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Implications on Livelihoods and the Environment of Uptake of Gasifier Cook Stoves among Kenya's Rural Households

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Abstract: A majority of people in developing countries use biomass energy for cooking and heating due to its affordability, accessibility and convenience. However, unsustainable biomass use leads to forest degradation and climate change. Therefore, this study was carried out in Kwale County, Kenya, on the use of a biochar-producing gasifier cook stove and implications of its uptake on livelihoods and the environment. Fifty households were trained and issued with a gasifier for free. After 2–3 months of gasifier use, a survey was conducted to investigate the implications of its uptake. The direct impacts included reduced fuel consumption by 38%, reduced time spent in firewood collection, reduced expenditure on cooking fuel, diversification of cooking fuels, improved kitchen conditions and reduced time spent on cooking. The potential benefits included income generation, increased food production, reduced impacts on environment and climate change and reduced health problems. Improved biomass cook stoves can alleviate problems with current cooking methods, which include inefficient fuel use, health issues caused by smoke, and environmental problems. These benefits could contribute to development through alleviating poverty and hunger, promoting gender equality, enhancing good health and sustainable ecosystems and mitigating climate change. The study recommends the promotion of cleaner cooking stoves, particularly gasifiers, among households in rural areas while paying attention to user needs and preferences.

Keywords: gasifier cook stove; biomass energy; households; livelihood; environment; biochar

1. Introduction

In 2013, World Energy Outlook reported that over 2.7 billion people globally were reliant on solid biomass with inefficient stoves and cooked in poorly ventilated places [1]. A majority of these people reside in low- and middle-income countries [2]. More than 700 million people in Africa and 90% of rural households in Kenya currently use biomass fuels for cooking and heating [3,4].

Biomass is expected to continue being the main source of energy in Sub-Saharan Africa (SSA) for the foreseeable future [5]. However, in Kenya there is a 27% and 55% deficit for firewood and charcoal, respectively [6], hence the need for the development of technologies that enhance efficiency in the utilization of biomass energy. Women and girls have the responsibility for firewood collection [7], which is hard work and a life-threatening exercise [8]. Firewood scarcity and the use of inefficient stoves makes the situation worse, as women must walk farther to find the resource and consequently lose time for other activities [9] such as income generation and education. The wood burned with inefficient stoves is converted into pollutants which impact the environment and human health [10]. Around 2%–7% of global anthropogenic greenhouse gas emissions are from the production and use of firewood and charcoal [11]. Globally, over 4.3 million deaths occur annually from illnesses associated to household air pollution, mainly affecting women and children who spend much time in the kitchen [12]. The introduction and adoption of improved cooking systems would be one step in the right direction towards sustainability [13–15].

The gasifier is a pyrolytic stove that produces its own gas for the production of heat for household cooking and char as a by-product [16]. The dual benefits of these changes help to reduce fuel consumption and emissions. If the produced char is used as soil amendment (known as biochar), it sequesters carbon and can increase crop yields [17]. The United Nations Sustainable Development Goals (SDGs) are a universal call to action to end poverty, protect the planet, and ensure that all people enjoy peace and prosperity [18]. Among the goals, SDG 7 targets access to affordable, reliable, sustainable and modern energy services for all by 2030 [19]. Clean cooking solutions could be realised through the uptake of improved stoves and may also contribute to the fulfilment of other SDGs, such as health, gender equality, "life on land", poverty alleviation and hunger eradication. Kenya's draft National Energy and Petroleum Policy and Vision 2030, among other planning documents, acknowledge access to affordable and cleaner cooking and heating energy as key to development.

Research on the use of gasifier cookstoves for biochar production has shown the potential to reduce emissions and fuel consumption [20,21], but there is a need for knowledge on the implications of their uptake from the users' perspective, which this study contributes to. Further, a systematic review by Vigolo et al. [22] reported low awareness on the environmental and health impacts of improved cook stoves by stove users. The aim of this study was therefore to assess the benefits of top-lit-updraft (TLUD) (natural draft) gasifier cook stoves (hereafter "gasifier") uptake from a holistic perspective, based on data obtained from a survey of the 50 households in Kwale County in Kenya who were issued with gasifiers for free. From the survey, the factors that affect cookstove uptake have been reported [23]. This paper focuses on direct and indirect implications of uptake from the users' perspective. The study was part of the "Farm-level production and use of biochar in Kenya" project which ran in two phases 2013–2016 and 2016–2019 and aimed to tackle issues of energy, soil fertility and health among smallholder farmers through the use of biochar-producing gasifier cook stoves.

2. Materials and Methods

2.1. Study Area

The study was carried out in Waa ward, Kwale County, Kenya (Figure 1). Waa ward has a population of 37,783. Kwale County lies about 33 km south of Mombasa (4.18° S, 39.45° E; 323 m above sea level) [24]. The county has a monsoon-type of climate, with mean annual temperature of 24 °C. Farmers in the area grow crops such as maize (*Zea mays*), cassava (*Manihot esculenta*) and cowpeas (*Vigna unguiculata*), and trees such as coconut (*Cocos nucifera*), mango (*Mangifera indica*), citrus (*Citrus spp.*), and cashew nut (*Anacardium occidentale*) for subsistence consumption or commercial purposes [25]. They use crop and tree by-products as fuel. Trees are also grown as a source of construction material, and prunings and offcuts are used as cooking fuel.

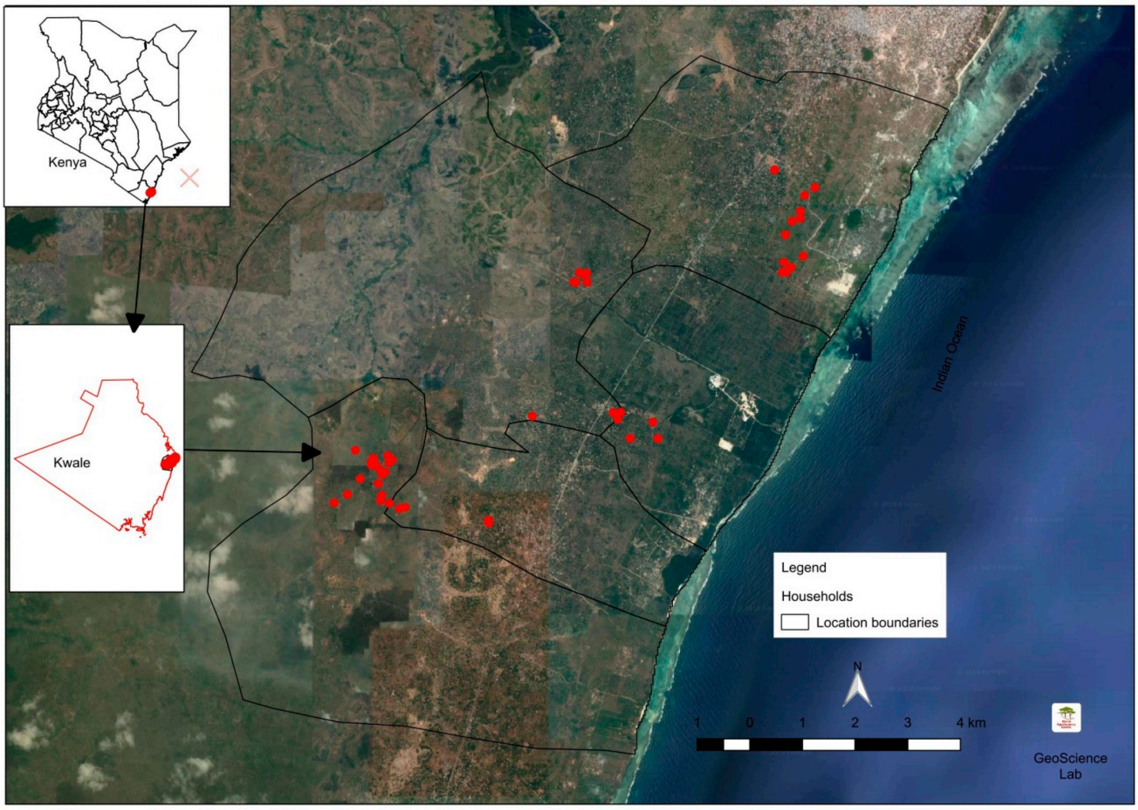

Figure 1. Map of the study area, Waa ward, Kwale County, southern Kenya.

2.2. Selection of Households and Training in Gasifier Use

The study respondents were the 50 households who participated in the baseline survey of the first phase of this project on biochar and smallholder farmers in rural Kenya. The selection criteria included that the households were to be smallholders and cover a range of socio-economic and socio-demographic variations, be available and willing to participate in the new innovation (i.e., gasifiers) which was being tested. The interviewed households had five members on average, where 52% of the female parents of these households had not completed any level of education, while 34%, 6%, 6% and 2% had primary, secondary, tertiary and university education, respectively [23]. Representatives from the 50 households were trained in gasifier use in October 2016 using a standard manual, given the stoves and asked to save the char produced for upcoming field participatory trials on biochar. Trained males who were not the stove users were urged to transfer the skills to the cooks in their households.

2.3. Gasifier Cook Stove

A TLUD gasifier model, brand name "GASTOV" (Figure 2), from The Kenya Industrial and Research Development Institute (KIRDI) was used in this study. The original model of the TLUD gasifier was developed by Anderson and Reed [26]. This model was selected by the research team after households in rural Kenya reported the galvanized gasifier they were issued with in an earlier phase of the project to pose some functionality challenges [20].

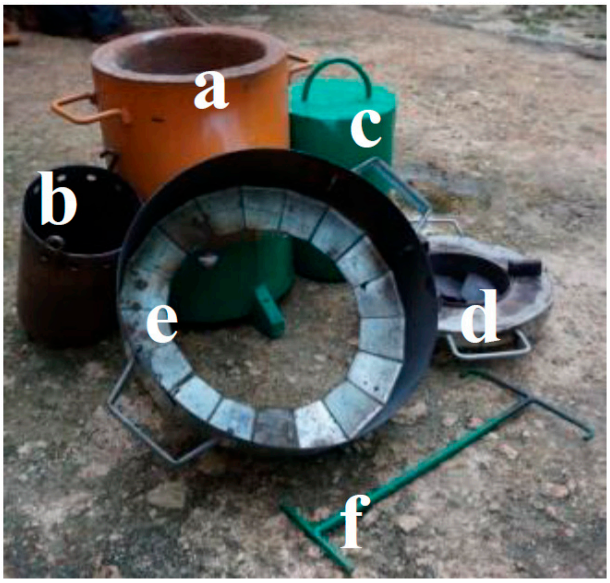

Figure 2. Gasifier (model GASTOV), comprising (a) an insulated casing with a 5.5 cm × 4.5 cm air entry vent that can be regulated at half or full height at the bottom, (b) fuel canister in the middle (19 cm high), (c) charcoal cover (snuffer) used to cool the charcoal by cutting off oxygen, (d) gas combustion chamber (6 cm high) on top as the main burner, fitted with a skirting (e) to hold the pot in position and protect flames from wind and (f) a canister holder.

2.4. Household Survey

Representatives from the 50 households issued with the gasifier were interviewed after 2–3 months of stove use using a semi-structured questionnaire. This aimed to find out how the gasifier was being incorporated into households' cooking system, the benefits and challenges of its use [23], the amount of fuel used by the household before and after receiving the gasifier, the time spent on collecting fuel and the sources of the fuel. The perceptions of the household representatives about the gasifier compared with the conventional three-stone open fire and households' willingness to continue using the gasifier and harvesting of the charcoal produced were also studied [23]. Before the household survey a focus group discussion (FGD) was held with representatives from 20 households with the aim of assessing the availability of biomass fuel types. During the FGD, householders identified and ranked the various fuels they used with the gasifier. Samples of the fuel types were displayed, and the householders were given 50 counters (small stones) and asked to rate the characteristics of the fuels by allocating the stones among the different fuel types displayed (Figure 3).

Figure 3. Householder ranking fuels with contributions from other householders in Kwale, Kenya.

2.5. Data Analysis

Data were entered into a computer using IBM SPSS version 24 and Microsoft Excel programmes. The data were analysed to obtain insights into the impact of gasifier uptake on livelihoods and the environment. A t-test was used to test for significant differences in the amount of firewood used and amount of firewood bought before and after introduction of the gasifier, with the significance level set at $p < 0.05$.

2.6. Limitations of the Study

This study was limited in that it only focused on one type of the gasifier, branded as GASTOV. This study also looked at the uptake of the gasifier after 2–3 months of use and not sustained long-term use, and the results discussed are based on users' perceptions. It is also the case that the number of participants was relatively small so as to study users' perceptions without funds limitations.

3. Results and Discussion

3.1. Stoves Used by the Households before the Gasifier

About 98% of the households reported using a three-stone open fire or other type of stove before the introduction of the gasifier (Figure 4) [23]. The most common combination was a three-stone open fire and a charcoal stove, practised by 22% of households. The three-stone open fire was reported by users to emit more smoke than the gasifier.

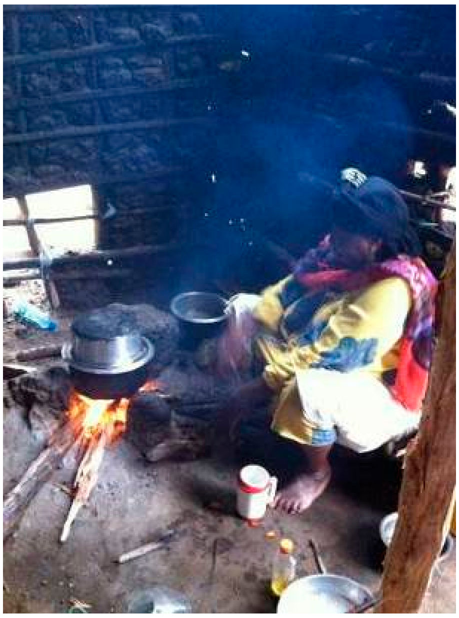

Figure 4. Three-stone open fire in use at Kwale, Kenya.

3.2. Direct Impacts of Gasifier Uptake on Household Livelihoods

3.2.1. Reduced Fuel Consumption and Time Spent in Collecting Firewood

Since the start of gasifier use, 94% of the households reported a decrease in the amount of firewood used (measured as headloads). A headload of firewood in the study area weighs 35 kg on average [23]. These households reported using eight headloads (280 kg) and five headloads (175 kg) on average per month prior to and after gasifier introduction, respectively, and thus a significant reduction in firewood use of on average 38% (t-test, $p = 0.0002$). Fuel saving by the gasifier extended the period of households' fuel supply. Before having the gasifier, 94% of households used a headload of firewood for five days on average and for eight days after receiving the gasifier. Thus, the length of time that firewood lasted in the household was increased by 60%.

Similarly, improvements in fuel savings by improved stoves have been reported previously. In rural Kenya, participatory cooking tests showed a reduction in fuel consumption by 40% compared with the three-stone open fire [20]. A study undertaken in Ethiopia reported a 38% fuel saving after switching from three-stone open fire to an improved cook stove [27]. Moreover, in Khairatpur village in rural India, the use of improved cook stoves lowered annual consumption of fuel by 41% compared to traditional stoves [28].

Due to reduced fuel consumption, the time spent on firewood collection was also reduced for 98% of the households. The firewood sources included natural forests, with households sourcing from it spending 3 h on average to collect one load of firewood, friends' farms (2.8 h), community land (4.5 h), private plantations (2 h) and on-farm (1.4 h). Even though fuel collection is not a daily activity, the use of inefficient cook stoves like the three-stone open fire by households can mean many hours spent on collecting fuel. Households spent on average 11 h per month collecting firewood (eight headloads) before the introduction of the gasifier and 7 h (five headloads) after the gasifier was introduced. Similar findings on saving time spent on firewood collection had been reported previously. For instance, after switching to improved cooking stoves from three-stone fires in the Dadaab refugee camp in Kenya, the number of times women needed to walk for 4 h to the forest to collect firewood per week was reduced by 2 times [29]. Further, a 32% reduction in the annual time spent collecting firewood has been reported in Idifu village in Tanzania as a result of using improved cook stoves rather than three-stone open fires [30], while in Chamwino and Kongwa districts in Tanzania 50% saving of fuel collection time was reported [31]. The differences in time saved in various geographic locations are dependent on the distribution of firewood sources and the wealth of appropriate vegetation. The women in the study area are main firewood collectors (Table 1) and they carry the loads of firewood from the various sources [23] on their heads (Figure 5). Firewood collection is hard work for women, is dangerous, and limits the time for productive activities [8]. However, users reported spending more time preparing fuel for the gasifier compared with the three-stone open fire, so there could be trade-offs in time spent in fuel collection versus fuel preparation.

Figure 5. Women at Kwale, Kenya carrying headloads of firewood from a private plantation.

Table 1. Household members involved in firewood collection, according to the present survey.

Member(s) of the Household Involved in Collecting Firewood	Percent of Households
Female head only	30.6
Male head + female head	16.3
Female head + young female + young male	22.5
Female head + girls + boys	16.3
Male head only	4.1
Young male only	2.0
Male head + female head + girls	2.0
Female head + young female + boys + girls	2.0
Male head+ female head + young male + young female	2.0
Female head + young female + hired labour	2.0

Girl/boy <18 years, young male/female 18–35 years.

3.2.2. Reduced Expenditure on Cooking Fuel

The survey showed that 26% of households bought some or most of the firewood they used, with 85% of them buying headloads and 15% handcart loads. These households bought firewood 1 to 10 times per month. A headload of firewood cost 50 KES (0.5 USD) on average. There was a significant difference ($p = 0.003$) in the number of headloads of firewood used before and after gasifier by the 26% of households that bought firewood and a 38% decrease (400 KES (4 USD) to 250 KES (2.5 USD)) in the amount of money spent on fuel after the gasifier was introduced. The gasifier can use fuel materials from tree pruning and crop residues, which are accessible on-farm (Figure 6a), hence reducing the need to buy firewood, which could constrain the household budget [32].

(**a**) (**b**)

Figure 6. (**a**) Biomass from the farm ready for use in the gasifier and (**b**) the charcoal produced.

Before receiving the gasifier, 42% of the households cooked with charcoal which they obtained either through purchasing, making on their own farms, collecting from friends' farms or picking from the remains of three-stone open fires. Of the households that used charcoal, 71% bought it in various units of measure. For example, seven reported using half a bag per month, costing 500 KES (5 USD) on average. The gasifier produces charcoal (Figure 6b) and 98% of the households using the stove also harvested the charcoal. Eighty-five percent of these households stored the charcoal produced, as they were asked to in the research project, and had collected 0.5–13 kg of charcoal (average 5.1 kg per household) after approximately 2.5 months of gasifier use. This amount of charcoal was collected from gasifier stoves being used nine times a week [23]. On average, 63% and 37% of the households using the gasifier for fast-cooking and both slow and fast cooking foods collected 0.10 kg and 0.13 kg of charcoal, respectively, for each day they used the gasifier. With daily use of the gasifier, these households have the potential to increase their charcoal collection rate from 2 to 3 kg and from 2.1 to 3.9 kg of charcoal per month, respectively. Even though the households were requested to store the charcoal they produced for an upcoming biochar field participatory trial, 23.4% of the households were using it to cook and hence reducing money spent on charcoal.

3.2.3. Reducing Time Spent on Cooking

Fifty percent of the households using the gasifier reported spending less time cooking compared to three stone open fire [23]. This was mostly for the fast-cooking food types which did not need fuel refilling. Foods that took longer to cook required more of the cook's time because fuel reloading was necessary at some point during the cooking process. Use of a larger TLUD gasifier by rural households in Kenya was reported to save 18% of time that would have been spent on cooking if using the three-stone open fire [20]. In Idifu village in Tanzania, the time spent on cooking was reduced by 20% when an improved cook stove was used instead of a three-stone fire [30]. However, arranging fuel in the canister and lighting fuel takes more time than with three stone open fire.

3.2.4. Improved Kitchen Conditions

Ninety-eight percent of households reported that the gasifier helped maintain kitchen cleanliness, especially of the cooking pots. This is attributed to the reduced smoke production by the gasifier compared with an open fire as reported by all the households. As a result, the users noted less soot on the cooking pots and anticipated less soot will stick to the kitchen walls and roof with the use of the gasifier. Consequently, less time is spent on cleaning pots after cooking. Being a portable stove, gasifier users were trained to light it outside, this further reducing smoke inside the kitchen. Even though this contributes to outdoor air pollution, air movement reduces the concentration compared with, for example, lighting a stove inside the kitchen. In a study in rural India, it was found that cleaning the soot-laden pots due to use of inefficient stoves, when added to other work done by women like cooking and fuel collection, brought the women's time spent on these activities to around three hours per day [32]. Households in Idifu village in Tanzania cited reduction in smoke from improved cook stoves compared with three-stone fires as the main advantage of the former [30].

For 95.8% of the households using the gasifier, they had been asked about it by their friends, with some referring to it as wood gas. These households are probably seen as much better by owning the gasifier, which has lower emissions than the three-stone open fire. This agrees with the claim that ownership of efficient and less-polluting stoves raises a woman's prestige, directly by being a sign of wealth and indirectly through reduced exposure to smoke [32]. Improvements in cleanliness of the gasifier may also encourage men to participate in cooking, as has been found following the adoption of biogas in Uganda [33].

3.2.5. Diversification of Fuel Types Used

Firewood and crop residues were used by the households as cooking fuel. The commonly used fuels and ranking of their qualities when used with the gasifier by 20 householders who participated in a FGD are presented in Table 2.

From the householders' perspective, the fuels that burned for a longer period and with a hot flame were rated higher. Householders rated neem as the best, with most scores given to the production of good charcoal. Coconut shell was rated as having the hottest flame (Table 2). Coconut shell achieved high scores despite burning for the shortest period, possibly because it is easy to prepare and ignite. Burning for a longer period could probably be the reason mango received the third-highest ranking despite its flame not being very hot (Table 2).

The survey showed that biomass types varied between the two regions, and that this influenced the frequency of their use (Table 3). For most fuels, the more accessible it was, the more frequently it was used as cooking fuel, as was the case with neem at Ng'ombeni and cashew nut firewood at Matuga (Table 3). However, fuel types such as coconut shell and maize cobs had a lower frequency of use even where they were available. This could be due to their shorter burning period, which necessitates reloading the stove before meals can be cooked fully an exercise reported to be challenging by the gasifier users.

Table 2. Ranking by householders of the fuels used with the gasifier cook stove, based on different fuel qualities.

Fuel	Easy to Prepare	Charcoal Production	Easy to Light	Hot Flame	Burning Period	Total Score
Neem (*Azadirachta indica*)	4	20	5	15	18	62
Coconut (*Cocos nucifera*) shells	12	4	20	20	3	59
Mango (*Mangifera indica*) firewood	8	8	4	5	15	40
Maize (*Zea mays*) cob	18	3	10	1	4	36
Casuarina (*Casuarina equisetifolia*)	3	10	8	7	5	33
Cashew (*Anacardium occidentale*)	5	5	3	2	5	20
Total	50	50	50	50	50	250

Table 3. Availability and frequency of use of fuels commonly used with the gasifier in different areas of Kwale County.

Fuel	Availability		Frequency of Use	
	Matuga	Ng'ombeni	Matuga	Ng'ombeni
Coconut shell	5	3	3	3
Casuarina	4	4	5	15
Mango firewood	11	10	15	7
Cashew nut	20	7	18	4
Neem	7	24	7	19
Maize cob	3	2	2	2
Total	50	50	50	50

The gasifier diversifies the feedstock used by households, as it can use crop residues and firewood. During one of the cooking demonstrations, 0.63 kg of neem tree firewood or 0.7 kg of coconut shell mixed with coconut leaf stalk was required to cook 2 kg of *ugali*, a starchy Kenyan dish made by vigorously stirring water and maize (*Zea mays*) flour. Most households using a gasifier sourced their firewood on-farm from tree prunings and crop residues, which can both be used with the gasifier. However, the residues used with the gasifier were leaving airspaces in between the individual pieces for the air flow which is necessary for combustion. They included coconut shells, maize cob, cassava stems, doum palm tree (*Hyphaene compressa*) seeds. This confirms previous reports that pyrolytic stoves can expand available feedstock options, as they can use residues to supplement firewood [34,35]. This can be of benefit because in circumstances where cooking energy is limited, some households are forced to abandon nutritious but cooking-energy-intensive foodstuffs for less-nutritious and faster-cooking foods [36].

3.3. Potential Implications of Gasifier Cook Stove Uptake

3.3.1. Income Generation

Adoption of gasifiers can result in income generation opportunities:

a. Sales of gasifiers: During follow-up visits and discussions with the respondents, they reported that other households that had not received a gasifier were asking where they could purchase one. The perceived demand among households at the study sites represents potential for more uptake of gasifiers, which could mean job creation in gasifier manufacture and sale by local community. However, at the local level, this would require capacity development with facilities and training.

b. Sales of charcoal: Some or all the charcoal produced from the gasifier could be sold to generate income. This could apply for the 58% of households surveyed that were not using charcoal prior to introduction of the gasifier.

c. Chopping firewood: Chopping wood to use with the gasifier either manually (or otherwise) could be a source of income especially for the youth, as this was a challenge for 42% of gasifier users [23]. Women used a machete and men a saw to cut the wood. Women using a gasifier in rural Kenya also reported preparing fuel to use with the gasifier as an extra task not experienced while using the three-stone open fire [20].

d. Sale of surplus firewood from trees on-farm: As reported in Section 3.3.1, the gasifier uses less fuel than the three-stone open fire. Fuel consumption was reduced by three headloads of firewood (105 kg) per month after the gasifier was introduced, and if it was sourced on-farm and household decided to sell the saved firewood at an average price of 50 KES per headload in the area, they could raise 150 KES (1.5 USD) per month.

3.3.2. Increased Food Production

Application of biochar to the soil (Figure 7) results in increased crop yield and water retention capacity of the soil [36]. For instance, the average yields more than doubled after farmers applied the biochar produced from the gasifier to their maize plots at Kwale [37]. Increased yields could help the households to have enough food to feed their members and hence be more food-secure as well as save money spent on purchasing food. In instances where more food is produced, the excess could be sold to raise some income for the household.

Figure 7. Biochar being applied to soil at Kwale, Kenya.

3.3.3. Impacts on the Environment and Climate Challenges

a. Reduced emissions from cooking: Uptake of the gasifier, which has been reported to produce less smoke than three-stone open fires [23] can reduce the negative environmental impacts of biomass fuel use. The three-stone open fire burns wood inefficiently, turning it into pollutants like CO and particulate matter (PM) [13]. The introduction of improved cook stoves has been reported as an important way of reducing the negative effects on health and environment resulting from burning of biomass [14,15].

For example, compared with the three-stone open fire, the use of the gasifier in rural Kenya decreased emissions of CO and $PM_{2.5}$ by 45% and 90%, respectively [20]. In Ethiopia, there was an estimated 0.45–2.45 tonnes year^{-1} reduction in CO emissions per household through the use of improved cooking stoves compared with the traditional three-stone open fire [27]. The use of improved cooking stoves in Khairatpur village in rural India reduced the emissions of various pollutants by 30% [28].

b. Reduced fuel use: Compared with the three-stone open fire, the gasifier was reported to use less fuel by all the households that were using it. With reduced consumption of fuel and diversified use of various types of fuels such as tree and crop residues for cooking by the gasifier, there would be less felling of trees. Reduced collection of forest residues for fuelwood gives time for the forest to regenerate, seedlings to grow and nutrients to be recycled. Higher availability of agricultural residues which can be used for energy can result from higher agricultural productivity when biochar is applied to soil, and could ease pressure on available biomass resources [38].

c. Reduced emission from charcoal production: The gasifier produces charcoal as a by-product of the cooking exercise [16]. The use of a similar gasifier by rural households in Kenya had a biomass-to-charcoal conversion efficiency of 20% [20]. In traditional charcoal-making kilns, volatile gases are released into the environment, causing global warming. Much energy is also wasted in the conventional charcoal-making process, and this increases its carbon footprint [39]. In SSA, the traditional earth kilns have wood-to-charcoal conversion efficiencies of 8%–20% [40], and hence use large amounts of wood per unit of charcoal produced.

d. Carbon sequestration: when biochar is applied to soil, it remains in the soil longer than untreated crop residues, which decompose rapidly [38]. This way, carbon is sequestered, and climate change mitigated [41]. Biochar application to soils has been found to increase crop productivity, including the production of roots and aboveground residues, and therefore biogenic carbon storage [37]. In a recent life cycle assessment, the gasifier was reported to perform better than the three-stone open fire in terms of climate change impacts, avoiding 89% of the climate change impact caused by the traditional system [42]. It can also potentially offset greenhouse gas emissions caused by the traditional system, hence generating a net carbon credit [42].

3.3.4. Reduced Health Problems

The gasifier produces less smoke, hence reducing the concentration of pollutants in the kitchen. Smoke from inefficient traditional cooking practices penetrates deep into the lungs of the users, causing a range of chronic diseases which are deadly with chronic or acute health effects, which makes cooking on an open fire indoors one of the world's greatest, but least well-known, killers [43].

However, even though all the households mentioned liking the gasifier because it produces less smoke, only 4% of the households were using it exclusively while the rest combined the various stoves they owned to appropriately meet their cooking needs. However, a complete switch to a new stove can only be achieved if it fully meets households' cooking needs. Even though there are expected health improvements in women and children with improved cook stoves due to their lower emissions, the reduced levels still do not meet the World Health Organization (WHO) recommended levels [44], probably due to partial switching to improved stoves, which is not enough [45]. Furthermore, scientific evidence of health improvements in users of improved stoves is still inconclusive [46].

3.4. Contribution of the Biochar-Producing Gasifier Cooking Systems to Development

The aim of this work on improved cooking systems is in line with global, regional and national development agendas. As presented in the above sections of the paper, the gasifier cooking system for example has benefits that address the Sustainable Development Goals (SDGs) targeting ending poverty and hunger; good health and wellbeing; access to affordable, reliable and sustainable modern energy, with the sustainable energy for all (SE4ALL) global action agenda working towards achievement of the same [47]; gender equality and the empowerment of women and girls; ensuring sustainable consumption; combating climate change; and sustainable ecosystems. Priority area 4, 2023 target 6 of the first goal of Africa's Agenda 2063 aims at increasing the efficiency of household energy usage by at least 30% by 2023 [48]. Improving cooking systems is also included in Kenya Vision 2030, which talks about increased energy use efficiency as a key aspect in its realisation [49]. Further, Kenya's national energy and petroleum policy 2015 aims at promoting cleaner utilisation of biomass energy [50]. Biomass fuels are the largest source of primary energy in Kenya, with 69% of the total primary consumption being from wood fuel. Lack of efficient technologies for the conversion of biomass energy is one of the challenges of biomass use. Most households are currently using open fires, and they represent a golden opportunity to substantially improve the health, well-being and time poverty of women and children in a wide range of communities. This could be through the uptake of cleaner and more efficient stoves like the gasifier.

3.5. Challenges with the Use of the Gasifier Stove

Despite all the actual and potential impacts associated with the gasifier cook stove, according to our survey there are various challenges with its functionality. These challenges include the need to chop fuel to the required size, reloading fuel when charring occurs before the food is fully cooked, and lighting the stove [23]. These challenges were addressed through co-design, where the researchers observed the cooking process and later held an FDG with the users and discussed the findings with engineers at KIRDI for gasifier cook stove improvement, which could help enhance uptake. Other factors that can influence the uptake of the gasifier include household head education, household income, household size, fuelwood prices and access to credit [51,52] and not being able to perform certain tasks effectively such as warming space and easy roasting of foods [20]. Other factors highlighted to affect the adoption of improved cook stoves (ICSs) in the systematic review on drivers and barriers to clean cooking by Vigolo et al. [22] include low income, perception that ICSs are expensive, resistance toward new technology, rural locations and low awareness of the negative impacts of traditional cook stoves by the users. In this study, in order to investigate the user aspects without cost limitations, the households were given the gasifiers for free. Thus, it was not possible to examine issues related to the cost of the stove.

4. Conclusions and Recommendations

In conclusion, uptake of the gasifier cook stove can have positive direct and indirect impacts on household livelihoods and the environment. The gasifier uses less fuel and produces less smoke than a three-stone open fire. This provides direct livelihood impacts that include reduced fuel consumption, saving time spent on firewood collection and cooking, reduced expenditure on cooking fuel, diversification of cooking fuels and improved kitchen conditions. Income generation through the sale of charcoal produced, sale of further gasifier cook stoves, increased agricultural production from the use of biochar for soil amendment, as well as reduced environmental and health impacts are some of the potential indirect benefits of the gasifier. However, these benefits can only be realised if households use their gasifier cook stoves. The benefits deriving from uptake of the gasifier can contribute, either directly or indirectly, to the achievement of SDGs on energy security, health, sustainable ecosystem, hunger alleviation and gender equality.

We recommend more awareness campaigns and training to enlighten people on the benefits of improved cooking systems. Research and development organisations need to address the functionality challenges of cookstoves for enhanced uptake. Stove users need to be involved from scoping stages of stove development to capture their views on the kind of stove that they would prefer. Cleaner cooking systems—particularly gasifiers—need to be promoted among households in rural areas with consideration of user needs and preferences.

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