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Long-term viability of biochar-producing gasifier stoves for energy and agricultural solutions in rural Kenya

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ABSTRACT

This report examines the long-term usage and satisfaction levels of a biochar-producing gasifier stove among rural households in Kenya. The primary objective was to investigate the factors that influence stove satisfaction and dissatisfaction among participants, with the aim of assessing the gasifier stove's viability as an alternative for rural households. Data for this study was collected from representatives from 30 households through survey-based interviews covering cooking practices, fuel collection, and user experiences with the gasifier stove six years after receiving it. The findings indicate that households typically use multiple stoves. Almost all participants used the three stone stove on a daily basis, while the gasifier stove had a lower use frequency. Although households acknowledged the benefits of the gasifier stove, they expressed difficulties in relying on it as their primary cooking appliance due to its lack of convenience. The main contributing factors were the additional workload required for fuel preparation and the extended cooking time. Participants prepared various dishes using the gasifier stove, and the char produced by the stove was utilized for cooking, farming, and other purposes. The differences between users and non-users in terms of perception of stove benefits were small, though users appreciated the biochar production more than non-users. The study offers insights into the long-term usage of the gasifier stove and its dual potential as a clean cooking solution, and a biochar-producing technology, for rural households across the world.

Introduction

Approximately 2.4 billion people do not have access to clean cooking services globally (SEforAll, 2022). Most individuals in low- and middle-income nations rely on traditional open fire cooking as it is readily accessible, convenient, and suitable for various feedstocks. However, cooking over open fires results in harmful pollutants, leading to poor health outcomes, with household air pollution accounting for over three million deaths annually (WHO, 2022). Moreover, it contributes to climate change and deforestation (Clean Cooking Alliance, 2022). Despite efforts from governments and non-governmental organizations to accelerate the shift towards cleaner cooking methods, merely investing in the equipment is not sufficient to ensure clean cooking in practice.

Many factors play into which households make the switch to an improved stove. Higher income level and general socioeconomic status are associated with ICS adoption, as is education (Lewis & Pattanayak, 2012). Though some studies are inconclusive, others find younger people are more willing to switch (Vigolo et al., 2018). The household's access to fuel can be a factor (as ICS are often fuel efficient) but is not always as fuel collection sometimes has social benefits. Although time-consuming, fuel collection is often a social activity and an opportunity to spend time outside (Gill-Wiehl, Price, & Kammen, 2021). If the ICS is handed out as part of an NGO or government program, frequent follow-ups and engagement from researchers is associated with higher adoption rates (ESMAP, 2021). Even when adopted by a household, the ICS is unlikely to completely replace the open fire stove. This is due to stacking; "concurrent use of multiple stoves and/or fuel", a phenomena common within all social groups (Shankar et al., 2020).

Furthermore, a stove requires certain characteristics to ensure long-term adoption. Practicality is crucial, which includes ease of assembly, lighting, and operation with minimal clean-up. Flexibility to use different sizes and shapes of fuel, including damp wood, is also valued (Gill-Wiehl, Ray, & Kammen, 2021), as is fast cooking time and reduced

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smoke emissions. Compatibility with the household's lifestyle is equally important, with the stove serving as a source of heat and light and a gathering point for the family (ESMAP, 2021). Furthermore, households are often anchored to open fire cooking due to the perception that only an open fire stove can make regional dishes and larger meals. As ICS are more fuel efficient, they tend to be smaller, which some users see as a negative (Gill-Wiehl, Ray, & Kammen, 2021). Despite its drawbacks, replacing the open fire stove is not an easy task. Research suggests that to be successful, an improved stove needs to maintain the ease of use of open fire cooking while having additional benefits (Stanistreet et al., 2014).

An ICS not yet widespread is the gasifier stove. It works through a thermochemical conversion process where the solid fuel reacts with an oxidant, in most cases air, at a high temperature and is converted to a gaseous fuel (Mukunda et al., 2010). In a TLUD (Top-Lit Updraft) gasifier, the fire is lit from the top and works its way down towards the bottom (Anderson, n.d.). As the pyrolysis is separated from the combustion, it allows for higher fuel efficiency and less pollution. It has been shown to reduce kitchen air concentration of carbon monoxide (CO) by 57 %, carbon dioxide (CO_2) by 41 % and fine particulate matter ($PM_{2.5}$) by 79 % as compared to open fire cooking (Gitau, Sundberg, Mendum, Mutune and Njenga, 2019). In addition, the stove produces biochar as a by-product, which can be reused for cooking or used as soil amendment, as its properties generate an increase in crop yield (Njenga et al., 2016; Sundberg et al., 2020).

Charcoal is most often created through earth pit or mound kiln pyrolysis. These are inexpensive but slow production methods which cause heavy pollution. As biochar is being introduced as a climate mitigation practice due it its carbon sequestration properties, it is important to also introduce it with clean production technologies, in order to provide overall climate benefits (Sundberg et al., 2020). Refined pit geometry or improvements in kiln technology have been found to streamline the process and reduce emissions (Cornelissen et al., 2016). Creating biochar with a TLUD gasifier is even more energy efficient as the gases from pyrolysis are combusted for cooking rather than lost to the atmosphere. Furthermore, it contains all the previously stated benefits of a clean cooking system. However, the biochar production volume is small and cookstoves are perceived as more technically challenging compared to alternative biochar production methods (Fridahl et al., 2021).

Gill-Wiehl, Ray, and Kammen (2021) highlight the tendency of many stove programs to focus on optimising stove performance while disregarding the importance of long-term user acceptance. This has resulted in a lack of follow-up studies in the field of improved cookstove adoption, which is unfortunate as long-term use is critical for achieving sustainable health benefits. For the gasifier stove, short term-studies show positive user ratings, but little is known about long-term cooking habits and satisfaction levels (Gitau, Mutune, Sundberg, Mendum and Njenga, 2019; Eltigani et al., 2022). The overall aim of this study was thus to investigate the long-term usage of a biochar-producing gasifier stove among rural households in Kenya. Investigating factors affecting stove satisfaction and dissatisfaction among participants allows for identifying its potential as a legitimate option for rural households.

Method

Location and previous research

To include a variety of social and agroecological conditions, in areas dominated by smallholder agriculture, the study was carried out in three counties of Kenya: Kwale, Embu, and Siaya. The locations of the field studies are depicted in Fig. 1.

Kwale county is located in the coastal region of Kenya. The study was carried out around the town of Waa (−4.18, 39.59) 14 km south of Mombasa at an elevation of 40 m. The daily mean temperature in the area is 28 °C and the annual precipitation ranges from 400 mm to 1680 mm, although the rainfall has been disrupted in recent years due to

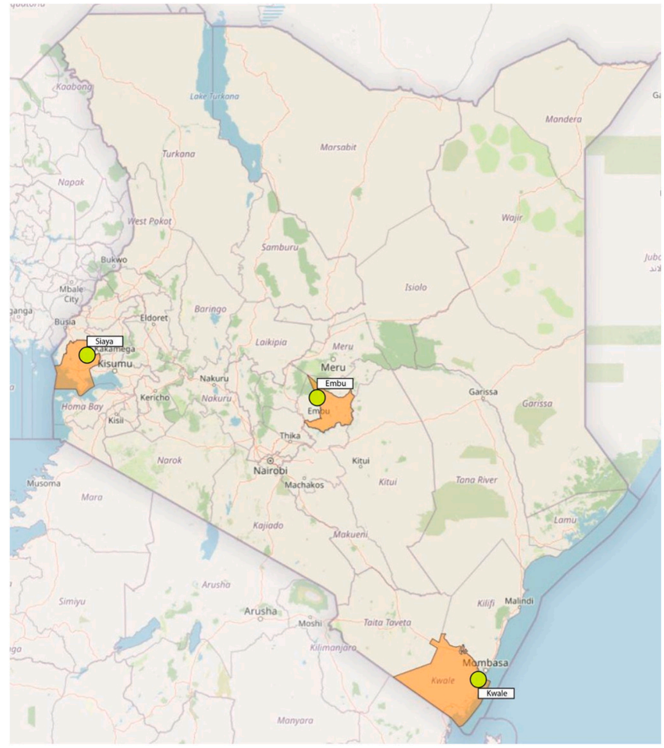

Fig. 1. Map of Kenya with study locations highlighted.

severe droughts. The topography is characterised by plains, and the area is known for its agricultural production of mangoes, coconuts, cashews, and maize. Embu county is located on the southern slope of Mount Kenya at an altitude of 1650 m. The study was carried out around the town of Kibugu (−0.44, 37.43), an area known for its agricultural production of maize, tea, coffee, bananas, and macadamia. The annual precipitation in the region is approximately 1495 mm and the daily mean temperature is 21 °C. Siaya county is located in the western region of Kenya. The study was carried out around the town of Sidindi (0.15, 34.39), 53 km west of Kisumu at an altitude of 1300 m. The area has a modified equatorial climate and is known for its agricultural production of maize, avocados, and beans. The annual precipitation in the region is approximately 1450 mm and the daily mean temperature is 24 °C (KNBS, 2021).

This study is the continuation of a project (Farm-level production and use of biochar in Kenya) running from 2013 to 2019 (Sundberg et al., 2020). 50 households in each of the three regions were selected, and after investigations and pilot studies, a TLUD gasifier stove was distributed to each of the households in 2016 (Njenga et al., 2016; Sundberg et al., 2020; Mahmoud et al., 2021). A series of measurements were conducted on the gasifier's performance (Gitau, Sundberg, et al., 2019). 2–3 months after distribution, a survey was performed with all 150 households, followed by semi-structured interviews with a selection of participants over the next two years (Gitau, Mutune, et al., 2019; Njenga et al., 2020).

Participants

For this study, ten participants from each region were selected for an in-depth interview performed in March–April 2022. The selection criteria were that half of the participants in each region had to be active users of the stove, defined as households who use the stove at least once a month, while the other half were non-users, defined as households who use the stove less than once a month. This allowed for investigating potential differences between users and non-users in their evaluation of the stove and their daily habits. Within this criteria framework, the participants were selected randomly through the assistance of a field guide. The predominant language varied between Swahili, English or a local language of the region, to accommodate the individual participants. Out of the 30, 14 reported being the household head, 10 as being the spouse and 6 as children of the household head. The average number of people in the households was 5.6.

Study design

Survey-based interviews were conducted with a representative from each of the households. The survey contained 58 questions and focused on background information, general cooking practices, fuel collection and experience with using the gasifier stove. The survey was designed to identify the key factors that differentiate users from non-users. This information was important to understand the adoption and utilisation of the stove, and to identify potential areas for improvement. The survey was based on a previous survey used in 2016–17 (Gitau, Mutune, Sundberg, Mendum and Njenga, 2019).

The data collection process involved a standard protocol to ensure ethical treatment of participants. Prior to each interview, the participants were provided with an introductory text which explained the nature of the study and their rights as participants. Informed consent was obtained from all participants through a consent form that they were asked to sign. After this, the interview was carried out in a semi-structured way; using the survey but also making room for additional questions and clarifications. A translator familiar with the local environment was present in all interviews to reduce the risk of communication errors as the majority of interviews were done in the local language. The average duration per interview was 41 min. The final question of the survey in each interview was followed by inquiring if the interview subjects had any questions for the researchers.

Analysis of data

The quantitative data was analysed in Microsoft Excel and Python, assessing averages, comparing users and non-users as well as investigating regional differences. For the part of the survey where participants were asked to rate gasifier characteristics on a scale from 1 to 5 compared to their open fire stove, the answers were analysed as falling on a scale from “prefers gasifier” (1) to “prefers open fire” (5). A 95 % confidence interval was calculated. For the qualitative data, answers to open ended questions were summarised and compared manually to detect general patterns.

Stove model

The gasifier stove is a TLUD model with the brand name “GASTOV” (shown in Fig. 2). It is produced by KIRDI. It is a top-lit design where air flows through a packed bed of fuels contained in the inner canister. Another stream of air enters below the top section, where it meets the gases, igniting a flame in the combustion chamber (the top part). When the meal is cooked, the flame is suffocated with the extinguisher (Gitau, Sundberg, et al., 2019). The stoves were produced in Kenya in small numbers.

Results

Stove & fuel type

Households had three stoves on average. In 29 of 30 households, one of those was an open flame stove. In Siaya, the average was 3.6 stoves, in Embu 3.0 and in Kwale 2.4. The difference was primarily due to all participants in Siaya having a charcoal jiko and many having the “Tembea jiko”, an improved stove from an NGO handout project (United Nations, 2017). More participants in Embu had a liquid petroleum gas (LPG) stove. According to participants, they saw different benefits of different stoves. For example; the open fire stove is quick and easy to use, the gasifier saves fuel and creates charcoal but is considered unfit for large dishes, and charcoal jiko and LPG are efficient but fuel can be costly. Many households also used several stoves simultaneously to facilitate cooking. For these reasons multiple stoves were kept, but to a varying degree (see Fig. 3).

In terms of fuel types, almost all households used firewood (30) and crop residue (28). Charcoal was also quite frequent (20) as it is used for both the gasifier and the charcoal jiko. It was especially common in Siaya. Paraffin and LPG use coincided with the number of paraffin and LPG stoves owned, so they were most common in Embu. The crop residue was mostly sourced from the farm, although a few bought it or were given from friends for free. For firewood, all but one collected some or all of it from their farm. Additional ways of acquiring firewood were buying, collecting from forest or community land or receiving from friends for free. Which type of firewood was used depended on what was available in a particular region, although high wood density was always

Fig. 2. Gasifier stove used in this study. The fuel canister is filled with fuel and placed inside the outer part. The top part is placed on top and the pot shield can be placed on top of the cooking pot. When cooking is done the extinguisher is placed over the canister to suffocate the flame (Sundberg et al., 2020).

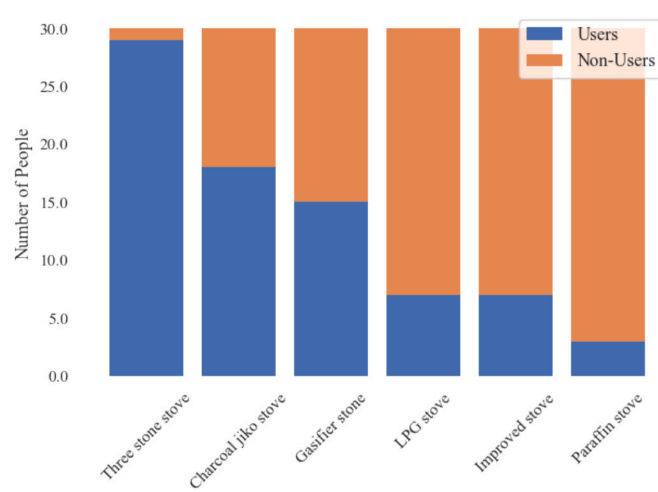

Fig. 3. Number of users per stove type in all regions. The open fire stove is used daily by almost all participants, the gasifier has an even use frequency distribution (partly as per design of the study), the charcoal jiko is commonly used on a weekly basis whereas the other stoves are mostly not used at all. Data from the 30 participant survey.

a common characteristic for the most appreciated wood type. The charcoal used as fuel was either bought (14) or made on the farm (16), which was done either with the gasifier or with traditional charcoal making methods.

Gasifier users, i.e. those who reported using the gasifier at least monthly, were more likely to acquire all their fuel from their own farm land. Non-users, on the other hand, who used the gasifier less than monthly, were more likely to buy firewood, charcoal, and fuel residue from external sources. Fuel collection was usually carried out by the women of the household, but in some cases, it was done by the husband, children, or hired labour. Gasifier users were more reliant on the assistance of children to collect firewood. Kwale was the region where the most diverse fuel collection methods were used, as many households supplemented their farm-acquired fuel with sources from nearby forests, borrowing from friends, or purchasing.

Gasifier using habits

Evenings were the most popular time for using the stove. As most members of the family are home there is more time. Also, the stove, once prepared, is self-going so the family can direct their attention to each other. Evenings were also appropriate as the stove could be transported to the common area to allow the person cooking to be with the family. This does, however, come with the drawback of increased exposure to smoke compared to cooking in a separate kitchen. During morning hours the business of getting everyone out of the house made the gasifier less appropriate, although a few people said they use it to make morning tea.

In terms of what dishes were made with the stove there was a big variety. Many used it to boil water or make tea as this is a quick procedure and means they do not have to change the canister. Some people said they use it for ugali, a local staple consisting of maize flour mixed with water, while others said the ugali goes bad as you have to pause cooking and change the canister. Some said they made beans on it while others said beans take too long. Other dishes mentioned were stews, cabbage, porridge and fried vegetables.

Whether the charcoal was harvested from the stove depended on the dishes made. With quick meals, the biochar was intact at the end, but with slower cooking meals, some participants harvested the charcoal while others let it burn to avoid changing the canister too often. As the gasifier can be left alone while cooking, some would also forget to harvest the charcoal as they were busy with other tasks and forgot to empty. Of the 30 participants, 22 stated they had always harvested the charcoal when cooking with the gasifier. In Siaya, all participants harvested the charcoal each time compared to only half in Kwale. The biochar has been used in a variety of ways. Almost all households used it for cooking and farming. Quite a few used it for ironing as well (Table 1).

Between users and non-users, both groups harvested the charcoal when they used (or had used) the gasifier. However, users were more likely to highlight the fact that charcoal could be harvested and used as soil additive as a major benefit of the stove.

User evaluation

The user evaluation of the gasifier stoves as compared to the regular three stone stove (Fig. 4) highlights benefits and drawbacks of using the gasifier stove. Decreased fuel consumption, smoke production and cleaning time were the main benefits with the gasifier. The extra time it takes to prepare the fuel to the right size to fit the gasifier canister was the main drawback for most households. Users and non-users had similar reports during the evaluation, but non-users experienced the fuel preparation as more burdensome, and felt that cooking took more time compared to users.

Table 1
Different ways the harvested charcoal has been utilized in the 30 households interviewed.

Charcoal usage	No. households
Cooking fuel	25
Use for farming	24
Ironing	9
Baking in oven	1
Sell	1

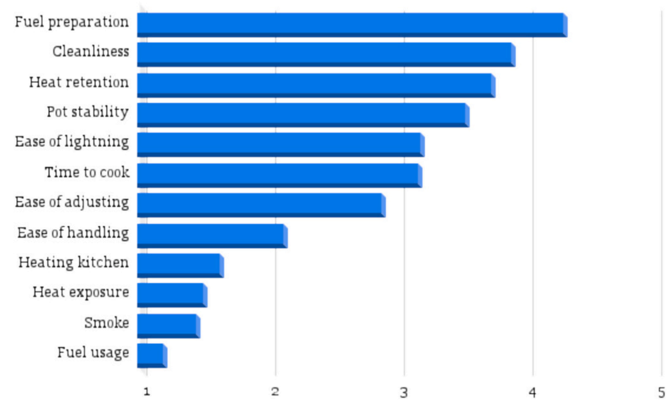

Fig. 4. User evaluation of the gasifier stoves as compared to the open fire method. The evaluation was done on a scale of 1–5 where 1 signified “very little” and 5 “very much”. Data from the 30 participant-survey with responses from 28 included, as two used other stoves than open fire stoves on a daily basis.

When asked in an open question about potential changes that could be made to the gasifier stove, 28 out of 30 households answered that the first thing they would change was the size of the canister. Almost all answered that they would like the canister, and therefore the entire stove, to be twice as big as the current model. Among non-users, the small canister was the reason most of them stopped using it. Users saw it as an issue as well, and one participant showed the procedure of cooking beans on the gasifier, and having to change canisters five times in the process, to illustrate the inconvenience.

A few people suggested other ideas for improvement, such as creating more space on the top part of the stove to allow for fuel to be slightly different lengths, to change the design to allow feeding fuel from the side of the stove while cooking, to make the stove lighter to facilitate transportation and to include an electric tool for chopping the fuel.

Additionally, two participants had found more unconventional ways to use the gasifier. One woman in Kwale used only dry coconut husk as fuel. As she had plenty in her farm, the fuel collection process would only take a few minutes. Thereby, she avoided chopping and preparing fuel, which many others reported as challenging. She was a daily user. A participant in Embu had developed a method of combining the open fire stove and the gasifier. She would start cooking her meals over an open fire, and when halfway done she lifted the pot and placed it on the gasifier where she resumed cooking. According to her, this helped her save fuel as the gasifier is more fuel efficient, and saved time and effort as the reduced cooking time on the gasifier meant there was less of a need to change the canister. She was also a daily user.

Discussion

The majority of gasifier users kept it as a secondary or tertiary stove, mainly to complement the open fire stove, which 27 out of 30 participants used on a daily basis. This confirms the previously identified phenomena of stove stacking (Shankar et al., 2020). Stove stacking is valuable to households as it reduces the risk of fuel insecurity by allowing them to adapt to changes in the cost, availability, and reliability of fuel sources (Jewitt et al., 2020). However, it hinders the transition to clean cooking when unclean methods such as open fire cooking remain in the mix. Stove developers can aim to eradicate the practice of open fire cooking by designing stoves intended to meet all cooking needs of a household. According to Gill-Wiehl, Ray, and Kammen (2021) this would require a stove to have multiple burners which accommodate a variety of pots. Alternatively, stove stacking should be accepted as a phenomenon likely to persist. This stance favours a solution of clean stove bundles which would include numerous stoves for a variety of purposes (Gill-Wiehl, Price, & Kammen, 2021; Gill-Wiehl, Ray, & Kammen, 2021). Though implementation of the gasifier in a bundle would likely lead to cost concerns for Kenyan rural households, the possibility of a redesign will be discussed further down.

This study relies on qualitative user assessments of the gasifier stove. The format allows for in-depth understanding of cooking habits and user priorities. Still, quantitative data on use frequency among all 150 participants that originally received a gasifier stove in 2016, would have complimented the interviews and given a fuller picture of long-term usage. Furthermore, the concern of a conflict of interest between researcher and participants, as expressed by Gitau, Sundberg, et al. (2019), remains. Fear of negative answers leading to the project being discontinued could potentially motivate participants to alter their answers in some regards. Such concerns are difficult to control for in stove hand-out based studies. However, researchers attempted to prevent it by encouraging participants to be honest in their assessment and ensuring them that the gasifier stove is theirs to keep.

When compared by the users, the gasifier outperforms the open fire stove on most metrics, but falls short on a few. The workload required to prepare fuel and the need to replace the canister during cooking (which prolongs cooking time) were identified as the main drawbacks. In addition, damp wood cannot be used with the gasifier, which some participants found problematic, as previously reported by Barstow et al. (2016). Aside from these limitations, the gasifier was found to be superior in terms of cleanliness, smoke reduction, heat retention, stability and ease of handling, important factors for stove adoption as confirmed by prior studies (Gill-Wiehl, Ray, & Kammen, 2021; ESMAP, 2021; Stanistreet et al., 2014). Furthermore, many participants reported the biochar production as a major benefit. Participants used the biochar in a variety of ways; in traditional manners such as for cooking or ironing, but also to complement fertiliser in the soil, a method taught during the stove distribution and training in 2016–17. This seems to have been especially important for active users as many describe biochar harvesting as a driving factor for their adoption of the stove.

In spite of outperforming the open fire stove in most ways, the gasifier has not been adopted as a primary stove. The fact that it was a hand-out could partially explain this; evidence suggests that adoption rates of improved stoves decrease when acquired for free (Stanistreet et al., 2014). The study results could also support another conclusion of Stanistreet and colleagues; to achieve long term adoption, an improved stove must maintain the benefits of the open fire stove as well as having added benefits. This is mainly due to the competitive advantage the open fire stove has as it has been used for generations and holds cultural value. Another possible explanation is that the areas where the gasifier lacks are especially important for participants, whereas some of the benefits are not. For example, a key benefit of the gasifier is fuel saving. Yet, in a survey by the Kenyan Ministry of Energy (2019), 76 % of rural households reported never or rarely having a shortage of woodfuel. Furthermore, the health benefits of an improved stove is often undervalued by participants (Vigolo et al., 2018), especially when at odds with short-term interests such as ease of use. In contrast, participants face daily challenges with burdensome fuel preparation and frequent canister changes. Relief from one of these problems amplifies the other; less meticulous fuel preparation will lessen preparation time, but it compromises the fuel's density in the canister due to asymmetrical pieces. Consequently, cooking time increases as more canister changes will be warranted.

A long-term study on biochar-producing cookstoves in Tanzania (Eltigani et al., 2022) notes similarly low adoption-rates, but reports different reasons as compared to the current study. Deficient cookstove durability and unavailability of feedstocks were the main reasons given for abandoning the stove, which 38 out of 50 participants had done by the end of the study. Furthermore, participants lacked interest in using biochar as soil amendment and did not report fuel preparation to be an especially burdensome task. These results demonstrate that even among the same category of improved stove, the specific design of the stove and the local circumstances can generate significantly different outcomes. Geographic conditions may have contributed to the contrasting levels of interest in biochar observed between the two studies. However, since the present study shows comparable interest across all three regions in Kenya, it is more plausible that the variance between the two programs stems from differences in the exposure and education on the concept of biochar as a soil amendment and its potential advantages. That participants in the Tanzania study not finding fuel preparation to be demanding is most likely due to sawdust and coffee husk being the most frequently used fuel source, which requires little to no preparation.

Interestingly, users and non-users in the current study reported similar benefits and drawbacks. This indicates it is not a contrasting understanding of the gasifier stove that causes the difference in use, but rather a different weighing of the pros and cons that motivates some to continue their usage but not others. This claim is supported by the fact that users put more emphasis on the biochar harvesting whereas non-users found the perceived downsides of the gasifier to be more troublesome. This could be due to circumstantial reasons within the household. Practical details in handling of stoves are important in stove choices, and an injury preventing fuel preparation or having no fuel-drying space indoors could be examples of decisive factors. Still, the agreement among all participants regarding the gasifier's drawbacks begs the question of if and how these problems can be solved.

When asked which improvements the participants would like to see, 28 out of 30 suggested enlarging the size of the stove to avoid frequent canister changes. Many specifically asked for the diameter of the canister to double. As the gasifier is carefully designed in terms of geometric properties, simply doubling the diameter would not prolong burning time but rather increase the strength of the flame (as more fuel will be burnt at once). Furthermore, changing the geometry of the stove would likely increase CO_2-emissions, unburnt hydrocarbons and particulates, thus undermining the current benefits (Mukunda et al., 2010). To achieve the desired effect, the diameter would have to increase in proportion to the height. Consequences of this would be a heavier, less transportable stove made at higher production cost. Another redesign option is adding a second burner (as suggested by Gill-Wiehl et al.). This could minimise canister changes as users could switch between burners to avoid disrupting the cooking process. Additionally, it would allow the user to cook multiple dishes at once. However, this option would also implicate a heavier, more expensive stove compared to the current model.

As the stationary open fire stove was preferred over the gasifier by the participants of this study, transportability might not be a primary priority. However, the potential of increased costs remains an issue. This is especially important as the households most likely to be interested in the gasifier stove are the ones motivated to save money on fuel and fertiliser costs, which would be low income households. As noted by Eltigani et al. (2022), there is potential for a biochar-producing stove to be subsidised through the carbon market. Because of this, the user-friendliness should be prioritised, as it is the reason no household in the current study replaced the open fire stove with the gasifier. Yet, even if these issues were resolved and a larger gasifier was made available at an affordable cost, the other concerns reported by the participants could limit the adoption.

Suggestions from participants included redesigning the gasifier to make it compatible with damp wood and enabling side feeding as a means to avoid the canister changes. Both of these changes are incompatible with the thermochemical process in the stove, as they would disrupt the gasification process which is key to biochar production and emission reduction. There are, however, other improved stoves which allow for side-feeding and are more forgiving in terms of wood dampness. One example is the rocket stove, which like the gasifier has been found to be energy efficient and to reduce household air pollution (Ochieng et al., 2012). The gasifier is unique in its ability to produce biochar, and whilst some drawbacks can be addressed through redesign, improvements at odds with the biochar-producing mechanisms cannot. Hence, its target demographic is households who value this quality over certain other benefits.

In regards to fuel preparation it is interesting to note that one of the daily users only used coconut husks as gasifier fuel, which allowed her to avoid fuel preparation all-together. This is similar to participants in the Tanzanian study who rarely used firewood as fuel (Eltigani et al., 2022), suggesting the prolonged burning time of high-density woodfuel is not vital to users. If the stove was redesigned to allow fewer or easier canister changes, it would be of even less importance. In that case, farm residue might be the way to go in terms of fuel. Alternatively, there might be a tool (less expensive than the electric saw suggested by a participant) which could facilitate fuel preparation of woodfuel, as doing the work with a traditional panga seems to be too much effort according to many. This could be an area of investigation for future studies.

Conclusion

Six years after receiving the gasifier, most participants used it as a secondary or tertiary stove, preferring the three stone open fire for everyday usage. This study identified the reasons keeping the participants from using the gasifier as their main stove, such as cumbersome changing of the canister and fuel having to be carefully chopped and added only from the top. The gasifier lacks in key qualities and does therefore not replace the traditional stove in its current state. Solutions include changes in the stove design, which could undermine the stove's current benefits. The production of charcoal for use as fuel or as biochar in soil was a driver for stove use. The stove has potential due to its many benefits such as faster cooking time, less pollution and higher fuel efficiency. Yet for daily usage to be realistic, further research is needed to design of a cooking system that fulfills the users' requirements.

CRediT authorship contribution statement

Alice Lagerhammar: Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Visualization, Writing – original draft. **Noah Sandgren:** Data curation, Funding acquisition, Investigation, Methodology, Visualization, Writing – original draft. **Cecilia Sundberg:** Conceptualization, Methodology, Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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