merit to a decision to use fuelwood for cooking in schools in a semi-arid country such as Botswana where coal is abundant. Mopane and miombo woodlands form part of the savanna woodland ecosystem in Southern Africa (Fuller, 1999), which is deforested by local communities for fibre and fuelwood (Dewees et al., 2010). The challenge of how to ensure sustainable utilization of biomass carbon pools through reduced deforestation, afforestation and enhanced conservation of forest and woodland resources remains. Adoption of the clean IC for cooking in schools that use the open fire cooking method coupled with afforestation programs offer a potential solution to address this challenge.

4.5 Financial viability analysis of the clean IC

The cost of one Hilux truck of firewood was US$ 25-30 in 2015. An institution such as a primary school with 120 students uses a maximum of 12 trucks of firewood per term when an open fire cooking method is used. This amounts to an annual cost of US$ 990. A financial analysis of the clean IC showed a potentially marked reduction in money spent on firewood, with annual savings of about US$ 660, and a payback time of two years and 5.5 months, as calculated by the following equation:

Payback time = initial investment / yearly net cash flow

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

4.6 Sociocultural barriers to the adoption of the clean IC

Although our results indicate that the clean IC has the potential to reduce the amount of fuelwood consumed and greenhouse gases emitted during food preparation compared to the traditional open fire method at locations where food is prepared in large quantities, there are some sociocultural barriers that could make the technology socially unacceptable at the household level. For example, during presentations of our results at a youth workshop in Maun, youth participants indicated their preferences for continuing to use firewood in order to maintain cultural values. Responses obtained from this group were: “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 generation to generation?”; and “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”. Additionally, similar sentiments were expressed at a seminar held at ORI, as was captured during our discussions. These included: “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 places 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”; and “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.” Kumar, Kumar and Tyagi, (2013) assert that cooking, especially the roasting of meat, was historically performed mostly over an open fire; a process that is still widely preferred in developing countries, including Botswana, where meat is among the staple foods. The clean IC will not interfere with traditional beliefs and norms at household levels because the technology will be transferred to schools. According to Yaqoot, Diwan and Kandpal, (2016), factors that affect the dissemination of new technologies are the inappropriateness of technology, unavailability of spare parts, unavailability of skilled manpower for maintenance, high cost, lack of access to credit, poor purchasing power and other spending priorities. All these points were taken into full consideration when transferring the technology from Ghana to Botswana.

5. Conclusions and Future Work

Clean cookstoves offer the best substitute for open fire biomass stoves and increase comfort through cooler ambient temperatures. The first clean cookstove prototype was successfully built and tested. It consumes two-thirds less firewood than the open fire cooking method. A financial viability analysis of the clean IC revealed the potential for a marked reduction in money spent on fuelwood by primary schools. The use of clean cookstoves will enable enhanced carbon sequestration by live mopane woodland resources. The challenge of how to ensure sustainable utilization of biomass carbon pools through reduced deforestation, afforestation and enhanced conservation of forest and woodland resources remains. Adoption of the clean IC for cooking in schools that use the open fire cooking method coupled with afforestation programs offer a potential solution to address this challenge. Demonstrations of the clean IC technology to cooks and teachers at primary schools yielded positive results because they expressed interest in having the technology deployed in their schools for cooking purposes.

Our results indicate that the clean IC has the potential to reduce the amount of fuelwood consumed and greenhouse gases emitted during food preparation compared to the traditional open fire method. However, there are some sociocultural barriers that could make the technology socially unacceptable at a household level. Therefore, a comprehensive analysis of cultural barriers will be carried out during the pilot construction phase of the clean cookstoves in selected schools before full deployment occurs. Further improvements in the energy efficiency of the clean IC are also possible through engagement with users on usage of optimally sun dried wood and new pot designs. The potential adaptation of the IC technology into the three-legged pot will also be explored in order to consider maintaining existing traditional practices in the country. Our future outlook is to deploy the technology to all schools that use fuelwood for cooking, in Botswana and Cubango-Okavango River Basin starting with piloting the technology in selected schools before full deployment occurs.

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