Source: Ndaro M.

CHAPTER 7

Gender and Improvement of Cooking Systems with Biochar-producing Gasifier Stoves

James K. Gitau,[1,2*] Ruth Mendum[3] and Mary Njenga[1,2]

[1] World Agroforestry Centre (ICRAF), P.O. Box 30677-00100, Nairobi, Kenya
[2] Wangari Maathai Institute for Peace and Environmental Studies, University of Nairobi, Kenya, P.O. Box 30197-00100, Nairobi, Kenya
[3] Office of International Programs, College of Agricultural Sciences, The Pennsylvania State University, 106 Agricultural Administration Building, University Park, PA 16802, USA

* Corresponding author, e-mail: jameskinyuagitau@gmail.com

7.1 Introduction

7.1.1 Gendered challenges in access to and use of biomass cooking energy

Firewood is a limited resource in high demand with about 90% of the households in rural Kenya using it for cooking and heating space (MoE 2002). Most people in sub-Saharan Africa (SSA) have limited access to less-polluting fuels (Rao and Pachauri 2017), hence they continue to rely on biomass, which is unsustainably harvested, undermining the environmental health of landscapes, especially in arid regions. Women spend much time on firewood collection which deprives them of opportunities to engage in other developmental activities. Women and children at a global level spend three to seven hours per day near the cookstove (WHO 2005) and hence inhale much smoke, an amount equivalent to 40 cigarettes per day (WHO 2006) which damages their respiratory systems. This is exacerbated by the use of inefficient cooking appliances which is a serious issue as globally 2.6 billion people, most of whom reside in rural areas of either SSA or developing areas of Asia, lack clean cooking facilities (IEA 2013). Peoples' eating and cooking habits are changed by lack of access to sufficient and appropriate cooking fuel. This is mostly evident by reduced numbers of meals per day, switching to less energy-intensive foods, undercooking of food and exchanging part of the food supply for fuel (FAO 2013). This in turn affects the quality, quantity and nutritional value of the food consumed (Sola et al. 2016). Despite the intervention in the 1950s to promote improved stoves which burn biomass more efficiently, use less fuel and have lower smoke emissions than traditional cookstoves, their uptake has remained low (Karekezi et al. 2004). This is mainly due to their relatively high prices and lack of consideration of sociocultural, technical aspects of cooking systems (Hollada et al. 2017). Lotter et al. (2015) envisioned a continuing challenge with the adoption of improved cooking technologies especially if they do not reduce the cost of cooking while improving the customary cooking characteristics. It has also been assumed that poor, uneducated women refuse the improved stoves out of ignorance.

This study framed the research assumption differently by looking at the home cooks who use biomass as experts on managing households and food security within their homes regardless of their educational background. Women's life choices are heavily influenced by their traditional and reproductive gender roles with many of them deeply embedded in long chains of knowledge generation gained

outside of formal educational systems. The failure of cooks in SSA but also South Asia and Latin America to abandon open fires for improved cookstoves or other fuel types (electricity, LPG [liquid petroleum gas] or solar) has frustrated development experts for decades. This is probably attributable to improved stoves failing to align with the priorities of the local users which they use to make decisions to adopt externally-initiated interventions, hence influencing the uptake of such interventions (Sesan 2014). Expert-driven efforts to develop people, especially women, without involving them at the problem-scoping stage and generation of the alternatives to solve the problem are among the reasons for the failure of improved cookstove initiatives in India as the interventions developed did not meet their needs and preferences (Khandelwal et al. 2017). As a result, there is a need to involve women, as the cooks and end-users, in cooking system research and development to ensure that their needs, aspirations and fears of losing the benefits of using open fires are integrated during stove development.

This case study is based on the farm-level production and use of biochar in Kenya, run by the Biochar-Energy project working on efficient energy and biochar-producing cooking systems. This partnership project operated by the World Agroforestry Centre (ICRAF), International Institute of Tropical Agriculture (IITA), Royal Institute of Technology (KTH), Stockholm, Swedish University of Agricultural Sciences (SLU) and Lund University and supported by the Swedish Research Council. The project was developed to address the challenges faced in accessing biomass fuel including farm residues, and the adoption of improved cooking systems for efficient use of this type of cooking fuel. It also aimed at increasing crop yields through soil amendment via the aforesaid biochar produced. Enhancement of environmental benefits through reduced pressure on tree resources as sources of cooking energy and efficient use of farm residues would be realized as well. The project began in 2013 and lasts until 2018, split into two phases of three-year periods. The project sites encompass Kwale a coastal area, Siaya a semi-arid area and Embu a highland area. The case study presents experiences mainly with households in Kwale where the data analysis on adoption has been completed. The first phase of the project (2013-2015) was implemented in Embu; it had a baseline of 50 households and worked with 20 households on a Top Lit UpDraft (TLUD) galvanized iron sheet gasifier stove produced by local artisans in Nairobi. Women joined participatory cooking tests to measure energy-use efficiency and emissions from the gasifier compared to a three-stone open fire (Njenga et al. 2016). The second phase (2016-2018) involves working with 150 households in the three sites who were issued with an improved version of the Top Lit UpDraft (TLUD) gasifier with the brand name Gastov sourced from a different producer, the Kenya Industrial Research Institute (KIRDI). The second version was sourced from a difference producer in response to the constraints highlighted by women after using the former version. This case study aimed at gathering the gendered findings on participation in technology development, uptake and impacts from the lessons learned by women using the stove. This helped to highlight some of the factors to be considered in the development of energy-efficient technologies for enhanced uptake.

7.1.2 *Household biochar-producing cooking system*

The gasifier cookstove is a recent innovation which has started to gain attention as a cooking stove in the developing world (Torres-Rojas et al. 2011). In the gasifier stove, biomass fuel produces its own energy-rich gases which mix with oxygen and combustion takes place to produce heat used for cooking. The burning process takes place under controlled oxygen delivery at temperatures between 700°C and 1,000°C (Torres-Rojas et al. 2011) turning the fuel into charcoal which is either harvested or left to continue burning to produce heat for cooking. The charcoal can be used for further cooking purposes (Njenga et al. 2016) or as a soil amendment where it is referred to as biochar (Jeffrey et al. 2013). The gasifier has the following components as shown in Figure 7.1.

Figure 7.1. The Gastov

Source: Gitau J./ICRAF.

(a) An insulated casing with a 5.5 x 4.5 cm air entrance door that can be regulated at half or full height at the bottom; **(b)** a 19-cm-high fuel canister in the middle; **(c)** a charcoal cover (snuffer) used to cool the charcoal by cutting off oxygen; **(d)** a 6-cm high gas combustion chamber on top as the main burner, fitted with a skirting; **(e)** casing (skirting) to hold the pot in position and protect flames from wind; and **(f)** a canister holder.

7.2 Research Design

In Kwale, the 50 households interviewed in the baseline survey agreed to use the gasifier. Before being issued with the gasifier, 22 women and 31 men were trained in October 2016 on gasifier use. Even though some of the trained male family heads were not the stove users, they were the decision-makers in some households and hence training male and female members would help to promote uptake of the stove. The trained men were advised to transfer their skills to cooks in their households. Follow-up visits were conducted every three weeks. Details on the study area and household selection are described in Gitau et al. (forthcoming). After two to three months of gasifier use, the stove users were interviewed using semi-structured questionnaires to ascertain their experiences in using the gasifier and perceived benefits and constraints of using it; they were also asked about fuel types and the amount of firewood used before and after introduction of the gasifier, sources of firewood for the households, the main fuel collectors in the households, time spent in firewood collection, costs for households that bought firewood and the amount of charcoal produced from the gasifier. Focus group discussions were held with cooks, mainly women, on areas for further improvement of the new version of the gasifier stove (the Gastov) and feedback was shared with KIRDI, the stove manufacturer.

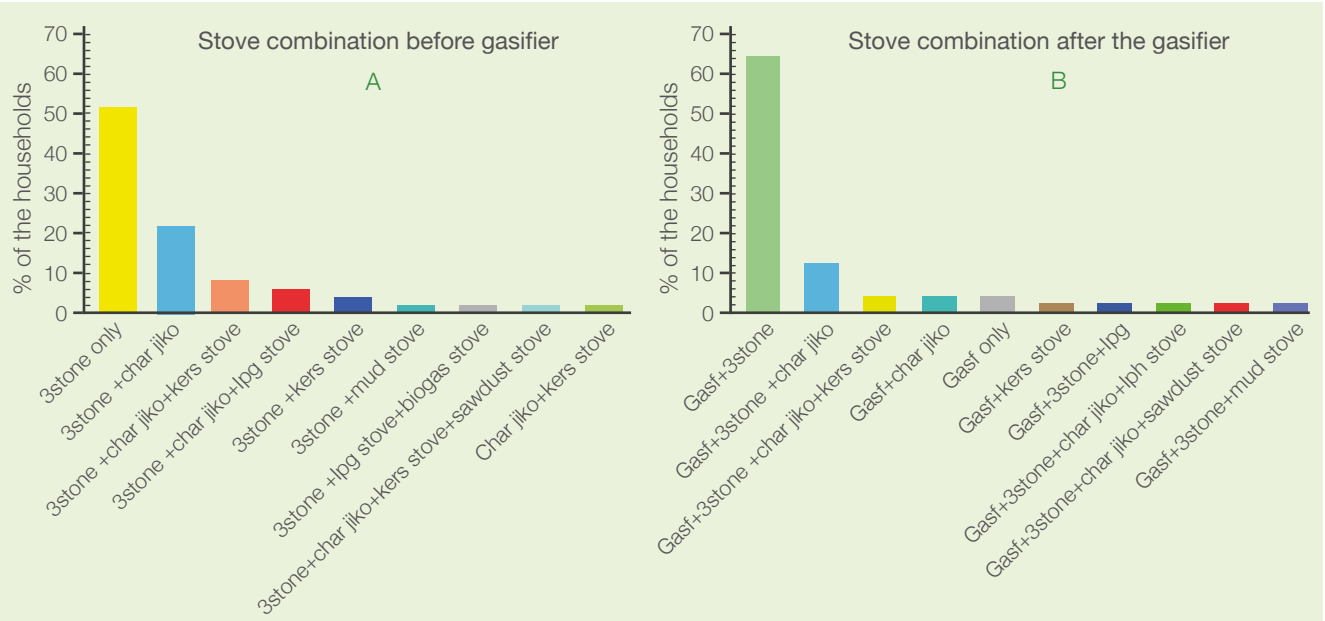
7.3 Results and Discussion

7.3.1 Stoves used by the households before and after introduction of the gasifier

The household size at Kwale ranged from one to eleven people with a mean of five members; 48 of the households were headed by men and two by women. Out of the fifty households, 52% of the female spouses had not completed any level of education while 34, 6, 6 and 2% had primary, secondary, tertiary and university education, respectively. A comparison of the adoption of the galvanized iron sheet gasifier stove and the improved version of the Gastov gasifier later in the study revealed that the former was being used by 35% and the latter by 96% of households at varied frequencies in Embu and Kwale respectively. Probably this is because the latter had been considerably improved to respond to cooks' needs.

To effectively meet their household needs, women stacked various stoves they had before and after the gasifier was introduced (Figure 7.2a, b). Stacking is the use of more than one stove to fulfil household energy needs (Ruiz-Mercado and Masera 2015; Ado and Darazo 2016). The gasifier was reported to be easier to use in terms of cleaning and maintenance, heat adjustment and handling; moreover it was noted that kitchens and cooking pots were cleaner, there was less exposure to flames and cooking pots were kept firmly in position. However, the gasifier did not perform well in heating kitchen space and required more time for fuel preparation (Gitau et al. forthcoming). Use of gasifiers reduced concentrations of carbon monoxide (CO) and fine particulate matter (PM2.5) by 40% and 90% respectively compared to three-stone open fires (Njenga et al. 2016). Two to three months after gasifier introduction, 30 households were using it for five days and nine times in a week on average for brief cooking chores while 18 households used it for four days and nine times a week both for brief and longer cooking chores. Therefore, with the uptake of the cleaner gasifier, indoor air pollutants were likely to have been moderated.

FIGURE 7.2. STOVE STACKING BEFORE (A) AND AFTER (B) GASIFIER



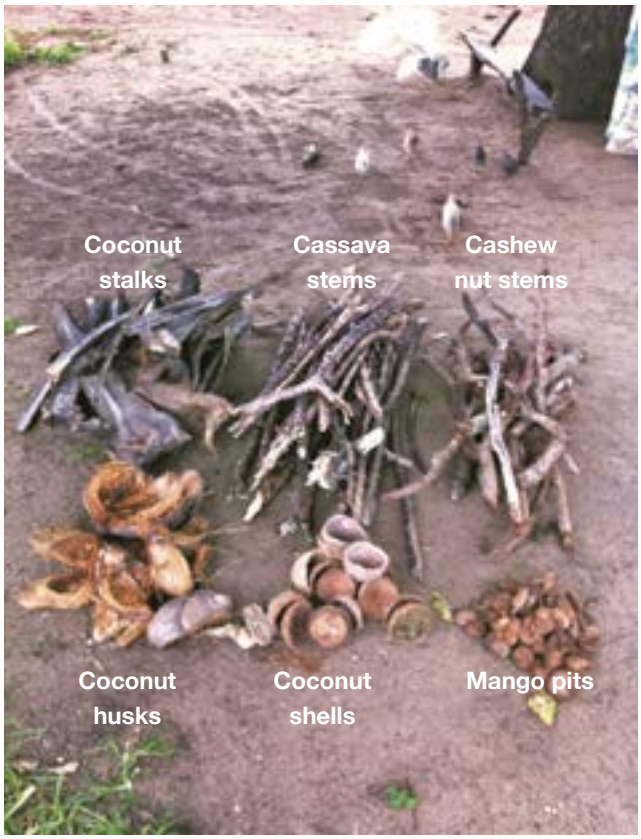
Note: Gasf = gasifier, char = charcoal, kers = kerosene.

7.3.2 *Use of the gasifier, fuel sources and preparation*

Firewood was used with the gasifier by 98% of the households and 96% of them used firewood together with crop residues. (Figure 7.3). Firewood was sourced on farm, from natural forest, from dealers (purchased), or from community land, friends' farms and private plantations. Pruning from trees on farm was the main and exclusive source of firewood for 98% and 41% of the households respectively. Even for the households that did not buy firewood, sourcing the fuel cost the collectors in terms of time and physical effort spent. Women were the main firewood collectors for 94% of the households. They spent one hour on average on a round trip to collect firewood within their farms from one to fifteen times per month. Twenty-six percent of the households bought firewood from once to ten times per month at KES 50 (USD 0.5) per headload of firewood on average. On average these households were buying eight headloads costing KES 400 (USD 4.00) before the gasifier was introduced but this diminished to five headloads for KES 250 (USD 2.50) on average per month after gasifier introduction (Gitau et al. forthcoming). With uptake of the gasifier, there is potential to save 38% of the money that would have been otherwise spent on firewood each month.

Before introduction of the gasifier, 42% of the households used charcoal for cooking and 71% of them purchased it, income that would be saved from using gasifier stove. The gasifier was used by 96% of the farmers and 85% of them stored the charcoal produced and collected 0.5 to 13 kg (5.13 kg on average) though some had produced more and used it for cooking and ironing clothes. Producing charcoal using the gasifier hence contributes to saving money otherwise spent on purchasing charcoal. It is an innovation that reduces expenses on cooking energy, thereby addressing nutritional opportunity costs associated with the high costs of cooking fuel.

FIGURE 7.3. Fuels used with the gasifier.



Source: Gitau J./ICRAF.

Women prepare pruned firewood and carry it to the homestead either when fresh or dry. They carry firewood loads on average weighing 35 kg on their heads (Figure 7.4a, b) along rocky routes from the collection points to their homesteads, risking injuries. Residues are also gathered and dried after crop harvesting and used as fuel to complement the available firewood, hence making the households more energy secure. However, use of these residues as fuel also competes with other residue uses such as nutrient recycling (leaving the residues on the land to decompose and improve soil fertility).

FIGURE 7.4. A WOMAN TRANSPORTING FIREWOOD **(A)**, A WOMAN BEING ASSISTED WITH HER HEADLOAD OF FIREWOOD **(B)**, A WOMAN PREPARING FIREWOOD **(C)**

Source: Gitau J./ICRAF. **A**

Source: Gitau J./ICRAF. **B**

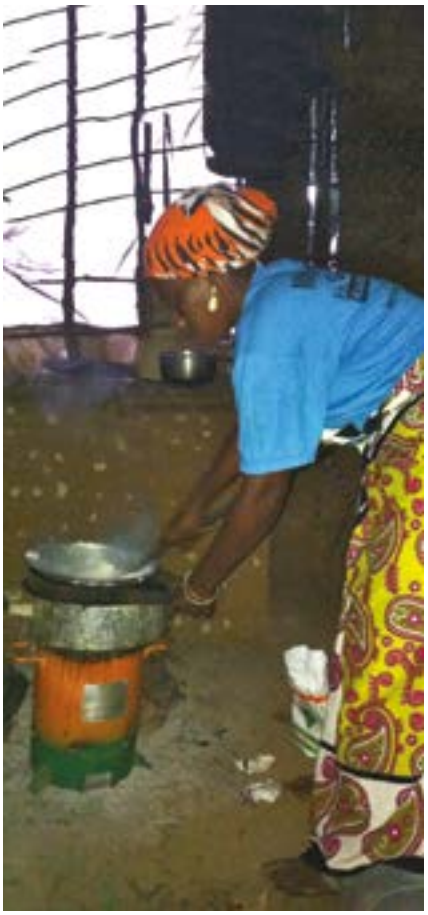
Source: Gitau J./ICRAF. **C**

Women chop the wood into smaller pieces of about 19 cm in length and varying diameters of below 5 cm to fit in the fuel canister (Figure 7.4c). This increases their workload; for instance in the first cycle of this project, women reported this task as tiring and time consuming (Njenga et al. 2016) while with the Gastov 42% had challenges with fuel preparation (Gitau et al. forthcoming). The firewood is arranged in the canister and lit with a match from above using light dry organic residues as tinder. When the fuel is burning well, the canister is returned into the outer casing of the gasifier and the combustion chamber is fixed back and cooking starts (Figure 7.5a). When the flame extinguishes this indicates that the charring process is complete and the charcoal is harvested by pulling the canister out of the outer casing, placing it on the ground and covering it with charcoal to cut off oxygen and facilitate cooling. After cooling, the charcoal is stored in a bag in a dry place (Figure 7.5b).

In Kwale, farmers applied the biochar in their plots to grow maize (Figure 7.5c). This resulted in more than double the average maize yields compared to plots where biochar was not applied (Sundberg et al. forthcoming). This can reduce the need to buy food and the excess produce can be sold to generate income. Due to its nutrient-holding capacity, biochar application on soils is likely to reduce the need to buy fertilizer and manure as the nutrients are available to the crops for a longer period.

After two to three months, 96% of the households were using the gasifier although at varying frequencies. Women were the main household cooks (45 of the gasifier users were women and only three were men). Two of the men cooked because they had separated from their spouses and the other's wife was in hospital, but he normally assisted her with cooking when she was at home. All the households liked the gasifier because it saved fuel, was less smoky and produced charcoal as a by-product (Gitau et al. forthcoming); however, some experienced challenges with fuel preparation, reloading of fuel, lighting and timing (when to collect charcoal). The challenges differed from one household to another; for instance, during a follow-up visit, an elderly lady reported that she liked using the gasifier but found it difficult to collect the charcoal and continued to use the heat from the charcoal till it burned into ashes. In some households the daughters, especially in school or college, preferred the stove compared to their mothers which could be attributed to education and age. The older women found lighting the stove and preparing fuel hard and time consuming while it was easy for their daughters. Thus the younger women found the gasifier more appealing than

FIGURE 7.5. A WOMAN COOKING WITH A GASIFIER **(A)**, CHARCOAL PRODUCED FROM A GASIFIER **(B)**, BIOCHAR BEING APPLIED FOR CROP PRODUCTION **(C)**.



Source: Gitau J./ICRAF. **A**

Source: Njenga M/ICRAF. **B**

Source: Njenga M/ICRAF. **C**

cooking on an open fire because it was more hygienic. To overcome some of these challenges, monitoring and capacity enhancement were carried out by a young male research assistant in every household every three weeks for about three months when the adoption study was carried out.

7.3.3. Implications of gasifier cooking system use for women

Reduced women's workload and risks in sourcing firewood from forests: The TLUD galvanized stove reduced fuel consumption by 40% (Njenga et al. 2016) and studies on the improved version TLUD Gastov are underway. Uptake of the gasifier means reduced need to collect firewood (hence less physical wear and tear), more time to engage in other activities and cost savings on firewood. For instance, using improved cook stoves in Chamwino and Kongwa districts in Tanzania resulted in 67% less firewood use and halved fuel collection time (Sererya et al. 2017). When searching for firewood, women are prone to accidents and encounters with dangerous wildlife. Some women (as in Kereita in Kiambu County) carry loads of firewood (67 kg) over hilly and rough terrain once a week to avoid making another trip over the same period. This makes them vulnerable to accidents, for example 'Margret' broke her arm on such a trip which stopped her from both collecting firewood and waged farm labor, yet she still needed to put food on the table for her household (Njenga et al. 2017). Some of the household income was used for treatment of her injuries which would have otherwise been used to address other household financial needs.

Reduced indoor air pollution: The galvanized gasifier reduced concentrations of CO and PM2.5 by 40% and 90% respectively compared to three-stone open fires (Njenga et al. 2016). CO in the kitchen causes headaches, dizziness and in high concentrations can result in unconsciousness or even death. Uptake of the gasifier can help to reduce smoke-related health problems which mostly affect women.

Potential for business creation: Young women can make money by providing services of preparing firewood by cutting it into small pieces in households with gasifiers. Men do this with saws while women use machetes (Figure 7.4c). There are women in the village who sell firewood and if they cut it into small pieces they may get better prices from households that are using a gasifier stove. Moreover, if women produce more charcoal than they need for cooking or for use as biochar in soil amendment they can sell the surplus. For instance, students from Chalmers University in Sweden testing grey water filters in Kisumu bought biochar from the farmers in this project at Siaya. Biochar can purify water as it absorbs hydrocarbons and other organic and inorganic substances (Hale et al. 2012; Mohan et al. 2012).

Environmental management: The gasifier has lower emissions and produces charcoal as a by-product. When used on farms, it remains in the soil for longer periods than biomass would if burned or left to decompose. Biochar production and use remove carbon from the atmosphere so it is considered to have carbon-negative properties (Bracmort 2010). Gasifier uptake is promising and this implies that women will contribute to carbon sequestration through the production and use of biochar (via reduced emissions from cooking and reduced need to fell trees for firewood). Harvesting of biomass (fuel) is an unsustainable activity which leads to deforestation and climate change issues (The World Bank 2011). The gasifier uses less fuel than three-stone open fires (Njenga et al. 2016), thus reducing pressure on forest resources. Harvesting deadwood may affect soil quality and consequently seedling regeneration (Kilian 1998) because if these residues are left to decompose, they enhance the soil fertility of the forest.

7.3.4 Women's contribution to the development of efficient cooking systems through co-learning

After 20 households in Embu had used the galvanized gasifier for five months, the project received feedback on their experiences and constraints (such as it being too hot and being unstable). This necessitated identification of an improved model from the market which could overcome functional challenges to avoid low uptake in the second phase of the project, which scaled up to 50 households in each of the three study sites. To participate in the cooking test agreed to help and this yielded scientific data on fuel use and emissions. For the improved model just like in the former version, the households perceived benefits (less fuel, less smoke and production of charcoal) and constraints (difficulties in lighting, reloading and need for firewood preparation into small pieces) and the however the problem of the wall of the stove getting too hot and instability of the stove were overcome in the improved version. The aforementioned constraints still persist and this would inhibit uptake of Gastov gasifier stoves by women who are the main users. This was addressed through work by female students in sustainable development and sustainable technology who applied design ethnography by observing cooking processes and later holding focus group discussions with the cooks; the results were later discussed with engineers at KIRDI (Saraswati 2018; Sujjesy 2018). Following the feedback from the women, the new Gastov was redesigned to have a dual purpose – using firewood and charcoal as well as control of the fuel required based on the type of meal being cooked. This exemplifies the

importance of involving women from the scoping stage of stove development research for enhanced uptake.

7.3.5 *Limitations affecting women's access to the gasifier*

The gasifier is produced by KIRDI and is not locally available. A unit costs KES 5,500 (USD 55) which is too expensive for most women who have limited sources of income, some working as casual laborers earning less than USD 3.00 per day, part of which they use to feed their families and meet other financial needs. Saving money to buy the gasifier is not easy for them. However, this can be solved through training of local artisans, mostly women being the main stove users, to jointly work with men to construct the unit at the local level, with quality control being exercised, especially on the type of metal used for frame distribution as it needs to withstand high temperatures. The government, through county development budgets, could support such activities for reduced input costs to make them affordable. Women could form groups and make small incremental credit contributions towards purchasing the gasifier stove. Education, skills and awareness also need to be pursued among men and women for increased demand and this is being addressed through training events and follow-up meetings.

7.4 Conclusions and Recommendations to Enhance Gender Equality through Uptake of the Gasifier

Gender implications on improvement of cooking systems: The public dialogue on the use of firewood and charcoal for home cooking and heating focuses on two main issues discussed in the introduction: the negative impact of smoky kitchens on respiratory health of women and children; and the unsustainable harvesting of biomass that undermines environmental health. In light of the seriousness of these two issues, there tends to be an assumption that given any reasonable alternative, biomass users could choose other options which is mostly not the case. Researchers framed the problem in this study differently by perceiving the home cooks as the experts on managing households and food security in the specific contexts in which they live hence making the adoption decisions that were observed more comprehensible.

In decision-making to use innovations such as the gasifier, women balance a wide range of factors such as: capacity to cut firewood into small pieces, availability of soft firewood species, relative availability of employment opportunities compared to cost savings produced by using less fuel, their interest in business opportunities afforded by cutting firewood into small pieces and the capacity of local households to pay for such services, and the market to sell charcoal or vegetables produced from improved soils and so forth.

This study points to the need for more nuanced consultation with biomass users as they make complex choices about home energy use. Younger women with perhaps fewer family responsibilities, less investment in open fire cooking and potentially more interest in business generation, may be more willing to shift their own use and that of their households in the direction of stoves like the gasifier. Even they, however, will probably maintain open-fire access for cooking of particular meals or in cases where heating is necessary. Homes with very young children and the elderly are more likely to need heating during rainy seasons in geographies located at elevation. The encouraging results of this study are that some women are willing and able to capitalize on gasifier technology. Further study is needed about the social context of home energy use perhaps with specific attention to the kinds of support that would help younger women develop the enterprises around providing services for cutting firewood into small pieces, charcoal, stove repair or stove production businesses. In addition, support for agroforestry initiatives that produce firewood and charcoal with fewer environmental impacts would possibly help to increase stove adoption rates. All of these innovations may lead to social changes as women benefit from cash generated by energy-related businesses and in turn can afford to spend money on other household or personal goals. In cases where a woman's participation in stove/energy provisioning allows access to cash income for the first time, one might expect changes in relationships between men and women, older and younger generations and those with greater and lesser ambitions. It is even possible to imagine that in households where members engage in biomass energy businesses, increased cash flow might be directed towards purchase of other energy sources such as electricity for lighting. In short, this study demonstrates that even incomplete shifts in cooking technology use could have positive impacts on women and communities even if the primary public health goals are not immediately met.

Benefits of gasifier use:

- Women liked the gasifier because it used less fuel, produced less smoke and produced charcoal as a by-product. Uptake of the gasifier reduces exposure to indoor air pollutants and associated health problems and women and children below school-going age will benefit more as they spend more time in the kitchen cooking. However, the burning process of the gasifier is not entirely clean, hence it should always be used in a well-ventilated environment;
- Households can be more energy secure through uptake of the gasifier which uses firewood and residues and produces charcoal for another cooking session. This can lead to freeing up of some of the time which

would have been used in firewood collection which in turn can be used by women in other productive activities;
- The gasifier contributes to saving time used by women on fuel collection and money to buy fuel, reduces the need to carry heavy loads of firewood and increases farm yields through use of biochar for soil amendment; and
- Young women were more willing to use the gasifier compared to their older counterparts but also stacked among the various stoves they had to meet their needs effectively.

Potential business opportunities:
- There is potential business opportunity for women who can offer services for cutting firewood into small pieces to be used with the gasifier; and
- Women can raise income through sale of the charcoal produced by the gasifier.

How to overcome fuel preparation challenges:
- Fuel preparation challenges can be addressed by cutting the firewood when it is fresh and soft, and then drying it.

Recommendations for enhanced uptake:
- Local artisans, mostly women, need to be trained on how to construct the gasifier to mitigate purchase cost. This can lead to increased uptake and diffusion of the technology. Women in groups can also save money together, hence they can pool resources and purchase for each other in a rotational manner; and
- Young women who are more interested in the stove should be targeted as trainers to train their fellow women rather than male research assistants as they have better understanding of the cooking needs of women.

7.5 References

Ado, A.; Darazo, I.R. 2016. Determinants of fuels stacking behavior among households in Bauchi metropolis. *The Business and Management Review* 7(3): 84–97.

Bracmort, K. 2010. *Biochar: Examination of an emerging concept to mitigate climate change.* Washington DC, USA: United States Congressional Research Service. (CRS Report for Congress).

FAO (Food and Agriculture Organization). 2013. *Safe access to firewood and alternative energy in humanitarian settings in emergencies.* Rome, Italy: FAO. (Guidance note).

Gitau, J.K.; Mutune, J.; Sundberg, C.; Mendum, R.; Njenga, M. Forthcoming. Factors influencing the uptake of microgasification cooking system among rural farmers. *Energy for Sustainable Development.*

Hale, S.E.; Lehmann, J.; Rutherford, D.; Zimmerman, A.R.; Bachmann, R.T.; Shitumbanuma, V.; O'Toole, A.; Sundqvist, K.L.; Arp, H.P.H.; Cornelissen, G. 2012. Quantifying the total and bioavailable polycyclic aromatic hydrocarbons and dioxins in biochars. *Environmental Science and Technology* 46(5): 2830–2838.

Hollada, J.; Williams, K.N.; Miele, C.H.; Danz, D.; Harvey, S.A.; Checkley, W. 2017. Perceptions of improved biomass and liquefied petroleum gas stoves in Puno, Peru: Implications for promoting sustained and exclusive adoption of clean cooking technologies. *International Journal of Environmental Research and Public Health* 14: 182–196.

IEA (International Energy Agency). 2013. *World energy outlook.* Paris, France: IEA.

Jeffery, S.; Bezemer, T.M.; Cornelissen, G.; Kuyper, T.W.; Lehmann, J.; Mommer, L.; Sohi, S.P.; Van De Voorde, T.F.J.; Wardle, D.A.; Van Groenigen, J.W. 2013. The way forward in biochar research: Targeting trade-offs between the potential wins. *GCB Bioenergy* 7: 1–13.

Karekezi, S.; Lata, K.; Coelho, S. 2004. *Traditional biomass energy: Improving its use and moving to modern energy use.* Bonn, Germany: International Conference for Renewable Energies.

Khandelwal, M.; Hill, M.E.Jr.; Greenough, P.; Anthony, J.; Quil, L.M.; Linderman, M.; Daykumar, A.H.S. 2017. Why have improved cook-stove initiatives in India failed? *World Development* 92: 13–27.

Kilian, W. 1998. Forest site degradation: Temporary deviation from the natural scite potential. *Ecological Engineering* 10: 5–18.

Lotter, D.; Hunter, N.; Straub, M.; Msola, D. 2015. Microgasification cookstoves and pellet fuels from waste biomass: A cost and performance comparison with charcoal and natural gas in Tanzania. *African Journal of Environmental Science and Technology* 9: 573–583.

MoE (Ministry of Energy, Government of Kenya). 2002. *Study on Kenya's energy demand, supply and policy strategy for households, small-scale industries and service establishments. Final report.* Kampala, Uganda: KAMFOR Company Ltd.

Mohan, D.; Sharma, R.; Singh, V.K.; Steele, P.; Pittman Jr, C.U. 2012. Fluoride removal from water using bio-char, a green waste low cost adsorbent: Equilibrium uptake and sorption dynamics modeling. *Industrial & Engineering Chemistry Research* 51(2): 900–914.

Njenga, M.; Iiyama, M.; Jamndass, R.; Helander, H.; Larsson, L.; de Leeuw, J.; Neufeldt, H.; Röing de Nowina, K.; Sundberg, C. 2016. Gasifier as a cleaner cooking system in rural Kenya. *Journal of Cleaner Production* 121: 208–217.

Njenga, M.; Mendum, R.; Gitau, J.; Iiyama, M.; Jamnadass, R.; Watson, C. 2017. Trees on farms could satisfy household firewood needs. *The Tree Farmers Magazine for Africa* 33: 20–23.

Rao, N.; Pachauri, S. 2017. Energy access and living standards: some observations on recent trends. *Environmental Research Letters* 12(2).

Ruiz-Mercado, I.; Masera, O. 2015. Patterns of stove use in the context of fuel-devise stacking: Rationale and implications. *Ecohealth* 12(1): 42–56.

Saraswati, S.M. 2018. *Design improvements for TLUD biochar producing gasifier stove in Rural Kenya from the user's perspective.* Master Thesis. Uppsala University, Sweden.

Sererya, O.G.; Kimaro, A.; Lusambo, L.; Uckert, G.; Hafner, J.; Sieber, S.; Graef, F.; Rosenstoc, T. 2017. Resilience and livelihood benefits of climate-smart agroforestry practices in semiarid Tanzania. *Poster presented at Tropentag 2017: Future Agriculture: Social Ecological Transitions and Bio-Cultural Shifts, 20–22 September, 2017.* Bonn, Germany: University of Bonn, Center for Development Research.

Sesan, T. 2014. Global imperatives, local contingencies: An analysis of divergent priorities and dominant perspectives in stove development from the 1970s to date. *Progress in Development Studies* 14(1): 3–20.

Sola, P.; Ochieng, C.; Yila, J.; Iiyama, M. 2016. Links between energy access and food security in Sub Saharan Africa: An exploratory review. *Food Security* 8(3): 635–642.

Sujjesy, L. 2018. *A climate change impact assessment of biochar system in rural Kenya*. Master Thesis. Royal Institute of Technology, Sweden.

Sundberg, C.; Karltun, E.; Gitau, J.; Kätterer, T.; Kimutai, G.; Mahmoud, Y.; Njenga, M.; Nyberg, G.; Roing, D.E.; Nowina, K.; Roobroeck, D.; Sieber, P. Forthcoming. CO_2-negative cooking and cultivation in smallholder farms in Africa – the potential role of pyrolysis and biochar. *Mitigation and Adaptation Strategies for Global Change.*

The World Bank. 2011. Household cookstoves, environment, health, and climate change: A new look at an old problem. Washington DC, USA: The World Bank.

Torres-Rojas, D.; Lehmann, J.; Hobbs, P.; Joseph, S.; Neufeldt, H. 2011. Biomass availability, energy consumption and biochar production in rural households of Western Kenya. *Biomass Bioenergy* 35: 3537–3546.

WHO (World Health Organization). 2005. *Indoor air pollution and health.* Geneva, Switzerland: WHO. (Fact Sheet No. 292).

WHO. 2006. *Fuel for life - household energy and health.* Geneva, Switzerland: WHO.

Acknowledgments

This chapter is based on research carried out in Kenya supported by The Swedish Research Council, project number 348-2913-182. The authors appreciate the active participation of householders, the Kenya Industrial Research Institute (KIRDI) and all members of the research team.