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Design Improvements for Top-Lit UpDraft Biochar-Producing Gasifier Stove in Rural Kenya from the Users' Perspective

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DEPARTMENT OF EARTH SCIENCES
INSTITUTIONEN FÖR GEOVETENSKAPER

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Saraswati, M. S., 2018: Design Improvements for Top-Lit UpDraft Biochar Producing Gasifier Stove in Rural Kenya from the Users' Perspective. *Master thesis in Sustainable Development at Uppsala University*, No. 2018/34, 42 pp, 30 ECTS/hp

Abstract: Energy plays a significant role in a country's development. Usage of an improved stove that produces biochar could help to reduce the pressure of deforestation, amend soil productivity, and provide cleaner technology for cooking. In Kwale, a county located on the south coast of Kenya, firewood is still used as the primary cooking fuel followed by charcoal. This research aims to investigate the improvements for a Top-lit UpDraft (TLUD) biochar-producing gasifier stove, which the users aspired through co-designing. Transformative mixed methods were used as the research design to empower the users' involvement in the *Biochar and smallholder farmers in Kenya – improved use efficiency of farm-level organic resources in relation to energy, crops and soil* project. Triangulation was used to process the collected data through structured user observations, a focus group discussion, and a semi-structured interview. Between two stakeholders, TLUD gasifier stove users and the manufacturer, there was a difference of opinion for the main priority. Ease of use was the main concern for the users while the manufacturer put forward energy efficiency. Further, the users desired for an increase in the stove's dimension as its capacity to produce biochar would increase.

Keywords: adoption study, co-designing, design for environment, mixed methods, participatory technology development, sustainable development

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Summary: In many cases of a country’s development, the energy sector drives its progress. It is a concerning fact that firewood is still used widely as the primary cooking fuel in a country, especially if it happens in a country that deals with the loss of forest coverage. Biochar-producing stoves offer less consumption of firewood while providing cooking energy that could decrease the pressure of firewood demand. The biochar can be used to increase soil productivity. This research aims to investigate the improvements to the stove by collaborating with the users to find out about their aspirations and highlight their role as a stakeholder in the project. It focuses on a county located on the south coast of Kenya, Kwale, which has firewood as their primary cooking fuel. Usability of the stove is the primary concern of the users. This finding is not aligned with what the manufacturer of the stove put forward, which is the energy efficiency.

Keywords: adoption study, co-designing, design for environment, mixed methods, participatory technology development, sustainable development

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Abbreviations

BSFK	Biochar and Smallholder Farmers in Kenya - Improved use efficiency of farm-level organic resources in relation to energy, crops and soil
DfE	Design for Environment
EDSC	Engineering Development and Service Centre
EMD	Environment Management Division
FGD	Focus Group Discussion
HAP	Household Air Pollution
KIRDI	Kenya Industrial Research and Development Institute
KREDP	Kenya Renewable Energy Development Project
LPG	Liquid Petroleum Gas
PICs	Products of Incomplete Combustions
PTD	Participatory Technology Development
RTI	Research, Technology and Innovation Department
SDGs	Sustainable Development Goals
TLUD	Top-Lit UpDraft
TSF	Three-Stones Open Fire
TT&ES	Technology Transfer and Extension Services Department
USAID	United States Agency for International Development

1. Introduction

Nearly all of the global challenges are connected to energy as it has the capacity to improve the quality of life, address global warming, and create economic opportunity to stimulate development (United Nations, 2013). In other words, energy and development are inseparable. There are three main challenges of this century according to Scholz et al. (2014) namely: the creation of resilience in facing difficult climatic environment, the need for food security by doubling the production by 2050, and the reduction of a significant amount of greenhouse gases in the atmosphere simultaneously. In tackling these global challenges, a commitment from the international community is required. As a response to this matter, the United Nations announced the Sustainable Development Goals (SDGs) consisting of 17 integrated and inter-related goals as target guides to achieve a healthy world without poverty and to promote inclusive societies that ensure a dignified life for everyone (United Nations, 2017b).

Goal 7 of the SDGs focuses on energy, aiming to "ensure access to affordable, reliable, sustainable and modern energy for all" (United Nations, 2017a). The concept of sustainability can be defined as reaching the balance of three pillars which are the economy, society, and environment (Connelly, 2007, Hopwood et al., 2005). According to the United Nations (2017b), almost all of the urban residents have access to electricity while only 73 per cent have it. Furthermore, there was only a seven per cent increase in access to clean cooking technologies and fuels in the last seven years and 3 billion people, mostly in sub-Saharan Africa and Asia, are exposed to household air pollution (HAP) due to this lack of access (United Nations, 2017b). Despite the availability of alternative energy sources, many people in developing countries still use firewood as their primary source of energy as well as animal dung, charcoal, and crop residues (Mehetre et al., 2017). In many parts of Asia and sub-Saharan Africa countries, HAP causes around 68 and 87 deaths in every 100,000 people. It is considered as one of the leading causes of illnesses such as acute respiratory infections and cardiovascular diseases in the rural areas, where mostly the households are low-income (Shackley and Carter, 2011, United Nations, 2017b). Their choice of fuel is dependent on the availability in their surrounding area, as it is available without economic costs.

As mentioned by Mehetre et al. (2017), the practice of cutting trees for firewood leads to deforestation when done on a mass scale without replanting plans; this is apprehensive considering the growing population in a rural area. One approach to reducing deforestation without neglecting the need of people in the rural area is the use of improved cook stoves through stove interventions projects. Improved means, a variation of replacements for traditional cooking techniques which have inefficient fuel use thus, emits products of incomplete combustion (PICs) such as carbon monoxide (Grieshop et al., 2011). The traditional cooking technique defined here uses three stones as supports for the pots while cooking using an open fire. In the following, I will refer to this cooking technique as three-stones open fire (TSF). To use efficient improved stoves means the emission from cooking decreases as the stove has a higher efficiency in combustion (Njenga et al., 2014). Since the improved stove has higher efficiency, it requires less consumption of fuel than the traditional cooking technique. Thus, the stove is more environmentally friendly and decreases the pressure on forests.

One type of improved stove pushes the environmental benefits even further, as it produces biochar that can be used to increase soil productivity and mitigate climate change. Biochar had been used to amend soils for a long time in Asia, Africa and the Amazon basin notably known as terra preta (Scholz et al., 2014). This type of stove, as stated by Whitman et al. (2011), is a pyrolysis stove which produces biochar and energy for cooking. Pyrolysis is a process where the biomass goes through thermal-treatment under limited oxygen and results in the carbon-rich matter (Scholz et al., 2014). Top-lit UpDraft, or widely known as TLUD, is a type of gasifier stove that releases gas for cooking while producing charcoal (Anderson and Schoner, 2016). This type of stove is used in the "Biochar and Smallholder Farmers in Kenya - Improved use efficiency of farm-level organic resources about energy, crops and soil" (BSFK) project as it fulfils the production of biochar in the household level while providing efficient cooking technique. Kwale is one of the counties where the BSFK project takes place. In 2009, only 20 percent of the households in Kwale that did not use firewood for cooking (Knbs, 2009a). Looking at that percentage, Kwale has to start immediately to move into a sustainable and affordable source of cooking energy.

By replacing TFS with the improved stove, development with sustainability addressed has taken place in the community (Huber, 2000). However, the sophistication of these improved stoves cannot ensure the success in achieving the primary goals of reducing environmental degradation and improving livelihoods, as the choice of the cooking techniques depends on the users. The conventional method in developing technology is to have the experts working remotely from the users and a real-life situation where this technology will be used. Most of the beneficiaries of the improved stove live in the rural area of a growing industrial country while the technology developers, or researchers, live in an urban area of an industrialised country. This discrepancy between the researchers and the beneficiaries makes collaborations a crucial element in developing the improved stove (Sweetman et al., 2010). Otherwise, the stove intervention might not prove sustainable when it is merely introducing the technology. Further, it could create dependency on the new stove, mainly when the purchase of the stove is subsidised, but when it wears out, it does not get replaced (Bates, 2007). Beneficiaries of the improved stove are the decision maker of whether the technology serves its purpose or not. This active role makes the beneficiaries a stakeholder, the central one, in the project since the technology is not merely adopted but instead being adapted by them to be used, as argued by Douthwaite et al. (2002).

Since technology is shaped by the people who use it, instead of being adopted (Glover et al., 2016), inclusion in the developing process of an improved stove is recommended to attain usability. As studies on improved stoves emerged from the crisis of firewood for cooking fuel in the 1970s (Arnold et al., 2003), most of these studies emphasised the advantages that improved stoves have compared to TSF (Ruiz-Mercado et al., 2011). Decades after these studies, TSF is still widely used despite all the negative impacts for the environment, health and society offered by the aforementioned improved stoves. As stated by Shackley and Carter (2011), all the improvements made for the stoves should consider the users' perspective, and not only aim for the environmental sustainability and health benefits – if one wishes for the improved stove to replace TSF. It goes along with participatory design which purpose is to create a product that will bring forward change in the users' practice (Bratteteig and Wagner, 2014). For this reason, I will refer the beneficiaries as the users to invite their involvement in shaping the improved stove in the project.

1.1. Aim

The purpose of this study is to assess the TLUD gasifier stove regarding its usability by involving the key stakeholders, which are the users of this technology, to ensure a sustainable cooking practice in Kwale.

To learn with the users about their cooking practices and preferences provides insights not only for the improvements of the TLUD gasifier stove but also how to move away from inefficient cooking techniques. In the long run, this study aims to encourage the adoption of a cleaner cooking technique in rural Kenya as a step towards the 17 SDGs.

1.2. Research questions

In achieving the aim, there are two central research questions formulated:

- What are the improvements required for the TLUD gasifier stove in response to the users' needs and aspirations while keeping the design environmentally friendly?
  - Are the users' aspirations met in the BSFK project?
- How does the TLUD gasifier stove compare to the three-stone open fire regarding cooking practice and implications on livelihoods?

2. Background

In this chapter, information in regard to the background of this study is presented. The relation between energy and development are explored in the first section. Then, facts about Kenya, where this study took place, are exposed from the perspective of energy consumption and development programs. Lastly, relevant details about the project of “Biochar and smallholder farmers in Kenya - improved use efficiency of farm-level organic resources about energy, crops and soil”, which this study is extended from, are shown.

2.1. Energy and development

As one of the factors for development, energy is known to be an essential part of it (Lands and Uncrd, 2011). Issues concerning energy supply concern all countries, regardless of their economic status as a developed-industrialised country or a developing country. For developed countries, the increase in future demand for energy will be small compared to developing countries, where the latter needs to improve accessibility to energy (Toth and Videla, 2012). According to United Nations (2017b), there is a need to improve the energy efficiency, to expand renewable energy usage, to increase the access to electricity and clean cooking fuels, as well as to technologies, in order to achieve sustainable development. Accessible and affordable energy for everyone is the starting point to alleviate poverty as it promotes equity and facilitates learning to develop the human capital (Toth and Videla, 2012). In fulfilling the energy demand, the economic cost is still the first consideration before the environmental or health impact. This fact is shown in a report by the United Nations (2013) stating that 3.2 billion people depend on solid fuels such as wood, crop or animal waste, and charcoal for cooking and heating. Imbalance of supply and demand of biomass also causes deforestation (Ministry of Energy and Petroleum, 2015). It is a concerning fact to know as these sources of energy bring negative impacts to the environment and human health.

The negative impacts of using biomass for cooking energy result from the incomplete combustion of biomass that released carbon dioxide (CO_2) to the atmosphere, called black carbon that results in the rise of global temperature which leads to climate change (Ekouevi, 2013). Carbon dioxide is not the only matter in the atmosphere to be a concern of; other products of incomplete combustion (PICs) also have significant global warming potential. The PICs are carbon monoxide (CO), methane (CH_4), non-methane hydrocarbons (NMHCs), nitrous oxide (N_20), oxides of nitrogen (NO_x), particulate matter (PM), black elemental carbon (EC), organic carbon (OC), and organic matter (OM) (Maccarty et al., 2008). It is estimated to cause more than four million deaths globally in 2012 (United Nations, 2017b). Mitigating climate change and conserving forest resources have been the two primary motivations for most of the improved stove projects. In many developing countries, the typical cooking technique that is used is the traditional open fire that has less than ten percent energy efficiency. This rate, however, can be increased with the use of an improved stove, thus reducing the consumption of firewood and combatting deforestation (Mehetre et al., 2017).

Energy consumption and economic growth have a two-directional causality, as stated by Toth and Videla (2012) since economic growth encourages energy consumption and the increase of energy consumption affects economic growth. The lack of technological advancement in efficient and clean cooking techniques led to research and project on improved stoves across the globe. Many of these projects are designed by international development agencies partnering with non-governmental organisations (NGOs) (Bielecki and Wingenbach, 2014). However, it should be considered whether the proposed solution brought by the projects will help to develop the beneficiary country in the long run or merely provides a temporary solution. Another thing that should be considered in development assistance is how the transfer of resources or knowledge should be done.

2.2. Kenya

The focus area of this study is a community in Kenya. This country is situated in Eastern Africa. Kenya has more than 38.6 million citizens and an area of 581,309.29 km^2 with the share of urban and rural being 32.3 per cent and 67.7 per cent respectively (Knbs, 2009b). According to the Ministry of Energy and Petroleum (2016), around 45.6 per cent of the population lived under the poverty line and most of them resided in rural areas. In 2016, the GDP was estimated at around 70 billion US dollars with 32 percent of it came from agriculture, forestry, and fishing (The World Bank, 2018). Kenya's topography consists of high mountains, semiarid desert, savannah, rivers and lake (Ham, 2015). Approximately 44.1 km2 of the country is covered with forests (The World Bank, 2018). Its neighbouring countries are Sudan, Uganda, Tanzania, Somalia, Ethiopia. Kenya has access to the sea, connecting to the Indian ocean. The country is divided into 47 semi-autonomous counties led by their governor (Knbs, 2015a). Nevertheless, some socio-economic functions related to energy, such as electricity and gas reticulation, are still the responsibility of the National Government although the County Governments can do planning and development of the county (Ministry of Energy and Petroleum, 2016).

Figure 2. 1. Geographical location of Kenya (TUBS, 2011) and the relief map of Kenya (National Aeronautics and Space Administration, 2006)

The current National Government has a long-term development programme called Kenya Vision 2030. The purpose of this plan is to transform the country into a globally competitive and prosperous nation with a high quality of life (Ministry of Energy and Petroleum, 2016, Mwenzwa, 2014). There are three main pillars for this long-term blueprint of the nation: political, economic, and social governance (Ministry of Energy and Petroleum, 2016). However, the Kenyan government recognised that land needs to be preserved as it is a crucial production factor for its economy, as mentioned by Ministry of Energy and Petroleum (2015), and this indicates their aspiration to develop the country align with the SDGs.

2.2.1. Household main energy consumption

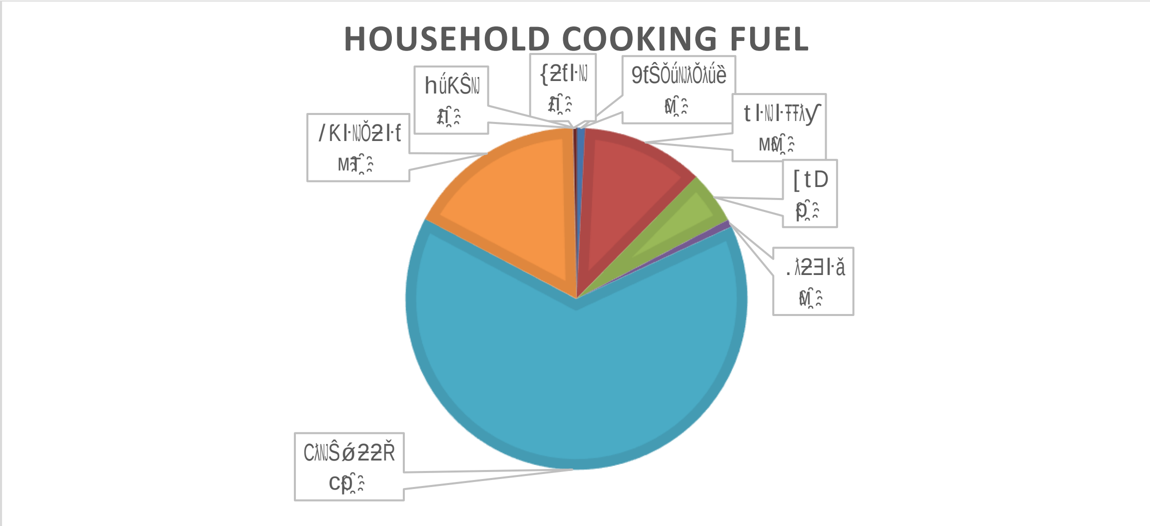


Figure 2. 2. Source of cooking energy in Kenya (KNBS, 2009a)

Firewood and charcoal are still the most commonly used energy source for the Kenyan population as shown in Figure 2.2. Most of the population lives in rural areas, and the firewood a s the preferred fuel is sourced from their farms or nearby natural forests or plantations. Meanwhile, charcoal is more favourable in urban areas because it has lower economic cost than electricity and gas (Ngui et al., 2011). The economic cost is still the main priority in choosing the energy source even though this practice leads to deforestation. As firewood and charcoal are not as efficient as oil or natural gas, it requires a considerable amount of firewood or charcoal to produce the same energy, and they emit more smoke (Ministry of Energy and Petroleum, 2015). It means that the households need more firewood to collect. Thus, more time is required for preparing the cooking activity. Malla and Timilsina (2014) argued that awareness, or education, is a critical factor that influences fuel choice for cooking.

2.3. Biochar and smallholder farmers in Kenya – improved use efficiency of farm-level organic resources in relation energy, crops and soil project

The current study is part of the "Biochar and Smallholder Farmers in Kenya – improved Use Efficiency of Farm-level Organic Resources in relation to Energy, Crops and Soil" project. The project examines the impact of biochar on soil productivity and living improvements through small-scale agriculture in rural Kenya (Njenga et al., 2015). It is funded by the Swedish Research Council, and Formas and partners in this project include experts from International Institute of Tropical Agriculture (IITA), KTH, Lund University, the Swedish University of Agricultural Sciences (SLU), Umeå University, the World Agroforestry Centre (ICRAF), and the University of Nairobi. In this multidisciplinary project, the researchers are studying the possibility of producing biochar in the households using TLUD gasifier stove (Adelsköld, 2015).

According to Smebye et al. (2017), TLUD gasifier stove is one of the methods to produce biochar in a rural and, or low-income, area. This method was also used in this project to provide biochar for the participants. As the primary focus of BSFK project is to study the biochar, so the manufacture of TLUD gasifier stove is outsourced. Several TLUD gasifier stove had been used, but the current one in the study is manufactured by the Kenya Industrial Research and Development Institute (KIRDI) in Nairobi, Kenya (Gitau et al., 2017).

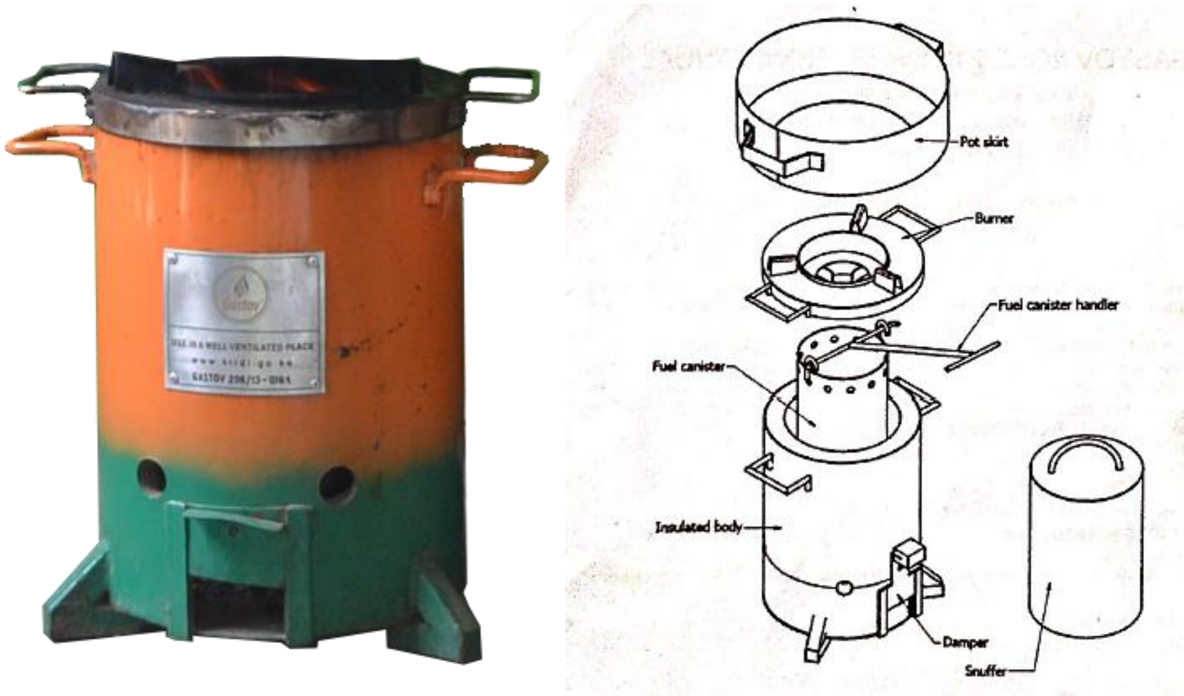


Figure 2. 3. TLUD gasifier stove used in BSFK project (left), and the accessories (right) ((KIRDI, n.d.-b)

The product name in the market is Gastov which I refer to as TLUD gasifier stove. It consists of a fuel canister, loading the fuel in batch, the ceramic insulated body, burner, and pot skirt. The dimension of this stove is 34,5 centimetres in height, and 23 centimetres for the outer diameter, with the weight, is 14 kilograms including the fuel canister inside. The TLUD gasifier stove was distributed without any cost to fifty selected households who have been receiving training on using this cookstove in three studied areas. The designated study areas chosen are based on the distinctive character of the geographical landscape. However, they are all in rural areas. According to Kirdi (n.d.), this TLUD gasifier stove can be fuelled with a variation of biomass such as maize cobs, coconut shells, briquettes, pellets, bamboo, and firewood. It can also be used indoor or outdoor according to the user’s needs.

2.3.1. Biochar

Biochar is a term used to identify charcoal that is applied as a soil amendment in projects focusing on carbon sequestration and emission reduction (Whitman et al., 2011). Therefore, when it is used as fuel, then it is called charcoal. To produce biochar, biomass has to be processed with a thermal treatment between 300°C and 700°C in a limited oxygen condition, called pyrolysis, so that the carbon can be sequestered (Scholz et al., 2014, Smebye et al., 2017). According to Gwenzi et al. (2015), biochar can improve soil productivity and increase yields by enhancing soil moisture and nutrient availability, stimulate microbial diversity and activity and improve acidic soils thus, it is suitable for agricultural purposes, energy supply, to counter environmental degradation, and mitigate climate change as shown further in Figure 2.4.

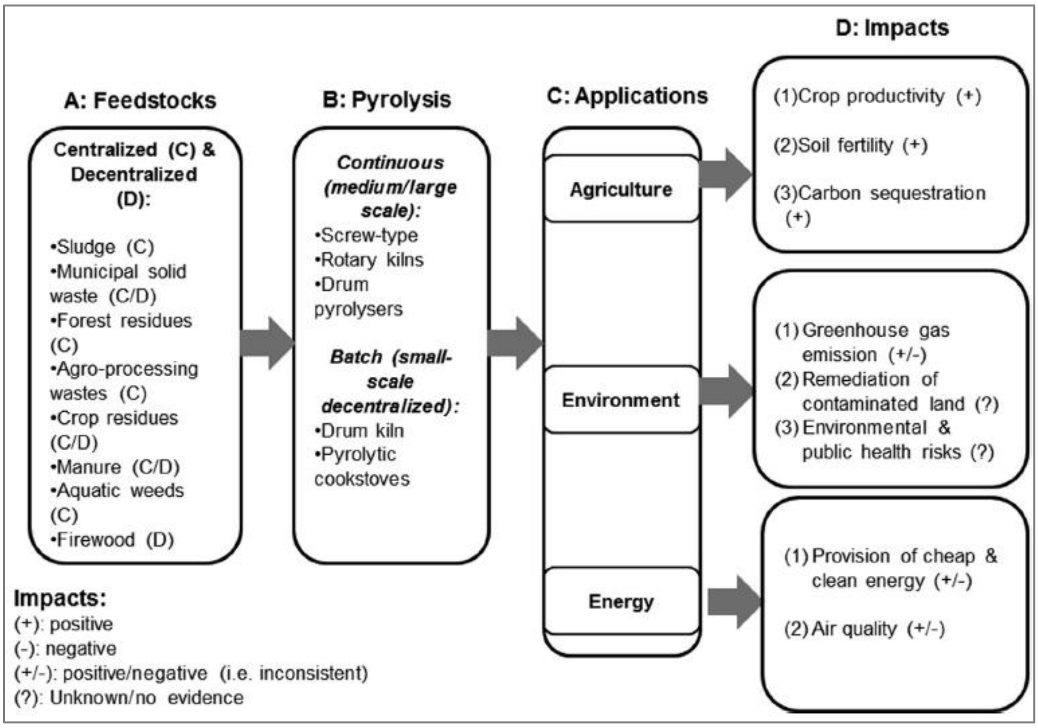


Figure 2. 4. Biochar technology summary in sub-Saharan Africa showing potential feedstocks (A), the pyrolysis systems (B), the potential applications (C) and forecast on the impacts of application (D) (Gwenzi et al., 2015)

From a life-cycle perspective, the production of biochar is considered to be climate neutral since the emissions produced are compensated by the carbon sequestration (Smebye et al., 2017). Nevertheless, if the biochar is produced with traditional charcoal producing kilns, then it will not fit the neutral life-cycle scenario as the production method uses inefficient combustion that emits air pollutants to the atmosphere (Nsamba et al., 2015). It is necessary to ensure that the sourcing of biomass is sustainable, and the production method is efficient. Nevertheless, the choice of biochar producing technology depends on the type of available feedstocks (Scholz et al., 2014).

2.3.2. Kwale County

Kenya is divided into seven regions: central, coast, Eastern, Nairobi, North Eastern, Nyanza, Rift Valley, and Western (Ngui et al., 2011). This study focuses on Kwale, a county in Kenya’s coastal region. It focuses on households that have been using TLUD gasifier stove since 2013. Located on the southern tip of Kenya, this county borders with the Indian Ocean and Tanzania as shown in Figure 2.1. In making a sustainable design, the product must be adjusted to the target user. It means that there is no design which works as a universal solution (Zaretsky, 2011). Geographical location affects the needs of the stove users. Thus, improvements on the stove design should meet these needs.

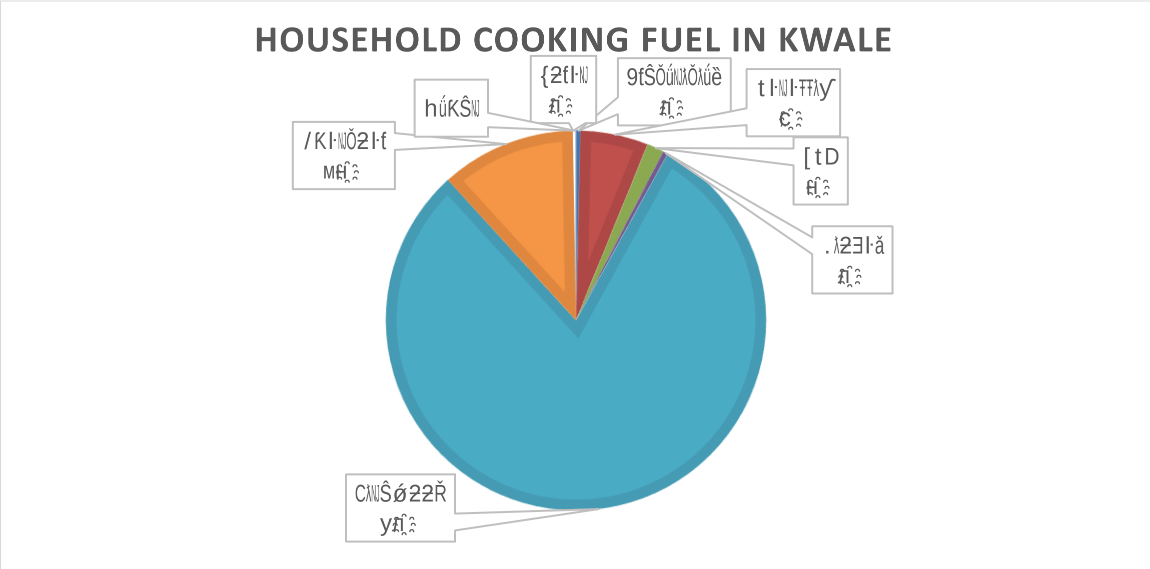


Figure 2. 5. The primary source of cooking energy in Kwale (KNBS, 2009a)

Around 2 percent of the total Kenyan populations live in Kwale (Knbs, 2009b). Most of them use firewood as their cooking fuel – making up to 80 percent as seen in Figure 2.5. In the Kombani, Matuga and Ng'ombeni sub-locations in Waa ward of Matuga constituency in Kwale County Kenya which are the study sites, firewood is the primary cooking fuel for all the households, 2 percent use it exclusively while the rest use it alongside other fuels such as crop residues. Use of Liquid Petroleum Gas (LPG) and biogas is found in only 8 percent and 2 percent of the households respectively (Gitau et al., Forthcoming). With such high demand for firewood, there should be compensation to ensure it will not exacerbate environment degradation.

The soils in Kwale have low to moderate fertility. Because of that the Lands and Uncrd (2011) recommended that action should be taken to increase the humus content in the soil to improve the crop yields in their 30 years development plan. Maize (*Zea mays*), beans (*Fabaceae*), rice (*Oryza sp.*), and cowpea (*Vigna unguiculate*) are the crops produced in this region (Knbs, 2015b). Approximately 7 per cent of the area in this region is covered by forest out of the total size 8,373 km^2 (Lands and Uncrd, 2011). In 2014, there are nine gazetted forests, which are forest or woodland declared to be a nature reserve, with the total size of 400 km^2 (Knbs, 2015b). The usage of firewood as household cooking fuel is still a prominent practice in this county. According to Majdan et al. (2015), this practice in the rural area of Kwale caused indoor air pollution which is a potential threat to public health.

3. Literature review

This chapter presents related studies to investigate projects in Kenya related to the improved stove by looking at their approaches in developing the cooking technology and their outcomes. The improved stove discussed in this part are using solid-fuel, or biomass, because these energy sources do not require economic cost as a preference for the low- and middle-income countries populations who are the primary target of most improved stove projects (Debbi et al., 2014, Hollada et al., 2017). Further, relevant studies on cooking with TLUD gasifier stove are analysed to identify the relation between environmental degradation and using this technology for cooking.

3.1. Improved stove projects in Kenya

The term *improved stove* is used broadly but it can be defined as cooking technology with the increase of fuel efficiency where Putti et al. (2015) divides it into two categories: improved solutions – legacy and basic stove, and intermediate stove; and clean cooking solutions – advanced stove, modern fuel stove, renewable fuel stove. TLUD gasifier stove falls in the second category, under the advanced, improved stove (Putti et al., 2015). To allow for the change in cooking technique to take place, the Kenyan government set a target of 5 million households that use clean technologies for cooking by 2020, called Kenya Country Action Plan (Ministry of Energy and Petroleum, 2016). This plan is not the first initiative to take place in transforming the traditional cooking technique into cleaner cooking technology. In 1981, a major collaboration project between the Kenyan Government and the United States Agency for International Development (USAID) called Kenya Renewable Energy Development Project (KREDP) was launched (Tigabu, 2017). Afterwards, there are more big projects on improved solid-biomass fuel stove projects in Kenya as shown in Table 3.1.

Table 3. 1. Outline of major projects on the improved solid-fuel stove in Kenya (Tigabu, 2017)

Launch year	Project	Major project activities
1981	Kenya Renewable Energy Development Project	Improved charcoal stove prototype development; Training of artisans on manufacturing Kenyan ceramic jiko; Creating public awareness about improved solid-fuel stove to entice adoption (stove promotion)
1983	Special Energy Program	Wood-burning stove prototype development; Training of women groups on wood-burning stove manufacturing, installation and business management; Public awareness creation (stove promotion)
1989	Rural Stoves West Kenya project	Developing portable jiko/”Maendeleo”, a fuel-efficient stove to be used in rural areas; Training of women to manufacture portable wood-burning stove in rural areas
1995	Upesi rural stoves project	Manufacturing, distribution, installation and commercialisation of “Upesi stove”; Training of women on the production and installation of “Upesi stove.”
2005	Energising Development Partnership (EnDev) stove Programme in Kenya	Manufacturing and distribution of “Jiko Kisasa” and “Rocket stoves”; Market development for the efficient stove; Public awareness campaigning (stove promotion)

From the summary in Table 3.1, many of the projects involved educating the public about the cooking technology and training of women. Since the 1980s, the framework for improving stove projects does not experience significant changes. It starts with the researchers developing the cooking technology, educating the local people on the benefits and disseminating its usage. Several factors in adopting improved stoves are related to its environmental and economic advantages but, in the biochar-producing stove, agriculture management becomes a factor too (Ochieng et al., 2013, Whitman et al., 2011). Development actors promoted the use of improved stoves to diminish health and environmental problems from using biomass. Nevertheless, the outcomes were not what they expected (Sesan, 2012). Although improved stove is a solution to overcome firewood demand, it is perceived as a temporary fix to balance the biomass energy supply while the transition towards cleaner cooking fuels and sustainable bioenergy strategies are being placed (Ministry of Energy and Petroleum, 2016, Ochieng et al., 2013). Furthermore, a study by Stanistreet et al. (2015) confirmed that the users see improved stoves to be used alongside TSF instead of as a replacement.

In relation to adoption studies, Glover et al. (2016) mentioned that the understanding of adoption concept is not comprehensive and has a tendency to be deceiving because it neglects other essential aspects but individual decisions. Nonetheless, Shackley and Carter (2011) argued that, in developing the cooking technology, it should be questioned from whose perspective that the improved stoves are improved – can it be identified as one when it neglects the users' needs and expectation with the expense of environmental sustainability? In accordance with this statement, Hafner et al. (2018) mentioned that ignoring the users' needs is the reason behind a considerable amount of improved stoves projects driven by industrialised countries fail to succeed. Indeed, the users have the final say in using the improved stove (or not) but government supports, policies, and researchers' awareness definitely help to determine the success of the projects.

3.2. Linking environmental burden – reduce fuel consumption

TLUD gasifier stove, or inverted down draft stove, is a type of gasifier which the fuel is lit at the top. Thus, it needs to have air flow from below the canister (Belonio, 2005). Figure 3.1 illustrates this process. Continuous reloading in this cooking technique is not advisable as it will disturb the pyrolysis process thus, the fuel reloading is done in batches when the gasification process has finished. Fuel preparation is essential to make sure that the TLUD gasifier stove is used correctly (Birzer et al., 2013). Unless it is used in the proper way, the efficiency rate cannot be optimal. It means that the users must learn a new skill and change their habit from previously using another type of cooking technique when they want to use the TLUD gasifier stove (Shackley and Carter, 2011). To do this, Hollada et al. (2017) suggested that users must cook with the stove repeatedly and have satisfaction with the performance while having secure access to fuel and stoves for the behaviour change to take place. Especially for fuel reloading where in TSF they can see the amount of fuel remaining and anticipate for refuelling, however, this is not the case for TLUD gasifier stove as the fuel is not visible from outside.

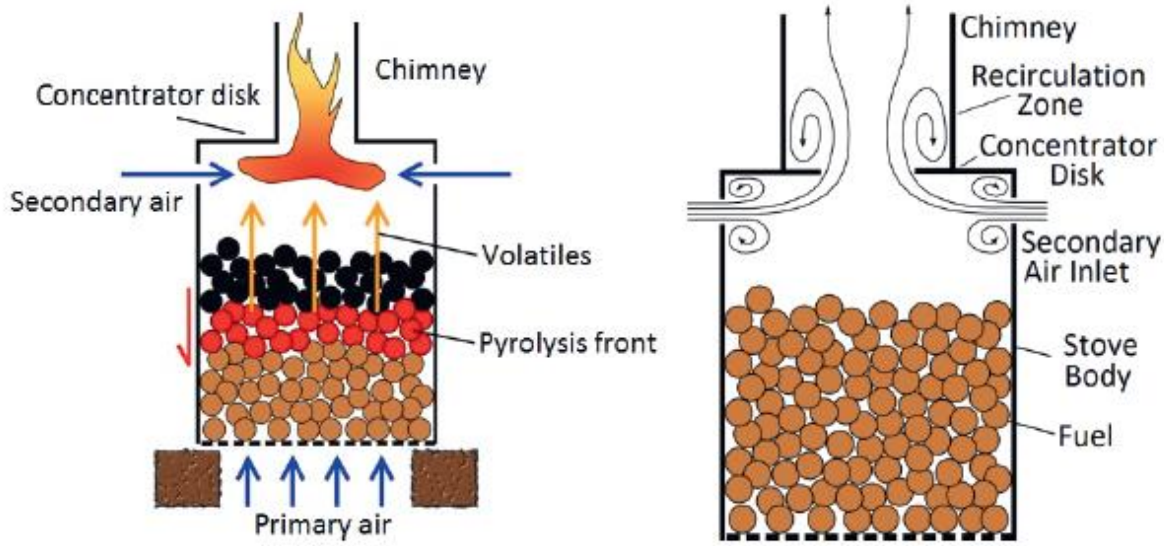


Figure 3. 1. Illustration of the combustion process and the fluid-flow patterns in a TLUD gasifier stove (Birzer et al., 2013)

Although Smebye et al. (2017) mentioned that the TLUD gasifier stove generates less emission compared to TSF, however, Birzer et al. (2013) argued that when dung is used as the fuel, it has a higher burning rate than TSF that it produces high levels of NO_x and $CO_{2(eq)}$, although the CO emissions is far less than the TSF. As stated above, one of the selling values of TLUD gasifier stove is the reduction of smoke emission. This feature alone may not be compelling enough to enhance the stove uptake while for some smoke in the kitchen is a good thing. As the users realised about the smoke emitted when they use traditional cooking technique but unwary about its implications to their health in the long run that they do not feel the urgency to change their habit especially if the smokes are deemed as something functional, such as the ability to repel insect (Hollada et al., 2017, Shackley and Carter, 2011). Despite the innovation to improve health in the community, if the cooking technology does not accommodate the needs and suits the local practice, then the users might experience an issue in adopting the stove. According to Ngui et al. (2011), there should be a partnership between the government and non-governmental organisations to educate and spread awareness about cleaner cooking technology to sustain the usage of this stove.

TLUD gasifier stove offers a complete and cleaner burning of solid biomass, making sure that they do not go to waste (Shackley and Carter, 2011). It is one of the propositions which the gasifier stove has, not wasting any biomass. In a study by Hafner et al. (2018) in Tanzania, the amount of firewood used to cook the same dishes using improved stove is 15.6 percent less than the firewood consumption in TSF; this amount of firewood is reduced as the ingredients to be cooked is increased. Nevertheless, Scholz et al. (2014) argued that if the reduction in firewood consumption for cooking is the objective then using TLUD gasifier stove is less suitable because as a biochar-producing stove it retains some biomass in biochar form that not as much energy would be generated compared to combustion stove. The choice of TLUD gasifier stove is suitable for projects that value the soil and/or climate benefits of biochar (ibid.). Even though TLUD gasifier stove does not have the most efficiency in fuel consumption, but it brings other environmental and health benefits to the table.

4. Theoretical framework

This chapter explains an approach and a concept that is used to guide the analysis for this study; they are the Participatory Technology Development (PTD) and Design for Environment (DfE). Together, these two frameworks guide this study to answer the research questions.

4.1. Participatory technology development approach

In developing technology, the technology developers focus on achieving a result that they have set, or expected, early in the start of the project. They want to attain a successful innovation as they assume that it explains for the next technology development – this mindset results in the implied adoption of the linear technological development model (Pinch and Bijker, 1984). This model is not ideal as the technology developers tend to live in an environment that is different from the target users of the technology, resulting in a different perspective of how the technology should be. The approach which is used in developing technology affects the development of a nation, mainly, when the technology is imposed to solve the issues that hinder the nation’s growth.

Participatory becomes a favoured approach for development initiatives after the short success of Green Revolution takes place globally with top-down approach during the 1960’s to 1980’s (Biggs and Smith, 1998). From station-based research in the 1970s, the approach shifts to farming system research in the 1980s and then it transforms to participatory technology development research starting from the 1990’s (Salas et al., 2003). Van Der Velden and Mörtberg (2014) argued that the outcome of a design process using the participatory approach would represent the value of the targeted users. When the users identify themselves with the technology, then it is very likely for them to incorporate the technology to their daily lives as the participation leads to a sense of ownership and clear definition of their needs (Salas et al., 2003).

Collaboration between the users and researchers within a long duration would produce exceptional innovations because each stakeholder could bring their expertise to the table, this process should be done through the suitable ways that would bring the most out of these advantages (Hoffmann et al., 2007). This collaboration is better to be conducted early in the project’s stage, to modify the innovative technology into the local environment, as it could save the cost if this technology has been promoted too early (Douthwaite et al., 2002). Other than this economic consideration, the technology could be more on point and successful when the key stakeholders (those who are directly affected from the innovation) synthesis their knowledge with the developers (Douthwaite et al., 2001, Suchman, 2002). Moreover, Suchman (2002) argued that making a clear stance of each stakeholders’ participation would easily identify their responsibilities in delivering the innovations. In doing participatory approach, it is more democratic to involve the users directly especially when they take the role as decision maker (Compagna and Kohlbacher, 2015, Stirling, 2008). As mentioned by Debbi et al. (2014), another advantage of using the participatory approach early in the project set up and operation is beneficial to achieve the long-term goals and short-term success.

One of the disadvantages of PTD is that it takes further effort to communicate with the same ‘language’. For example, the users might have difficulty in discussing technical topics with the engineers although they would not experience perplexity when having discussions on social goals (Rogers, 2008). Hoffmann et al. (2007) add another disadvantage from adopting this approach, stating that the research might not be a priority when they have income-generating activities to be done. Furthermore, this approach does not automatically solve the challenge of transferring the users’ opinion to the technology development as it requires a long-term commitment from the practitioners to be involved in the project (Heiskanen et al., 2005). In all, using the participatory approach does not mean that it is better unless there could be a balance in the labour division and transparency for the research budget and emerging property rights (Hoffmann et al., 2007). Practitioners and researchers (the research and development team) should be ready to adopt their new roles in facilitating this process, primarily to pave the way for initiating development interventions (Reed, 2007).

4.2. Design for environment concept

The concept of DfE, or eco-design, refers to a design that focuses on increasing the environmental performance of a product in all stages of its design and development (Hauschild et al., 2004, Poulikidou et al., 2014). According to Ramani et al. (2010), the environmental considerations are seen as a business opportunity in the practice of DfE. From the end of the 1980s, the focus on environmental issues in the industries was towards making manufacturing processes clean through decreasing pollution and waste as well as using energy and materials efficiently (Roy, 1994).

During the 1990s, various research took place to develop methods for DfE (Hauschild et al., 2004). Then, research on DfE investigated the organisational and strategic consequences during 2001 to 2010 where social dimension was included in the research to expand this concept with 'design for sustainability' as a result (Luiz et al., 2016). The understanding of this concept evolves from initially a technical, or engineering, focus on manufacturing process and its components to 'people-centred' design (Sherwin, 2004). This change in the perspective can be linked to the fact that a product has to be manufactured and adopted on a large scale to have a significant impact on environmental issues (Roy, 1994).

Improvements in design and sustainability can be accomplished together, as argued by Romli et al. (2015). However, Ramani et al. (2010) mentioned that product design is only the initial step of product development that they suggest to also focus on achieving environmental-friendly product through clean manufacture, profound end-of-life scenarios, and efficient infrastructures. Related to this argument, an environmentally-friendly product does not always have to be durable because when the product requires an enormous energy to be operated, and innovation can come up with a more energy-efficient version, then it is better to have a shorter product life such as in the case of kitchen refrigerator; the main point is to identify the actual environmental issue to decide on the most suitable strategy for DfE (Hauschild et al., 2004). It is necessary to identify the needs and environment in the real world before manufacturing a product to reduce the unnecessary environmental, economic and social impacts.

5. Methodology

This chapter explains the data collection and analysis methods conducted for this study. There are two parts to this methodology chapter. The first part consists of methods in the collection of empirical data. These methods are structured user observations, a focus group discussion with co-designing, and a semi-structured interview. In the second part, the research design used in this study, which is the transformative mixed methods, is elaborated. Transformative means that the research puts forward social justice by advocating the marginalised community in order to change the current power relation and achieve equity (Mertens, 2010). This method is taken to provide insights in achieving sustained use of TLUD gasifier stove as it is beneficial to mitigate climate change and reduce HAP. As Delyser and Sui (2014) mentioned, a complex problem required a variety of approach to deal with the problem from different perspectives.

5.1. Methods

A set of mixed methods was used to understand the TLUD gasifier stove and how the users perceived this technology. Mixed methods research were described with various characteristics but the primary definition was the collection of data using qualitative and quantitative approach, methodical analysis from both forms of data, integration of those data (by merging, connecting or embedding them), and a theory or a philosophical worldview underpinning the research (Creswell, 2014, Sweetman et al., 2010). The quantitative research was valuable to measure the usability of the TLUD gasifier stove, and the qualitative approach was necessary to examine the perspectives of the stakeholder. There are many terms used to refer this approach such as *multi-strategy designs*, *multimethod*, *mixed methodology*, *integrating*, *quantitative and qualitative methods*, *synthesis* – however, the majority and recent writings used the term *mixed methods* (Bryman, 2012, Creswell, 2014, Robson, 2011). According to Watkins and Gioia (2015), the use of mixed methods deviates from the acknowledgement of how vital our worldview in which affecting the methodological position, construction of research question to data collection, analysation and interpretation that was used in research.

The quantitative and qualitative research was carried out around the same time, instead of one type of research done followed up by the other, making this a convergent parallel mixed method (Creswell, 2014). Then the findings were analysed on their own to be merged later with triangulation, resulted in a comprehensive perspective of the TLUD gasifier stove. Triangulation confirmed the research findings from each method by emphasizing the overlapping information (Robson, 2011, O'grady and O'grady, 2017). Then, these findings were processed with the theoretical frameworks as transformative mixed methods approach was taken. Thus, it would be possible to shift the perspective regarding the role of the technology's beneficiaries into users where the latter are acknowledged as the key stakeholder.

5.1.1. Structured user observations

In a user-centred approach, it was necessary to understand the users' logic (Wever et al., 2008). To study this and their behaviour in cooking with TLUD gasifier stove and three-stone open fire, fifteen systematic observations in ten households were conducted. This method fell into the quantitative research type as it used formulated rules, such as a checklist, for all the observations done (Bryman, 2012, Robson, 2011). These observations were taken place during the rainy season which made the location of the cooking place varied between indoor or semi-outdoor kitchen. Ten of the observations used the TLUD gasifier stove while five observations used the three-stone open fire. This implies that out of the sample of 10 households, five of them cooked with both TLUD gasifier stove and TSF. These observations took place alongside the cooking tests that were done by other researchers in the BSFK project. A sampling of the households was randomly chosen from the participants in the project who volunteered to be in the cooking test. Date availability for the cooking test and choice of the dish were not controlled. Instead they were decided by the users.

Participants chose the date for the cooking tests, the type of dish(es) to cook and the type of fuel to use. However, all of the observations were conducted in the evening as this was the time for them to cook dinner. On each day, an observation was carried out where on average the time spent in the kitchen for observation was an hour and twenty-four minutes. Dinner time was a household was observed during their dinner preparation (from the preparation of fuel until the dishes were finished). These observations were done for five weekdays in a row in the afternoon. Documentation such as pictures was gathered to complement the observation's checklist, which was used for all observations. Information such as the duration of the cooking, fuel quantity, and household size were investigated with this method. The recording of cooking time started when the firewood was lit up until the last dish was taken out of the TLUD stove, or the three-stone open fire.

These observations aided us to obtain observable information by watching the participants' action and looking at what they used in the activity (Sanders, 2002). This is because aspects might have missed from the identification by the participants when they were asked to tell their cooking activity, or that they have a different mental construction with the reality. This difference resulted in the inconsistency between what the participant said they have done and what they actually did (Robson, 2011). Although it took place in a natural setting, the observer was visible to the participants who might affect the dependability of the observation as the participant was conscious of their behaviour being recorded – also (Sanders, 2002). This reactive effect could be reduced by eliminating interaction between the observed and observer (Bryman, 2012) which was done in this study. One of the observable behaviours that were a result of the presence of researchers was the amount of dish portion being cooked. This behaviour emerged because the participants perceived the researchers as their guests, and it was the norm to serve food to the guests in their culture. The observation was done before the focus group discussion. Hence, the findings from the observations could be discussed with the participants in the focus group discussion and gather explanations from them based on their activity instead of their memory.

5.1.2. Focus group discussion

Since this research aimed to empower the beneficiary of TLUD gasifier stove, by identifying them as the user of the technology and promote inclusivity in the developing process, a focus group discussion (FGD) with co-designing session was held. Focus group discussion was categorized under qualitative research (Bryman, 2012, Robson, 2011). I decided to carry out this method because it provides insights from the participants to assess the performance of the TLUD gasifier stove. Furthermore, with an FGD, it enabled interaction among participants that could lead to topics that I did not anticipate as pointed out by O'grady and O'grady (2017).

This method was conducted after all the observations took place. All the participants in the structured user observation were also the participants in the FGD. Thus, ten households were represented by their members who were cooking during the observations. During the planning of this research, I designed this session to have only women as the participants because there was an assumption that women were the main cook in the household, and that they would be reluctant to express their opinion if there were participants from the opposite gender. Nevertheless, two out of ten observed households had male responsible for cooking duty. Moreover, the participants had a common background, and this made them a homogeneous group in which a sense of safety to express concerns and opinions had been established (Robson, 2011). As a response to this, I ruled out the gender exclusivity.

In conducting this method, three sessions were organised in the morning, which was the proposed time of the day from the participants, with a total duration of two hours. The first session was a discussion with all the participants to study their perspective in using the TLUD gasifier stove and examine related aspects of stove adoption in the household. I took the role of moderator while the field research assistant helped in language translation and a fellow researcher in BSFK project lent a hand to take notes on the discussion. A TLUD gasifier stove was brought to the discussion venue as a visual aid for the participants. The discussion continued to the second session, co-designing, where the participants envisioned the improvements and recommendations for TLUD gasifier stove to suits their needs in illustrations – assisted by the researchers. Participants were categorised into three sub-groups based on their usage frequency of TLUD gasifier stove within a week. The first category was *very often* where it was used almost every day. In the second category, the participants used it for three to five days a week labelled as *often*. For the participants who used the TLUD gasifier stove for a day or two within a week, were categorised as *less often*. These categorisations were necessary for this co-designing session because in every group there had to be a representative from each category to allow divergent ideas and opinion. Co-design, or participatory design, gives the opportunity to empower the marginalized people as it recognizes that every individual has something to offer to the design process (Sanders, 2002). Further, as stated by Robson (2011), FGD was the appropriate method for empowerment as it did not exclude participants who could not read nor write and other disability.

Figure 5. 1. Participants presented their discussion result for their aspirations

The last session of the FGD was when the participants presented their discussion outcome to fellow participants and the researchers. Each of the groups had a representative to present their visual ideas. After this session, I concluded what we had discussed and thanked them for their participation in the discussion and the project. Before the focus group started, I had conveyed to the participants that the discussion results would be brought forth to the relevant authorities. Thus, I could not guarantee the change that would happen. Regardless of this statement, all of the participants joined all the three sessions in this FGD.

5.1.3. Semi-structured interview

As one of the stakeholders in the TLUD gasifier stove, the perspective from KIRDI towards the development of this technology should be taken into account for the continuity of its usage. With this method, I intended to investigate how would the manufacturer of the TLUD gasifier stove answer the users' aspirations related to its improvements. The interview took place at the head office of KIRDI in Nairobi after the observations and focus group were conducted in Kwale. The advantage of face-to-face discussions with users was to have the possibilities to follow up interesting responses, improvisation of questions to understand underlying motives also, observation of the non-verbal cues to get a complete understanding of the interviewee (Irvine et al., 2013, Robson, 2011).

Since this study aimed to understand how the TLUD gasifier stove manufacturer approaches the needs of their end-users, the interviewee should have been related to the development of the stove in question. After setting up contact via e-mail, date and time were organized for an interview. There were four interviewees from two different departments in KIRDI. Two interviewees were representing the Engineering Development and Service Centre (EDSC) under the Technology Transfer and Extension Services Department (TT&ES). Two other interviewees represented the Environment Management Division (EMD) under the Research, Technology and Innovation Department (RTI). The TLUD gasifier stove belongs to the latter division. A list of topics and relevant questions for the interview were prepared in advanced; the session interview session was recorded in audio alongside notes. This method is suitable to be used in a small scale research project where the interviewer was also the researcher, argued by Robson (2011).

The interview lasted about one hour and thirty minutes. First, the introduction of this study and the purpose were explained as it was only one interviewee who I had been in touch with in arranging this interview. Then, the questions were asked with two topics. The first topic was about collecting background information about the TLUD gasifier stove such as the purpose of its developing, how it was developed, and the source of materials. These questions helped to grasp the reason behind the creation of this technology, the role that it was designed to play, as well as how the manufacturer positioned themselves in the BSFK project and the TLUD gasifier stove's environment. The second topic was talking about the users' feedback, and recommendations gathered from the FGD. Also, I incorporated queries from the observations that was conducted earlier in the study.

5.2. Transformative mixed methods design

Transformative mixed methods were often used when a researcher attempts to address specific issues in relation to an underrepresented community with an advocacy-theoretical, or transformative, perspective (Sweetman et al., 2010). In mixed methods research, both quantitative and qualitative methods were used complementary to neutralized the weaknesses and bias that each method had, by collecting the data quantitatively (closed-ended) and qualitatively (open-ended) (Creswell, 2014). However, the challenges from this methodology were the substantial data collection needed and the time taken to analyse both quantitative and qualitative data that require effort and expertise to conduct research with this type (Creswell, 2014, Maudsley, 2011, Robson, 2011). Furthermore, it should be recognised that the concept of transformative perspective was vague (Sweetman et al., 2010). To help in identifying the transformative framework, Creswell (2014) mentioned three common themes; they were: assumptions on the moral stand of inclusion and challenging undemocratic social structures, distribution of findings that promote social justice and human rights, and transparency on goals and strategies to build trust with the community.

In this study, I intended to acknowledge the beneficiaries of TLUD gasifier stove as the users, which was one of the key stakeholders in the BSFK project. This was the reason to conduct a co-designing session in the focus group discussion. The result from the focus group was then synthesised with the results from the interview and observation with triangulation. This process of merging the results was useful to confirm the type of improvements that were needed by the users and possible to be done. I incorporated the convergent design model to the transformative mixed methods because the data collection in this design model went concurrently for both quantitative and qualitative research.

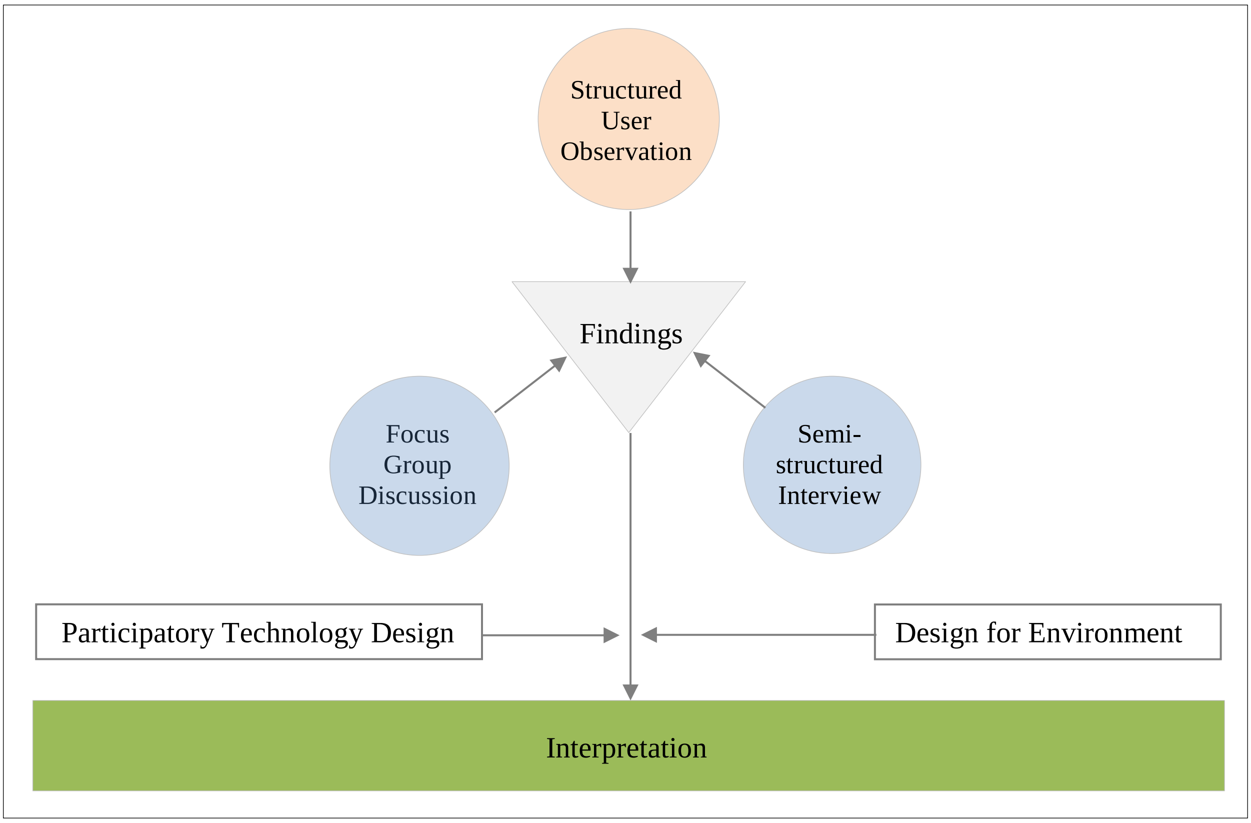


Figure 5. 2. Visualisation of the research design used in this study with the triangulation process incorporated into the convergent parallel mixed methods under the transformative design of Creswell (2014)

The blue circles in Figure 5.2 indicate qualitative data while the orange circle was the quantitative data. The qualitative data plays an important part to generate insights into the ICS adoption process through the collection of perspectives from the users, industry and government (Rehfuess et al., 2014). Furthermore, it gave the users “a voice” to express reasons behind their choice in using or not using the ICS while the quantitative data delivered findings when there are specific behaviours identified in using the stove (Stanistreet et al., 2015). According to O'grady and O'grady (2017), the convergence, where the area was overlap, represented the most genuine truth.

The structured user observation data was processed with univariate analysis, where one variable was analysed at a time (Bryman, 2012). These quantitative data were processed manually and using computer software, Microsoft Excel. Meanwhile, the focus group discussion findings were processed with classical content analysis. For this analysis process type, the data were divided and labelled with descriptive title, or code, then they were placed to similar groups and counted with the addition of description (Leech and Onwuegbuzie, 2007). The additional description was to incorporate the qualitative information to the quantitative information (counting of code) thus, creating a mixed method content analysis (Onwuegbuzie et al., 2009). As for the result of the semi-structured interview, the constant comparison analysis was put to use inductively with codes emerged from the data. As mentioned by Leech and Onwuegbuzie (2007), this type of analysis was helpful to identify fundamental themes transpired through the data. When the triangulation was done, its findings became the interpretation of the convergent parallel mixed methods. These findings were taken to the transformative framework to be analysed with the Participatory Technology Development approach and Design for Environment concept.

6. Results

This chapter delivers the results gathered from the field. This chapter is divided into three parts where the first one provides information about the users in this study and their cooking behaviour. On the second part is the information retrieved from the FGD. Lastly, the information retrieved from the perspective of TLUD gasifier stove manufacturer is presented on the third part.

6.1. Studies of users and cooking practice

From the structured user observations, I gathered quantitative data about the users who volunteered to be in this study, their households' information and cooking practice with TLUD gasifier stove and TSF. In this part, the data was gathered from the structured user observations using an observation checklist and visual documentation. The observation checklist is available in Appendix 13.1. This knowledge of the users' background is to understand and assess their needs in using the TLUD gasifier stove.

6.1.1. The demographic of users

Two out of ten users in these observations were male while the other eight users were female. One of the male users was the main cook in his households, but the other only cook when his wife was not able to do it. The average height of all participants was 161 centimetres. Table 6.1. presents the total average height for each gender categories of the users. The results show that the height of the male users is much higher on average compared to the female users. However, most of the users that I observed used a stool, or chair, to sit down when they were cooking as seen in Figure 6.5 This seating style was varied for each user, especially the height as shown in Table 6.9. Sometimes, they used a different seating during the second observation.

Table 6. 1. The average height of the observed cook in this study

Height	Mean (cm) ± SD
All	161 ± 5.4
Female	159 ± 4
Male	168 ± 4.5

As for the household size, half of the users consisted of seven to nine members. There were ten users in total of this observation, and all of them were observed using a TLUD gasifier stove. Thus, they were categorised them into one column in Table 6.2. Only 10 percent of the households consisted of one to three members. Meanwhile, 40 percent had four to six members in the households. The users who volunteered to be observed again using TSF consisted of more than three members in their household.

Table 6. 2. Members of the households

Household size (n)	All (and/or) TLUD gasifier stove (%)	TSF (%)
1 – 3	10	0
4 – 6	40	40
7 – 9	50	60

There were seven households that used TLUD gasifier stove and TSF for cooking. The other three households used more than the two types of cooking techniques mentioned earlier. Figure 6.1. illustrates the type of cooking techniques that were found in the households. The charcoal stove, commonly known as "Kenyan charcoal jiko" (*jiko* means stove in Swahili), was found in two households. Only one household had LPG stove alongside the TSF and TLUD gasifier stove. This pattern was also found for the household which had kerosene stove and mud stove. Charcoal stove and mud stove fell to the category of improved solutions whereas the other two types, LPG and kerosene, were categorised as clean cooking solutions (Putti et al., 2015).

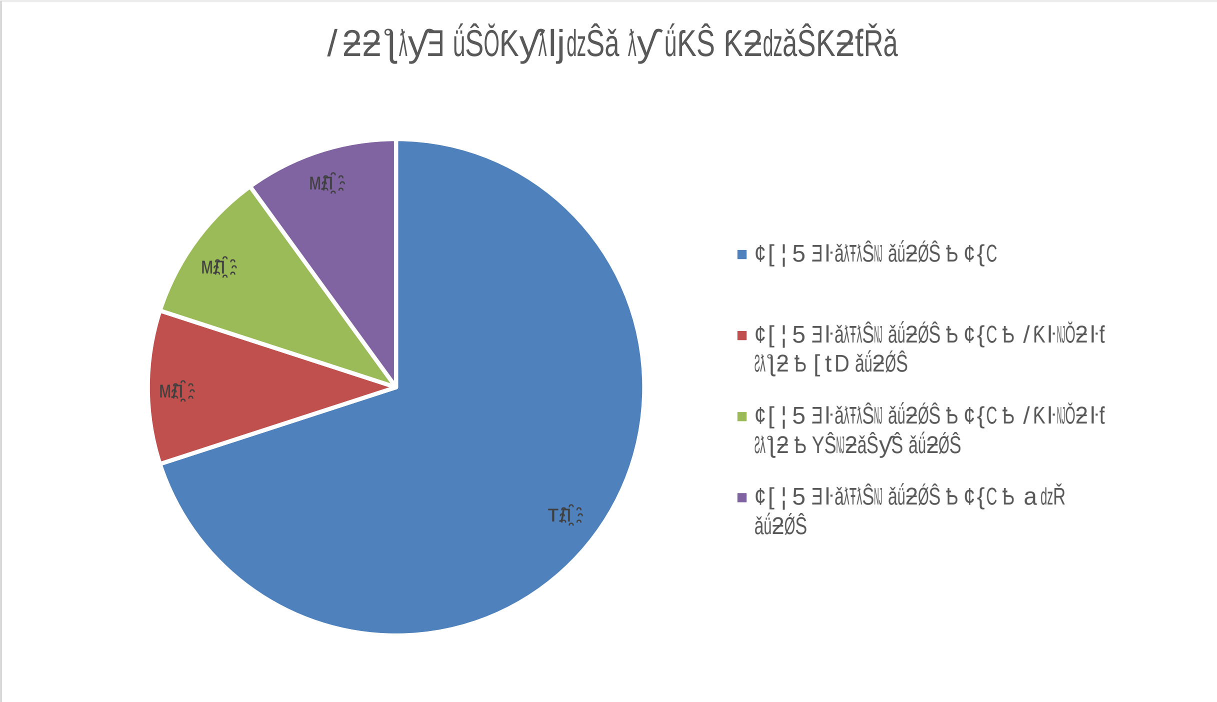


Figure 6. 1. Percentage of cooking techniques that were practiced in the households

In a separate informal discussion with the user which had mud stove in their household, they mentioned that it was only used to cook dishes that took a long time to cook. As for the LPG stove, the user said that it was being used every day in the morning to cook breakfast since had to get the children ready for school and this stove did not take a long time to prepare. The charcoal and kerosene stoves were barely used due to the necessity to purchase the fuel.

6.1.2. Cooking practice

Among ten users, only four people used the TLUD gasifier stove more frequently – approximately three to five days within a week. Table 6.3. displays the frequency of users cooking with TLUD gasifier stove in a week. Three of them used the stove only one or two days within a week, and another three users utilised this cooking technique almost every day. This composition was later used to divide the users into small groups for the co-designing session in the FGD.

Table 6. 3. Frequency table showing the users intensity in using TLUD gasifier stove per week

Frequency	Users (n)
Less often (1 – 2 days)	3
Often (3 – 5 days)	4
Very often (6 – 7 days)	3

There were seven sets of dishes that were prepared during the cooking observations. *Ugali*, considered as a staple food in Kenya made from maize flour, was the most cooked dish followed by tea (referred to as chai) and fish stew. Details on the dish types are available in Figure 6.2. Potato stew was made from *Solanum tuberosum* while *sukumawiki* is a sautéed dish made from *Brassica oleracea*. Generally, they had one staple food consisting of carbohydrates, a side dish and a drink – which would explain the type of dishes that were often cooked. Only two dishes that were done in TLUD gasifier stove but not in TSF, they were *mandazi*, or fried bread, and tomato stew.

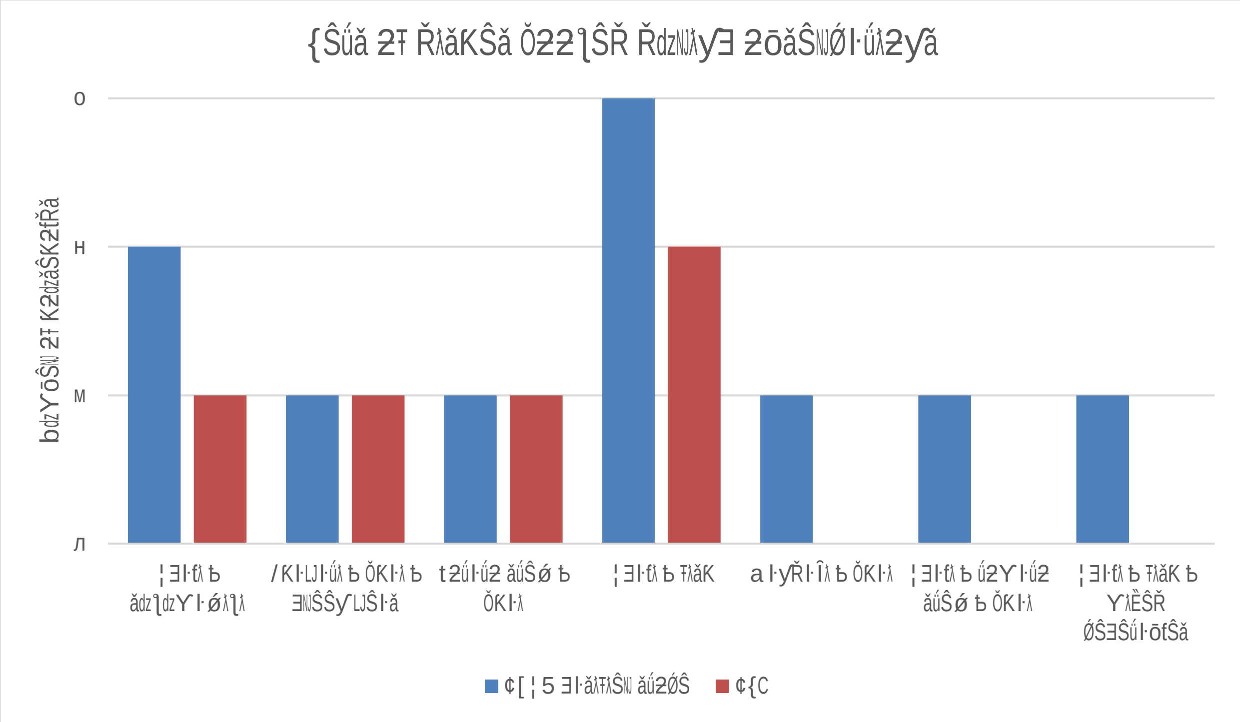


Figure 6. 2 Sets of dishes cooked during the observations

From ten households that were observed cooking with TLUD gasifier stove, they had 1.6 kg for the average weight of the cooked dish. The dish weight referred to the total weight of the ingredients measured before they were being cooked. There was a difference of 4 kg between the minimum and maximum weight of the dish using the TLUD gasifier stove, while it was 3 kg for the TSF as shown in Table 6.4. The cookware weight for both cooking techniques did not vary much as the five households who were observed with TSF cooked the same sets of dishes, so they used the same cookware. When the dish and cookware were weighed together, the average weight in TSF was heavier.

Table 6. 4. The weight of the dish, cookware and cookware with a dish for both cooking techniques

Weight	TLUD gasifier stove (kg)	TSF (kg)
Dish		
Mean ± SD	1.6 ± 1.15	1.8 ± 0.9
Minimum	0.16	0.6
Maximum	4.6	3.8
Cookware		
Mean ± SD	0.44 ± 0.38	0.46 ± 0.35
Minimum	0.13	0.13
Maximum	1.5	1.5
Cookware with dish		
Mean ± SD	1.96 ± 1.14	2.29 ± 0.97
Minimum	0.34	0.73
Maximum	5.19	4.07

There were several sizes of cookware used in the observations, but on average of diameter, the users had 23 centimetres for the TLUD gasifier stove and 24 centimetres used in TSF (Table 6.5.). For both cooking techniques, two dishes are done within one observation averagely. Also, for the cooking behaviour in the users' household, more or less there were two members of the house involved in the cooking activity. This could mean help to prepare the firewood, put together the ingredients for cooking or stirred the dish on the fire.

Table 6. 5. Details on the cooking practice with both cooking techniques

	TLUD gasifier stove	TSF
Pot diameter [Mean (cm) ± SD]	23 ± 3.7	24 ± 4
Dishes cooked [Mean (n) ± SD]	2.3 ± 0.4	2.2 ± 0.4
Members cooking [Mean (n) ± SD]	2 ± 0.8	1.8 ± 0.7

Only three out of ten households in this study had a combination of two firewood types for cooking. Neem (*Azadirachta indica*) was the most used type of firewood among six other types, followed by casuarina (*Casuarina equisetifolia*). For the cooking that used TSF, there were only three firewood types used; they were neem, African custard apple (*Annona senegalensis*), and casuarina. The users sourced their firewood on-farm. Detailed information on the types of firewood used for which cooking technique is illustrated in Figure 6.3.

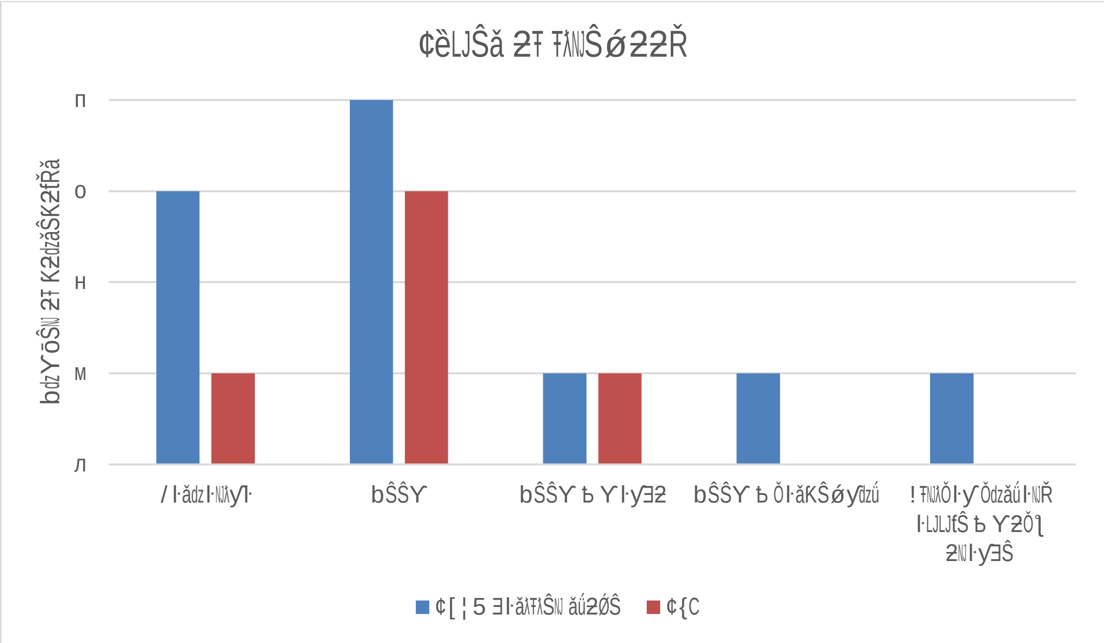


Figure 6. 3. The types of firewood used in the cooking observations

Table 6.6 shows the gross fuel consumption of firewood, which was weighed before the cooking takes place, so it was loaded to the TLUD gasifier stove before they were charred. The mean for TLUD gasifier stove was 1.36 kg with standard deviations of 0.48 kg. On the other hand, 1.71 kg of firewood, with 0.33 kg of standard deviations, was consumed on average with TSF. The difference implied that the TLUD gasifier stove used less firewood than the TSF by 20 percent. The gross fuel consumption for TSF in Household A to E showed that they always used more than one kilogram of firewood while the range for TLUD gasifier stove started from 0.76 kg to 2.46 kg.

Table 6. 6. Firewood gross fuel consumption

Household	TLUD gasifier stove (kg)	TSF (kg)
A	1.12	2.12
B	1.92	2.02
C	1.32	1.51
D	0.88	1.65
E	0.76	1.24
F	2.46	-
G	1.6	-
H	1.26	-
I	1.10	-
J	1.18	-
Mean ± SD	1.36 ± 0.48	1.71 ± 0.33

Four out of the 10 households experienced a changeover during the cooking observations. These changeovers took place with an average of 19 minutes (standard deviation was 0.004). The longest time taken for the changeover was 29 minutes with the fastest one occurred for 14 minutes. In TSF, the changeover was not needed since the firewood could be replenished directly unlike TLUD gasifier stove which fuel was refilled in batch. Figure 6.4 displays the specific length of cooking time from the two cooking techniques.

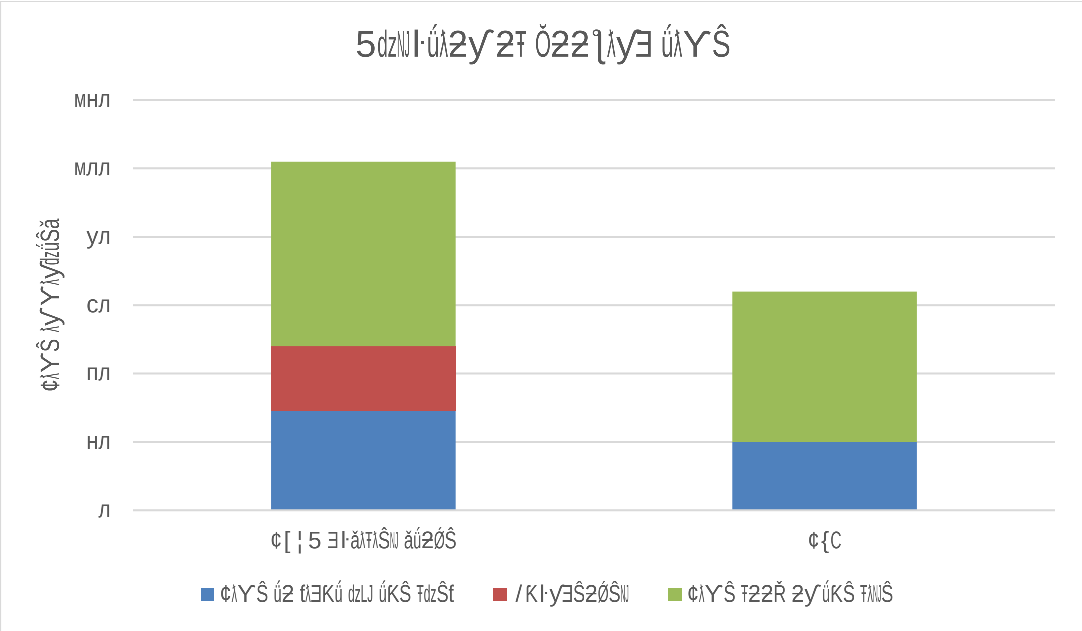


Figure 6. 4. The average cooking time for both cooking techniques

The amount of time needed to light up the fuel between TLUD gasifier stove and TSF did not appear to have a substantial difference as shown in Figure 6.4 above. However, TLUD gasifier stove took 45 percent longer time to light compared to TSF. Meanwhile, for the time duration of food on the fire, TLUD gasifier stove took 23 percent longer time than TSF. This longer time for the gasifier required less amount of firewood as showed in Table 6.6 for Household A to E while TSF gave faster cooking time in total for the users. Nevertheless, they saved more firewood by using the TLUD gasifier stove.

To delve more in-depth into the cooking time, I retrieved information about the tasks from each cooking technique using the observation checklist in Appendix 11.1. The tasks were broken down into several categories. Looking at the task flow of both TSF (Figure 6.5) and TLUD gasifier stove (Figure 6.6), it was clear that in using a TLUD gasifier stove there were more tasks that the users needed to do. Nevertheless, the first and second task categories were similar for both cooking techniques: fuel activities and cooking activities. There was an additional third task category for TLUD stove which was the charcoal activities. This category consisted of the tasks of placing the canister outside of the house and wait for the charcoal to cool down so that it was ready to be used as biochar. The users could do another activity while they were in this task category.

During the observation, cutting the firewood for TLUD stove was not as simple as the task looks. The users had to cut the firewood into a specific length and placed them to the canister. Due to the variation in shape and diameter of the firewood, placing them to the canister could take some time. On the other hand, firewood for TSF did not require a specific length or capacity which made this task much more comfortable and quicker to do.

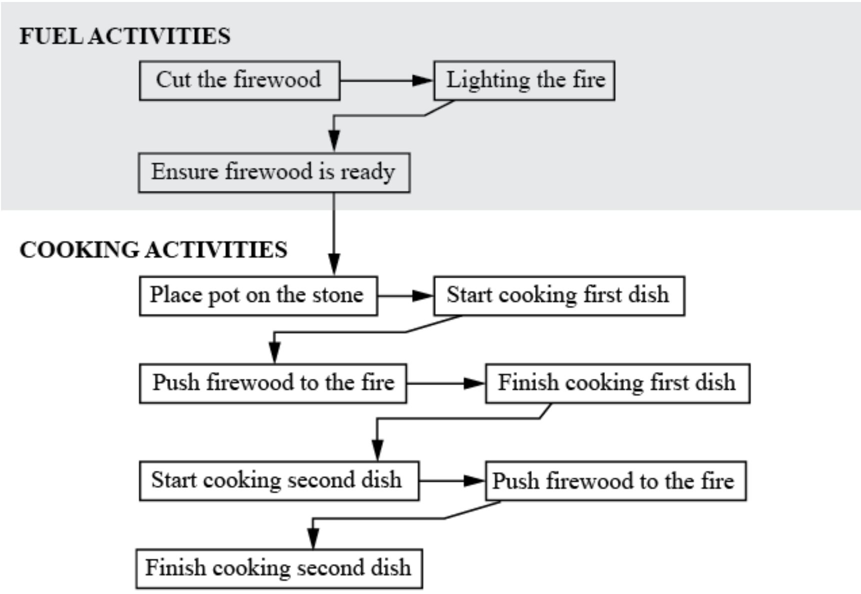


Figure 6. 5. Task flow of TSF consisted of two categories

Another finding from this observation was during the cooking activities the TLUD gasifier stove was more convenient than the TSF as the users did not need to push the firewood to the flame. The absence of this task provides continuous cooking activities, and better hygiene as the user's hands did not touch the firewood and food that was being cooked at the same time.

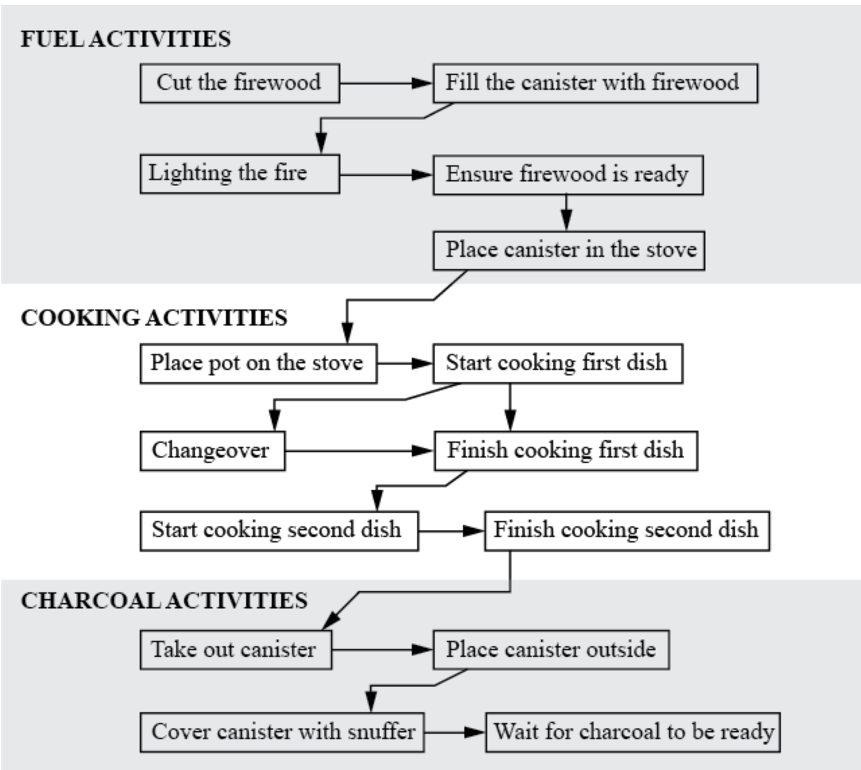


Figure 6. 6. Task flow of TLUD gasifier stove consisted of three categories

For both of the cooking techniques observation, most of the users cook while sitting on a stool which was made out of chopped log, wood, or jerrycan. The illustration of the users' cooking posture is shown in Figure 6.5. Only two out of ten users did stand during the whole time they were cooking. Even when the ceiling of the kitchen was higher than the users, they did not consider piling up the TLUD gasifier stove to allow them to cook while standing without the need to bend over. Nonetheless, some of the users cook in a low-ceiling setting that they had to sit or bend over to cook.

Figure 6. 7. Documentation of users' cooking posture using TSF and TLUD gasifier stove

As observed in this study, the users did not have a standardised design of seating to be utilised. Table 6.7 presents the stool height information for both cooking techniques. In the TLUD gasifier stove, there was a wide range of stool height starting at 12 cm to 47 cm. Meanwhile, the range of stool height that was used for cooking with TSF started from 16 cm to 27 cm. As seen in Figure 6.7, TSF tends to be in lower height than the gasifier. There was 6 cm difference in the average stool height used for cooking with TLUD gasifier stove and TSF, where the latter is shorter with 21 cm. Even though the height difference between these two cooking techniques might not be an exclusive factor, but this could be a substantial factor to look into in comparison to the physical health as there is less bending when using TLUD gasifier stove.

Table 6. 7. Stool height utilised by the users

Cooking technique	Mean (cm) ± SD	Minimum (cm)	Maximum (cm)
TLUD gasifier stove	27 ± 11	12	47
TSF	21 ± 4	16	27

6.2. Study with the users

Following the findings from structured user observations, content analysis is applied to process the findings obtained from the focus group discussion. In this part, the classical content analysis is used, where constant comparison analysis is required to be conducted first hand (Leech and Onwuegbuzie, 2007).

6.2.1. Experience in using TLUD stove

There were two factors that the users find delightful in using the TLUD stove, portability and reducing firewood consumption. By being portable, the stove provides freedom for the users to choose the most convenient location to cook. This element could also mean that they are able to do another task while cooking. There was an opinion from the users that they could cook the meal while entertaining the guest, which was a benefit for them. A complete list of code that is used is shown in Table 6.9.

Eight out of eleven codes were positive impressions. One of the positive impressions from the users was the agricultural benefit. A user mentioned that he only went to farming because he agreed to participate in the BSFK project. The negative impressions from using the TLUD stove were the need to do changeover which affected the cooking time, and the inability to cook a local dish. This local dish required grilling in the process which was able to be done using TSF but not the improved stove. TLUD gasifier stove was deemed as functional to serve energy for cooking, but also, it offers additional benefits. The additional benefits mentioned by the users were the agricultural training from BSFK researchers and using the warm canister as a heater in the chick brooder. Also, the users appreciated emission reduction and less exposure from the flame's heat.

Table 6. 8. Positive (+) and negative (-) impressions on using TLUD stove

Impression	Code	Frequency	Description
+	Additional benefit	3	Benefits other than cooking energy and biochar
+	Agriculture	3	The agricultural benefit from TLUD stove
-	Changeover issue	3	The problem on changeover when using TLUD stove
-	Cooking time	3	Limited time to cook with TLUD stove or the longer duration if the changeover is needed
-	Cultural issue	1	The traditional dish cannot be done with TLUD stove
+	Functional	1	TLUD stove cooks the food well and flavourful
+	Less heat	2	Exposure to direct heat from the flame was reduced
+	Less smoke	2	Smoke emitted from cooking was reduced
+	Multitasking	2	It allowed users to do other tasks while cooking
+	Portable	4	Flexibility to choose an indoor/outdoor cooking location
+	Save firewood	4	Less firewood was used for cooking

Most of the participants in the FGD agreed that the member who usually cooks for the household was the decision maker to decide the cooking technique that they will use or buy. Usually, the main cook was the female head of the household. In case of the absence of a female head, then the male head became the decision maker and had a say about the cooking technique.

Non-governmental organisations (**NGO**) were the primary source of information for new cooking technique or technology in the areas (Figure 6.8). Neighbours were the second primary source and only one user mentioned the internet as a source of information. Use of the internet as a source of new cooking techniques could be connected to age and education background.

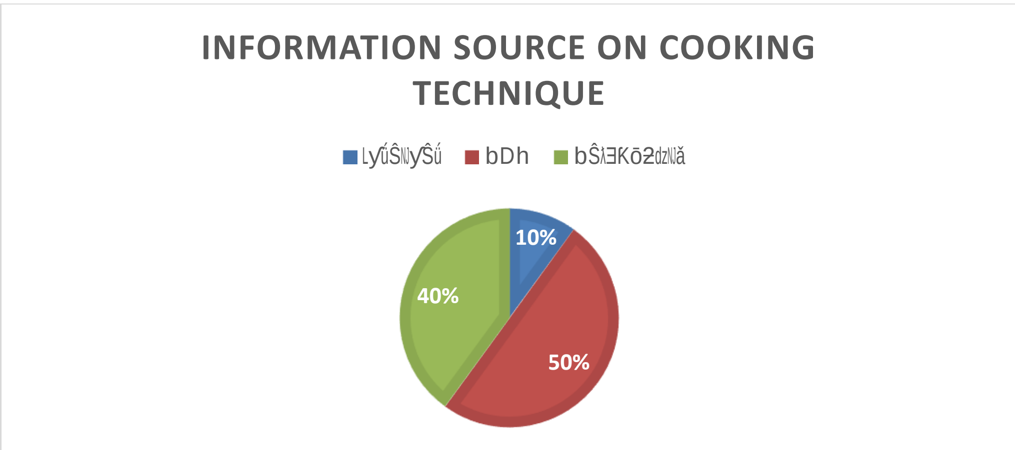


Figure 6. 8. Source of information for the latest cooking technique update

6.2.2. Users' aspirations for TLUD gasifier stove

The discussion continued to the co-designing session where the participants were gathered in small groups to visualise their aspirations for the TLUD gasifier stove improvements. The drawings from this session are presented in Appendix 13.2. Two main aspirations were revealed, they are the wish to have a bigger size of TLUD gasifier stove and a more extended canister handler. The reasons for the first aspiration were to produce more biochar and to have a longer cooking time, especially if the size of the household was quite big. As for the second main aspiration, this was mentioned because the users did not see that the current canister handler had an adequate length to protect their hand from touching the flame when transporting the canister to the insulated body.

In addition to their desire to have a bigger TLUD gasifier stove, they also brought up the wish to have more biochar. These two aspirations were related as they expressed that by increasing the size of the gasifier then they could harvest more biochar for the farm. Another thing which the users identified was the difficulty that they experienced when using the pot skirt. This feature, which they were told to increase the efficiency of the gasifier, limits their options of cookware size and flexibility to handle the cookware. They requested to have the benefit of the pot skirt without the discomfort that they experienced now. Furthermore, the pot skirt was necessary as cooking outdoor was a frequent practice when the weather was too hot to cook indoor. When the wind blew, the pot skirt helped to protect the flame and keeping the efficiency. Other issues that they discovered from using TLUD gasifier stove were related to its durability, cooking time, the quantity of biochar produced, energy generated, and a quick-fix for the issue that they faced right now – changeover. Apparently, they had requested for a second canister to allow them cooking the dish continuously as it was a hassle to use one canister when a longer cooking time was required.

Table 6. 9. Issues for improvements identified from the FGD

Code	Number of times used	Description
Bigger size	4	Increase diameter and height of TLUD gasifier stove
Changeover issue	1	Refilling and preparing the canister as the food was not ready when the biochar was
Durability	1	The lifetime age of the material and stove
Limited pot size	1	Pot size that can be used was limited
Longer cooking time	1	More energy to cook longer
Longer canister handler	4	Canister handler length was not adequate
More biochar	2	Users wanted to harvest more biochar while also have a longer cooking time
More firewood	1	Increase the canister capacity to prolong the cooking time and harvest more biochar
More heat	1	Decrease distance of flame and cooking pot, so it got more flame (stability on heat level)
New flexible design	1	Two sizes of the canister which will be used one at a time, for one stove
Skirting inconvenience	2	Useful but limiting feature of the stove
Two canisters	1	Allowed continuous cooking when the dish was not cooked when biochar was ready

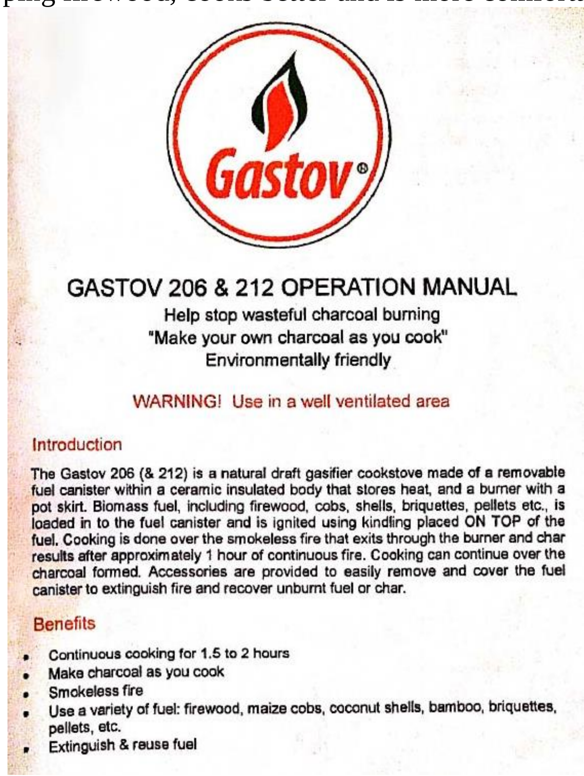
6.3. Understanding the technology

As one of the stakeholders in the BSFK project, KIRDI held a significant role as they were the one developing and manufacturing the TLUD gasifier stove. From the interview, it was found out that KIRDI developed the TLUD gasifier stove to provide affordable and clean cooking energy at the household level. They did not necessarily take into consideration the agricultural benefit from the use of the produced charcoal as biochar. They had another technology that solely produces charcoal, but it was not suitable for the BSFK project since the emitted gas during the charring process was released to the atmosphere instead of being used for cooking energy. Charcoals that were produced from the gasification process by the TLUD gasifier stove could be used directly for cooking, and in this charring process, there was no energy loss as it was used for cooking. Two interviewees highlighted this fact as a marketing proposition. Thus, the gasifier was not initially designed for biochar producing. However, when they heard about the economic benefits of biochar application based on previous studies conducted in the BSFK project, they were considering incorporating biochar harvesting into the marketing proposition.

In relation to biomass waste issue, they would rather have the users to use pellets instead of firewood,

> *We prefer for the people to use the gasifier with pellets because we can make the pellets from agricultural waste from fast growing energy crops.*

The reason behind this built on the government's policy to ban charcoal harvesting. It was actually one of the purposes why KIRDI developed the TLUD gasifier stove, as a way to reduce charcoal burning. To further decrease the pressure of firewood demand, they thought of using pellets for TLUD gasifier stove since the pellets could be produced from agricultural waste. Moreover, they proposed to use pellets as it eliminates the issue of chopping firewood, cooks better and is more comfortable to pack and sell.



Gastov®

GASTOV 206 & 212 OPERATION MANUAL

Help stop wasteful charcoal burning

"Make your own charcoal as you cook"

Environmentally friendly

WARNING! Use in a well ventilated area

Introduction

The Gastov 206 (& 212) is a natural draft gasifier cookstove made of a removable fuel canister within a ceramic insulated body that stores heat, and a burner with a pot skirt. Biomass fuel, including firewood, cobs, shells, briquettes, pellets etc., is loaded in to the fuel canister and is ignited using kindling placed ON TOP of the fuel. Cooking is done over the smokeless fire that exits through the burner and char results after approximately 1 hour of continuous fire. Cooking can continue over the charcoal formed. Accessories are provided to easily remove and cover the fuel canister to extinguish fire and recover unburnt fuel or char.

Benefits

- Continuous cooking for 1.5 to 2 hours
- Make charcoal as you cook
- Smokeless fire
- Use a variety of fuel: firewood, maize cobs, coconut shells, bamboo, briquettes, pellets, etc.
- Extinguish & reuse fuel

Figure 6. 9. TLUD gasifier stove operation manual from KIRDI

On their product operation manual sheet, it was written 'environmentally friendly'. They explained that aside from achieving fuel efficiency they also aim to reduce the emission from TLUD gasifier stove. This explanation showed that they also take regards to the household air pollution and not just towards the natural resources (forest). To the extent the notion of environmental-friendly product, they sourced the materials to make this stove from abroad. In the first time I asked whether they sourced the material locally or globally, one of the interviewees replied that they sourced from the local. After some questions, the topic of material sourcing came again, and the interviewee's answer was changed as they stated that they sourced the steel from abroad. This steel was shipped in roll-form to Mombasa, then transported to Nairobi with trucks or train, where the manufacturing of TLUD gasifier stove took place. After the production, the stoves were distributed to the users across the country with trucks.

6.3.1. Expectations for the TLUD gasifier stove

At the moment, the price for a TLUD gasifier stove was five thousand Kenya shillings (US$50) without the pot skirt. An extra five hundred Kenyan shillings (US$5) was charged for the pot skirt. The cost of the TLUD gasifier stove is about 25 percent higher than the Kuniokoa firewood stove by Burn company which costs Ksh4000 (US$40) and used firewood, although the later lacks the benefit of producing biochar. This high price was a result of manual labour in manufacturing the stove. They stated that they would like to invest in a machine that would allow them to do mass-production. An interviewee expressed that the machine could improve their production ability by at least thirty percent and cut the cost since they would produce the TLUD stove efficiently.

We are looking for partners to work with us to improve the uptake of the stove. So, once the demand is there, we can now invest in the machine for mass production. Because that machine can produce twenty or thirty in a day.

They mentioned that the readiness of mass production state was dependent on the demand of the TLUD stove. Hence, they were expecting partners to work with them in promoting the use of the stove. KIRDI relied on other stakeholders to retrieve information about the stove's usability and performance in the field. All the research and development that were conducted in KIRDI took place in the laboratories as they focus on improving the energy efficiency of the TLUD stove. They did several tests such as Kitchen Performance Test, Controlled Cooking Test, and ISO test. They did not conduct research on the users as an interviewee asked,

But that feedback, this one, is very good for our innovation. I'm curious to find out the usability of this gasifier. How user friendly is it? Is it easy to put off? Stability?

When one of the researchers delivered an observation from the field about the TLUD stove, an interviewee was intrigued to know the usability of the stove. They mentioned that this was the type of partnership that they wanted, where the researchers from BSFK project provided a detail report on the study of the users to them so they could work on these feedbacks for the next generation of the stove. Indirectly they took the role in developing and manufacturing the technical part while placing the researchers to be the connection between them and the users.

6.3.2. Response to the users' feedback

Design improvement suggestions from the focus group discussion were delivered to KIRDI in this interview. The first thing that the users wish to have is a second fuel canister. Since the charcoal produced from the gasification process was to be harvested thus, the users need it in order to eliminate the time spent during a changeover while operating with one canister. The second canister will also allow continuous cooking without having to keep the food down so as to empty the canister, refill fuel and light as the second canister can be prepared in good time. Apparently, this suggestion already emerged before this study was conducted as KIRDI was already producing the requested second fuel canister. This will also allow users to harvest more charcoal. However, there was a proposal for the next generation of the TLUD stove from a user, who participated in the focus group discussion, to have two sizes of fuel canister that could fit in one size of the stove. This proposal was not deemed as a possible improvement as it might reduce fuel use efficiency as more fuel will be loaded. KIRDI has made a modification to the low cooking of different amounts of fuel as stated in the below quote.

We usually give options to the client. If the numbers of time you will be cooking is a lot, meaning that you need more time – you can buy the bigger gasifier which is the GASTOV 212 that comes with a bigger canister, which can hold double the amount of fuel [than GASTOV 206]. That is around 2 kg of fuel. Now, what happened is that when you want to cook less meal, we have a new design of gasifier. In our new design, we incorporate something called a fuel platform. So, you have that fuel canister then you put the fuel platform inside the big canister. So, that you can now place firewood in the same canister, but it is sort of raised that you put less fuel.

The main idea from the modification being made by KIRDI is to have flexibility in the volume of fuel to be used in cooking while taking care not to waste biomass when the dish was done before the charring process had finished. The fuel platform gave flexibility to the amount of fuel that a user could use. This did not precisely answer the proposal from the focus group participant, but it offered similar ideas. Furthermore, the interviewee added that the fuel platform is more innovative and cheaper in the long run as it did not need two canisters.

There was another wish for the design improvements related to the canister; it was to increase the length of the fuel canister handler. When this aspiration was put forward, an interviewee responded with an alternative of holding the canister,

> *There is a way for you to still use the current handler without getting burnt. What you do, you hold the handler horizontally. Because the flame goes vertically, this way [showing gesture], you will not get burnt. Like how it is pictured in the product sheet. So, they can hold it horizontally.*

After an explanation from the researcher that holding the canister vertically would not prevent the flame from touching the users' hand when they were placing the canister inside of the insulated body, the interviewee changed his opinion that the problem lies in the shape of the canister handler as he suggested to design it in L-shape. Other accessories of the TLUD gasifier stove to be improved was the pot skirt. Currently, this pot skirt had a fixed size that resulted in inconvenience for the users to cook with a smaller diameter pot than the pot skirt. In response to this feedback, an interviewee mentioned that in the idea for the stove design there was no pot skirt. Further, he mentioned that users could just remove the pot skirt and cook as the efficiency of the stove did not drop so much, though according to their test it was good to have the skirting.

In the interview, one of the interviewees stated that he used the TLUD gasifier stove for cooking in his house. At first, he mentioned that the TLUD gasifier stove was more comfortable to use instead of LPG stove. Then he revised his statement saying that the LPG stove was more comfortable to use but the TLUD gasifier stove was more economical. When cooking with the TLUD gasifier stove, he claimed that cooking while standing was better because his face was not on the same height as the stove. He was able to stack the TLUD gasifier stove making the height comfortable for him to stand when cooking. This way of cooking was not common to see in Kwale during the cooking observations.

There was a concern arose during the FGD which was about the durability of the stove. A participant noticed that there were cracking inside of the insulated body of her stove. She was worried if this would affect the performance of the stove and wonder if this crack could be fixed. KIRDI addressed the concern by stating that the crack would not affect the efficiency of the stove because it was impossible for the insulation material to fall off. However, they also mentioned that the user could get her stove fixed if she took it to their repair centre. They have several repair centres such as Nandi, Kisii, and Kisumu. In the future, they hope that those repair centres would turn to be a factory for the stove as the demand for the stove increased. Their ideal was to have a centre to handle manufacturing and repairing within each county as it could decrease the cost of transportation.

7. Discussion

In this chapter, the results are analysed using triangulation to process the data from three collection methods. Further, transformative language is used to deliver the analysis in fulfilling the research design. There are three parts in this chapter to answer the research questions, stated below:

- What are the improvements required for the TLUD gasifier stove in response to the users' needs and aspirations while keeping the design environmentally friendly?
  - Are the users' aspirations met in this project?
- How does the TLUD gasifier stove compare to the three-stone open fire in terms of cooking practice and implications on livelihoods?

The first part talks about improvements for TLUD gasifier stove and aspirations from the users' point of view. Evaluation of how the other stakeholders, such as the stove manufacturer and researchers, in BSFK project responded to the feedback from the users is on the second part. As for the third part, the differences between TLUD gasifier stove and TSF are assessed by building upon the observed cooking practice and their impact on the livelihoods.

7.1. Designing with the users

One of the improvements which the users aspired is a bigger stove size. Half of the users had more than six members in the household, and from the observation, approximately 3 kg of food per dish was prepared with a TLUD gasifier stove. In the interview, the manufacturer said that the stove could even hold 7 kg of weight including the cookware, but the pot skirt should be used to enhance its efficiency. Despite this suggestion, the users mentioned that utilising the pot skirt was troublesome because the users needed to hold the pot when stirring with a pot holder.

Figure 7. 1. A user cooking ugali utilising both pot skirt and pot holder

When the pot skirt was in use, it was in the way of the pot holder, so the user had to place the pot skirt improperly as shown in Figure 7.1. This feedback was taken to the manufacturer, and their response was to ignore using the pot skirt whenever it is not applicable because there is not much efficiency kept from using it anyway. Their response is inconsistent with their previous suggestion about the stove efficiency. Further, it indicates a different priority of stove's efficiency and convenience between the stakeholders. While the manufacturer put forward efficiency, the users are more concern about the convenience aspect in using TLUD gasifier stove. This finding relates to a study by Salas et al. (2003) and Urmee and Gyamfi (2014) where technologies are usually developed according to outside interest, values, and needs of the users in a controlled setting. Research for energy-efficient or sustainable product design originates in a very technical field that barely addresses the human side of the product as it prioritises energy efficiency (Wever et al., 2008).

The reason why the users requested a bigger TLUD gasifier stove is because they would like to have a longer cooking time and produce more biochar for their farm within a batch of cooking. It appears that the users have realised the importance and benefit of producing biochar, which is a result of the education and training from the researchers (Scholz et al., 2014). Two groups in the FGD visualised an increase in the diameter and height for both stove with the canister while only one group stated that they would like to increase the diameter only, shown in the sketches from the FGD attached in Appendix 11.1. The users solely reasoned about increasing the TLUD gasifier stove dimension for two aspects above; they did not touch upon comfort issue with its height.

Regarding the product's operation manual sheet, all the information is written in English with minimal illustrations about the instruction to use the TLUD gasifier stove. I find this aspect is a discrepancy between the manufacturer's expectation of the target market and the current users. Not all of the users that I came across in Kwale could read and/or understand English. Earlier in the BSFK project, researchers gave training on how to use this cooking technology, so the current users know how to cook using this. Assuming that there is a plan to upscale this TLUD gasifier stove in the future, it will be troublesome if the manufacturers do not change their manual sheet to a version that has more informative illustrations and using local language(s). The gasifier's manual sheet in the local language(s) can be seen as a synthesis of the users' knowledge with the researcher, as argued by Douthwaite et al. (2002) in practicing PTD.

7.2. Meeting the aspirations

In BSFK project, the researchers play the role of connecting the users with the manufacturer. This is an expected role for the researchers from the manufacturer as stated during the interview. It appears that in general, the users have no direct contact with any cooking technology's manufacturer as they retrieved the information on cooking techniques from NGO, their neighbours or the internet. A missing connection between the users and technology developer usually resulted in a detached technology where it is unclear who created the technology, what is being solved and to whom. This "view from nowhere" derives from seeing the technology as a commodity that is able to be detached from the production site and distributed in a mass to the users thus, dismissing that the technology developer's view is still a stance from somewhere which they are held accountable for (Suchman, 2002).

When developing technology in accordance with DfE, it should answer not only the environmentally friendly aspect and user-centred design but also the needs of society, resources and practice of the local users (Melles et al., 2011). As argued by Glover et al. (2016), technology is constructed socially instead of adopted or received. This phenomenon also happened when the manufacturer aspired for the users to use pellets instead of solid biomass as fuels because they regard this method as being more efficient and supports the Kenya 2030 vision and 17 SDGs. Again, this statement from the manufacturer indicates a disconnect between the users and them because they do not consider the socio-economic aspect of the users that influence the choice of cooking technique. Further, mentioned that in order to design the technology with the users, the technology developer must not be biased and should investigate the solution according to the users' needs and aspiration.

However, researchers in BSFK delve into the users' response to the project including the TLUD gasifier stove, and this stimulates feedbacks from them. It is necessary to continue the research and development of a technology involving the users instead of assuming that the technology is fully developed which PTD advocates (Douthwaite et al., 2001). When these feedbacks are followed up with design improvements, such as in the case of the second canister, then the users would feel that their cooking needs are being addressed and possibly make TLUD gasifier stove more familiar to them. Since the purpose of TLUD gasifier stove is to have a cleaner cooking technology with sustainable consumption of firewood and the biochar production then involving users at the early stage of technology development would be beneficial because it demands cultural sensitivity (Heiskanen et al., 2005).

7.3. Comparing TLUD gasifier stove and TSF

The average height between the female users and male users has quite a big gap. Even so, both gender groups adjusted their cooking postures to suit their convenience. When using TSF, the average height of their stool is lower by 6 cm than when they used the gasifier. This height difference might affect the users' health as they need to bend more while cooking with TSF. Adjustment to the stove height is also practiced by one of the interviewees at KIRDI as he stated that he piled the TLUD gasifier stove, so it would allow him to cook while standing, which was his preferable cooking posture. Stove stacking was a widespread practice in Kwale as all of the households used both TSF and TLUD gasifier stove to fulfil their cooking needs even though only three of them had more than two cooking technologies at home. There was 40 percent of the households that often used the TLUD gasifier stove. Based on these two findings, TSF is still the favourable cooking technique for them. Using only one cooking technique for all the cooking needs is a rare case as users often utilised multiple cooking techniques to fulfil their daily needs (Loo et al., 2016, Namagembe et al., 2015). This finding also confirms the conclusion from Stanistreet et al. (2015) that improved stoves are seen to complement the traditional cooking technique instead of replacing it. When using TSF, the users had a smaller number of tasks. Thus, the length of cooking time with TSF is shorter than using a TLUD gasifier stove. The changeover was the aspect which the users brought up the most during FGD. From a study by Loo et al. (2016) in Western Kenya, changes in workload and fuel preparation affect the time consumed to cook.

As one of the aspects that the users appreciate is portability of the TLUD gasifier stove as it gives freedom to the users to adjust this cooking technology to their cooking practice such as moving the stove outdoor or indoor according to their preference on that time. It means that the manufacturer has considered the number of cooking practice among the users. In this sense, TLUD gasifier stove is deemed to be cleaner than the TSF as it allows lighting to be carried out outside reducing smoke in the kitchen. TLUD gasifier stove also provides flexibility in using numerous type of fuel and options to use the charcoal as a soil amendment or cooking fuel (Scholz et al., 2014).

Ugali is the staple food for Kenyan, and it was shown from the findings that in 7 out of 15 observations, ugali was cooked. When cooking ugali, constant stirring is needed that sometimes the cook stands up and bend over to get better control of the pot and stirring. In TSF, this task was troublesome because the pot slipped from the stones causing the cook to fix the position again after it fell to the fire. Meanwhile, in TLUD gasifier stove, it provided stability for the cook when stirring the almost baked ugali.

Other than portability and stability, reducing firewood consumption was a factor that the users like about TLUD gasifier stove. The firewood consumption for the gasifier starts from 0.76 kg to the highest is 2.46 kg – surpassing TSF (Table 6.6). On average, the TLUD gasifier stove could save 20 percent of firewood compared to TSF. This result confirms the finding from Hafner et al. (2018) where a TLUD stove consumed 15.6 percent less firewood than TSF. Since the stove consumes less firewood than TSF, it contributes to reducing firewood demand that caused deforestation. Also, it aligns with Kenya Vision 2030 to have 57.7 percent of cleaner cooking technology used as it improve livelihood and reduce greenhouse gas (Ministry of Energy and Petroleum, 2016). It was stated in the operation manual that TLUD gasifier stove is environmentally friendly. This statement is also related to the ability to produce charcoal as the cooking process happened thus, related to diminishing the pressure of biomass sourced fuel. It could be taken further by sourcing the material locally whenever possible thus, reducing the environmental impacts of transportations.

7.4. Co-designing for environmentally friendly technology

In one of the users' aspirations (Table 6.9), they mentioned a decrease in the distance between the flame and cookware to have more flame. This aspiration cannot possibly be done as it will result in incomplete combustion. Thus, more emission will be produced. Collaboration between the users and researchers is to improve the cooking technology means both parties are in the same level with each brings out their expertise and negotiate (Bratteteig and Wagner, 2014, Salas et al., 2003). Feedback from the users regarding the existing gasifier can be included to the technology's development, but the researchers should ensure that the improvement is functional (Romli et al., 2015). Instead of treating the users' aspiration as a whole, the researchers should examine it which in this case the users want more heat. Then again, the purpose of TLUD gasifier stove is to promote sustainable cooking practice which includes a clean cooking technology. To achieve DfE, Hauschild et al. (2004) mentioned that the most appropriate strategy should be taken by identifying the environmental issue. Looking at the harmful effect of HAP, less emission should be one of the design specifications to take forward.

A system perspective should also be incorporated when developing an environmentally friendly technology. Adoption problem, mentioned by Glover et al. (2016), is an agricultural system problem. It requires a comprehensive understanding of the system where the cooking technology takes place instead of looking only at the stove. Further, focusing on clean manufacturing, insightful end-of-life framework, and systematic infrastructures are needed to achieve DfE (Ramani et al., 2010). Since DfE comes from a technical discipline, a cross-discipline approach to study the cooking technology is demanded (Glover et al., 2016, Wever et al., 2008). It is where PTD comes in and fill in the gap. Other than studying the users in interacting with the technology, PTD offers a process where the users and researchers can develop the technology together (Reed, 2007).

A field evaluation by Loo et al. (2016) in Western Kenya revealed that improved stoves acceptability occurred with stove stacking. This finding is also found in Kwale through this study. However, the cooking technology is better to be evaluated iteratively and aimed at adaptation to provide a more robust development and promotion to the technology (Glover et al., 2016). This approach is currently taking place in BSFK project where the researchers have been working together with the users in three counties to assess the cooking technology. In doing the evaluation, the qualitative data (open-ended) is necessary to yield insight into the user perspectives and the technology acceptability (Loo et al., 2016). However, the quantitative data (close-ended) is also needed to provide a comprehensive study regarding the cooking technology that using mixed methods will give leading evidence for the scale-up plan in the future (Stanistreet et al., 2015).

7.5. Limitations

The most apparent limitations in this study were the difference in the language spoken between the stakeholders and the researcher during the data collection. To overcome this challenge, the field assistant from BSFK project took the role of the interpreter role. However, some expressions might have gotten lost in the translation process that could have contributed to the study results. Also, there could be a bias with the questions on how I meant it to what they perceived. Usually, a follow up question was put forward to confirm the response. From the FGD, the impressions of using the TLUD gasifier stove was mostly positive. It should be studied further whether this result is due to the presence of BSFK researchers as the organisers or these impressions are not bias. It would be interesting to know about their impressions of using TLUD gasifier stove in a neutral environment where no power-relation exist.

The use of transformative mixed methods in this study provides a clear position for the researcher in approaching the problem and giving solutions that unconfirmed bias can be eliminated. Even so, literature that used this approach are not widely available yet. Studies on improved stove evaluation with the necessary design improvements to increase its uptake are limited as well. However, the available literature used mixed methods in conducting the research. Promoting the users' position in developing TLUD gasifier stove might lead to sustain acceptance of this cooking technology, but the result will only emerge in the future which is also a downside of PTD.

8. Conclusion

An improvement recommended for the TLUD gasifier stove is to increase the capacity for the firewood as the users aspired to have a longer cooking time and harvest more biochar. The users also wish that the TLUD gasifier stove could stop hindering their current cooking practice such as what they experienced right now with the pot skirt. This inconvenience is a result of developing the stove without involving the users. Conflicting priorities between the users and manufacturer indicated a lack of communication that could be overcome by increasing interaction of both parties. To make upscaling possible, all stakeholders should collaborate in achieving the mass use of this cleaner cooking technique. As TSF consumed less time for the cooking activity and the users are more familiar in using this cooking technique, the TLUD gasifier stove must be better than just alleviate HAP and reduce firewood consumption for the users to choose the latter instead of the familiar technique. This familiarity feeling is the reason why it is necessary to develop the cooking technology with the users and see them as a key stakeholder instead of a detach consumer.

In the future, assessments of the environment and the users will be better to conduct before an innovation takes place as a solution. These assessments can make the innovation more robust in targeting to address the problem directly instead of creating another one. The one who is conducting the assessments should be clear on their objectives and biases, which can exist from their perspective, to eliminate unconfirmed bias. Investigation on how the usage of TLUD gasifier stove affect the social and cultural aspect of the users will also be beneficial to know as every innovation and technology will have impacts on the society.

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10. References

Adelsköld, N. 2015. Slu Goes Global: Farmers Make Biochar In Efficient Stoves. *New Insights.* Uppsala: Division of Communication SLU.

Anderson, P. S. & Schoner, J. S. 2016. Origins, History, and Future of TLUD Micro-gasification and Cookstove Advancement. *Version,* 2**,** 1-35.

Arnold, M., Köhlin, G., Persson, R. & Shepherd, G. 2003. Fuelwood revisited: what has changed in the last decade? Bogor Barat Indonesia: Center for International Forestry Research (CIFOR). *Occasional Paper*.

Bates, E. 2007. Good technologies...but do they really work? *Boiling point*, 53**,** 3-5.

Belonio, A. T. 2005. Rice husk gas stove handbook. *Appropriate Technology Center. Department of Agricultural Engineering and Environmental Management, College of Agriculture, Central Philippine University, Iloilo City, Philippines***,** 1-155.

Bielecki, C. & Wingenbach, G. 2014. Rethinking improved cookstove diffusion programs: A case study of social perceptions and cooking choices in rural Guatemala. *Energy Policy,* 66**,** 350-358.

Biggs, S. & Smith, G. 1998. Beyond methodologies: coalition-building for participatory technology development. *World development,* 26**,** 239-248.

Birzer, C., Medwell, P., Wilkey, J., West, T., Higgins, M., Macfarlane, G. & Read, M. 2013. An analysis of combustion from a top-lit up-draft (TLUD) cookstove.

Bratteteig, T. & Wagner, I. Design decisions and the sharing of power in PD. Proceedings of the 13th Participatory Design Conference: Short Papers, Industry Cases, Workshop Descriptions, Doctoral Consortium papers, and Keynote abstracts-Volume 2, 2014. ACM, 29-32.

Bryman, A. 2012. Social research methods. Oxford University Press Inc. *New York*.

Compagna, D. & Kohlbacher, F. 2015. The limits of participatory technology development: the case of service robots in care facilities for older people. *Technological forecasting and social change,* 93**,** 19-31.

Connelly, S. 2007. Mapping sustainable development as a contested concept. *Local Environment,* 12**,** 259-278.

Creswell, J. W. 2014. *Research design: qualitative, quantitative, and mixed methods approaches,* California, SAGE Publications, Inc.

Debbi, S., Elisa, P., Nigel, B., Dan, P. & Eva, R. 2014. Factors influencing household uptake of improved solid fuel stoves in low-and middle-income countries: A qualitative systematic review. *International journal of environmental research and public health,* 11**,** 8228-8250.

Delyser, D. & Sui, D. 2014. Crossing the qualitative-quantitative chasm III: Enduring methods, open geography, participatory research, and the fourth paradigm. *Progress in Human Geography,* 38**,** 294-307.

Douthwaite, B., Keatinge, J. & Park, J. 2001. Why promising technologies fail: the neglected role of user innovation during adoption. *Research policy,* 30**,** 819-836.

Douthwaite, B., Keatinge, J. & Park, J. 2002. Learning selection: an evolutionary model for understanding, implementing and evaluating participatory technology development. *Agricultural Systems,* 72**,** 109-131.

Ekouevi, K. 2013. Household Energy for Cooking: Project Design Principles. *Energy and Mining Sector Board Discussion Paper Series*.

Gitau, J. K., Mutune, J., Sundberg, C., Mendum, R. & Njenga, M. Forthcoming. Factors influencing the uptake of gasifier cooking stoves by households in rural Kenya. Forthcoming.

Gitau, J. K., Njenga, M., Mutune, J. & Sundberg, C. 2017. Introducing biochar-producing gasifier cook stoves in a rural community. *Rural transformation and urbanization - Agricultural research for development (Agri4D) conference 2017.* Uppsala, Sweden.

Glover, D., Sumberg, J. & Andersson, J. A. 2016. The adoption problem; or why we still understand so little about technological change in African agriculture. *Outlook on AGRICULTURE,* 45**,** 3-6.

Grieshop, A. P., Marshall, J. D. & Kandlikar, M. 2011. Health and climate benefits of cookstove replacement options. *Energy Policy,* 39**,** 7530-7542.

Gwenzi, W., Chaukura, N., Mukome, F. N., Machado, S. & Nyamasoka, B. 2015. Biochar production and applications in sub-Saharan Africa: Opportunities, constraints, risks and uncertainties. *Journal of environmental management,* 150**,** 250-261.

Hafner, J., Uckert, G., Graef, F., Hoffmann, H., Kimaro, A., Sererya, O. & Sieber, S. 2018. A quantitative performance assessment of improved cooking stoves and traditional three-stone-fire

stoves using a two-pot test design in Chamwino, Dodoma, Tanzania. *Environmental Research Letters,* 13**,** 025002.
Ham, A. B., Stuart; Thomas, Kate 2015. *Kenya*, Lonely Planet.
Hauschild, M. Z., Jeswiet, J. & Alting, L. 2004. Design for environment—do we get the focus right? *CIRP Annals-Manufacturing Technology,* 53**,** 1-4.
Heiskanen, E., Kasanen, P. & Timonen, P. 2005. Consumer participation in sustainable technology development. *International Journal of Consumer Studies,* 29**,** 98-107.
Hoffmann, V., Probst, K. & Christinck, A. 2007. Farmers and researchers: How can collaborative advantages be created in participatory research and technology development? *Agriculture and human values,* 24**,** 355-368.
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.
Hopwood, B., Mellor, M. & O'brien, G. 2005. Sustainable development: mapping different approaches. *Sustainable development,* 13**,** 38-52.
Huber, J. 2000. Towards industrial ecology: sustainable development as a concept of ecological modernization. *Journal of environmental policy and planning,* 2**,** 269-285.
Irvine, A., Drew, P. & Sainsbury, R. 2013. 'Am I not answering your questions properly?'Clarification, adequacy and responsiveness in semi-structured telephone and face-to-face interviews. *Qualitative Research,* 13**,** 87-106.
Kirdi n.d. Gastov 206 & 212 Operation Manual. *In:* INSTITUTE, K. I. R. A. D. (ed.). Nairobi: KIRDI.
Knbs 2009a. Household Source Of Cooking Fuel By County And District. *Kenya Population and Housing Census.* Nairobi: Kenya National Bureau of Statistics.
Knbs 2009b. Population Distribution by Sex, Number of Households, Area and Density by County and District. Kenya National Bureau of Statistical.
Knbs 2015a. Kenya Facts and Figures, 2015. Kenya National Bureau of Statistics.
Knbs 2015b. Kwale County Statistical Abstract. Nairobi: Kenya National Bureau Of Statistics.
Lands, M. O. & Uncrd 2011. Kwale District and Mombasa Mainland South Regional Physical Development Plan 2004–2034. Nairobi: UNON Publishing Services Section.
Leech, N. L. & Onwuegbuzie, A. J. 2007. An array of qualitative data analysis tools: a call for data analysis triangulation. *School psychology quarterly,* 22**,** 557.
Loo, J. D., Hyseni, L., Ouda, R., Koske, S., Nyagol, R., Sadumah, I., Bashin, M., Sage, M., Bruce, N. & Pilishvili, T. 2016. User perspectives of characteristics of improved cookstoves from a field evaluation in western Kenya. *International journal of environmental research and public health,* 13**,** 167.
Luiz, J. V. R., Jugend, D., Jabbour, C. J. C., Luiz, O. R. & De Souza, F. B. 2016. Ecodesign field of research throughout the world: mapping the territory by using an evolutionary lens. *Scientometrics,* 109**,** 241-259.
Maccarty, N., Ogle, D., Still, D., Bond, T. & Roden, C. 2008. A laboratory comparison of the global warming impact of five major types of biomass cooking stoves. *Energy for sustainable development,* 12**,** 56-65.
Majdan, M., Svaro, M., Bodo, J., Taylor, M. & Muendo, R. M. 2015. Assessment of the biomass related indoor air pollution in Kwale district in Kenya using short term monitoring. *African health sciences,* 15**,** 972-981.
Malla, S. & Timilsina, G. R. 2014. *Household cooking fuel choice and adoption of improved cookstoves in developing countries: a review*, The World Bank.
Maudsley, G. D. L. a. U. 2011. Mixing it but not mixed-up: Mixed methods research in medical education (a critical narrative review). *Medical Teacher,* 33**,** e92-e104.
Mehetre, S. A., Panwar, N., Sharma, D. & Kumar, H. 2017. Improved biomass cookstoves for sustainable development: A review. *Renewable and Sustainable Energy Reviews,* 73**,** 672-687.
Melles, G., De Vere, I. & Misic, V. 2011. Socially responsible design: thinking beyond the triple bottom line to socially responsive and sustainable product design. *CoDesign,* 7**,** 143-154.
Mertens, D. M. 2010. Transformative mixed methods research. *Qualitative inquiry,* 16**,** 469-474.
Ministry of Energy and Petroleum 2015. Draft National Energy and Petroleum Policy.
Ministry of Energy and Petroleum 2016. Sustainable Energy For All Kenya Action Agenda. *In:*

INTEGRAL MEDIA (ed.). Nairobi: Ministry of Energy and Petroleum.
Mwenzwa, E. 2014. Kenya’s Social Development Proposals and Challenges: Review of Kenya Vision 2030 First Medium-Term Plan, 2008-2012.
Namagembe, A., Muller, N., Scott, L. M., Zwisler, G., Johnson, M., Arney, J., Charron, D. & Mugisha, E. 2015. Factors influencing the acquisition and correct and consistent use of the top-lit updraft cookstove in Uganda. *Journal of health communication,* 20**,** 76-83.
Ngui, D., Mutua, J., Osiolo, H. & Aligula, E. 2011. Household energy demand in Kenya: An application of the linear approximate almost ideal demand system (LA-AIDS). *Energy policy,* 39**,** 7084-7094.
Njenga, M., Iiyama, M., De Leeuw, J., De Nowina, K. R., Kätterer, T., Kimutai, G. & Sundberg, C. 2015. Keeping Healthy And Saving Trees. *Miti.* Nairobi: Better Globe Forestry Ltd.
Njenga, M., Karanja, N., Karlsson, H., Jamnadass, R., Iiyama, M., Kithinji, J. & Sundberg, C. 2014. Additional cooking fuel supply and reduced global warming potential from recycling charcoal dust into charcoal briquette in Kenya. *Journal of cleaner production,* 81**,** 81-88.
Nsamba, H. K., Hale, S., Cornelissen, G. & Bachmann, R. T. 2015. Designing and performance evaluation of biochar production in a top-lit updraft upscaled gasifier. *Journal of Sustainable Bioenergy Systems,* 5**,** 41-55.
O'grady, J. V. & O'grady, K. V. 2017. *A Designer's Research Manual, Updated and Expanded: Succeed in Design by Knowing Your Clients and Understanding what They Really Need*, Rockport.
Ochieng, C. A., Tonne, C. & Vardoulakis, S. 2013. A comparison of fuel use between a low cost, improved wood stove and traditional three-stone stove in rural Kenya. *biomass and bioenergy,* 58**,** 258-266.
Onwuegbuzie, A. J., Dickinson, W. B., Leech, N. L. & Zoran, A. G. 2009. A qualitative framework for collecting and analyzing data in focus group research. *International journal of qualitative methods,* 8**,** 1-21.
Pinch, T. J. & Bijker, W. E. 1984. The social construction of facts and artefacts: Or how the sociology of science and the sociology of technology might benefit each other. *Social studies of science,* 14**,** 399-441.
Poulikidou, S., Björklund, A. & Tyskeng, S. 2014. Empirical study on integration of environmental aspects into product development: processes, requirements and the use of tools in vehicle manufacturing companies in Sweden. *Journal of Cleaner Production,* 81**,** 34-45.
Putti, V. R., Tsan, M., Mehta, S. & Kammila, S. 2015. The state of the global clean and improved cooking sector. Washington: Energy Sector Management Assistance Program, Global Alliance for Clean Cookstoves, The World Bank.
Ramani, K., Ramanujan, D., Bernstein, W. Z., Zhao, F., Sutherland, J., Handwerker, C., Choi, J.-K., Kim, H. & Thurston, D. 2010. Integrated sustainable life cycle design: a review. *Journal of Mechanical Design,* 132**,** 091004.
Reed, M. 2007. Participatory technology development for agroforestry extension: an innovation-decision approach. *African journal of agricultural research,* 2**,** 334-341.
Rehfuess, E. A., Puzzolo, E., Stanistreet, D., Pope, D. & Bruce, N. G. 2014. Enablers and barriers to large-scale uptake of improved solid fuel stoves: a systematic review. *Environmental health perspectives,* 122**,** 120.
Robson, C. 2011. Real world research: A resource for users of social research methods in applied settings 3rd edition. West Sussex: John Wiley & Sons.
Rogers, K. 2008. *Participatory democracy, science and technology: An exploration in the philosophy of science*, Springer.
Romli, A., Prickett, P., Setchi, R. & Soe, S. 2015. Integrated eco-design decision-making for sustainable product development. *International Journal of Production Research,* 53**,** 549-571.
Roy, R. 1994. The evolution of ecodesign. *Technovation,* 14**,** 363-380.
Ruiz-Mercado, I., Masera, O., Zamora, H. & Smith, K. R. 2011. Adoption and sustained use of improved cookstoves. *Energy policy,* 39**,** 7557-7566.
Salas, M., Jianchu, X. & Tillmann, T. 2003. *Field Manual Participatory Technology Development (PTD): Linking Indigenous Knowledge and Biodiversity for Sustainable Livelihoods,* Kunming, Yunnan Science and Technology Press.
Sanders, E. B. 2002. From user-centered to participatory design approaches. *Design and the social sciences: Making connections,* 1.

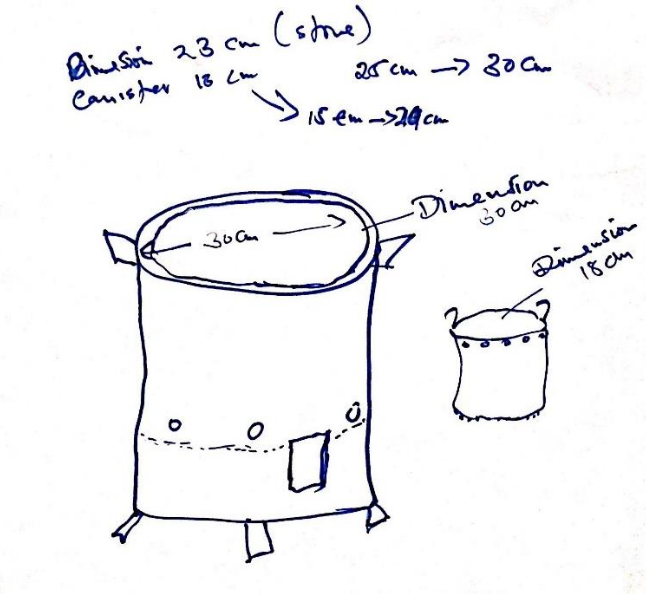
Scholz, S. B., Sembres, T., Roberts, K., Whitman, T., Wilson, K. & Lehmann, J. 2014. *Biochar systems for smallholders in developing countries: leveraging current knowledge and exploring future potential for climate-smart agriculture*, The World Bank.
Sesan, T. 2012. Navigating the limitations of energy poverty: Lessons from the promotion of improved cooking technologies in Kenya. *Energy Policy,* 47**,** 202-210.
Shackley, S. & Carter, S. 2011. Biochar Stoves: an innovation studies perspective. *UK Biochar Research Centre, University of Edinburgh*.
Sherwin, C. 2004. Design and sustainability. *The Journal of Sustainable Product Design,* 4**,** 21-31.
Smebye, A. B., Sparrevik, M., Schmidt, H. P. & Cornelissen, G. 2017. Life-cycle assessment of biochar production systems in tropical rural areas: Comparing flame curtain kilns to other production methods. *Biomass and Bioenergy,* 101**,** 35-43.
Stanistreet, D., Hyseni, L., Bashin, M., Sadumah, I., Pope, D., Sage, M. & Bruce, N. 2015. The role of mixed methods in improved cookstove research. *Journal of health communication,* 20**,** 84-93.
Stirling, A. 2008. "Opening up" and "closing down" power, participation, and pluralism in the social appraisal of technology. *Science, Technology, & Human Values,* 33**,** 262-294.
Suchman, L. 2002. Located accountabilities in technology production. *Scandinavian journal of information systems,* 14**,** 7.
Sweetman, D., Badiee, M. & Creswell, J. W. 2010. Use of the transformative framework in mixed methods studies. *Qualitative inquiry,* 16**,** 441-454.
The World Bank. 2018. *Kenya* [Online]. Available: https://databank.worldbank.org/data/views/reports/reportwidget.aspx?Report_Name=CountryProfile&Id=b450fd57&tbar=y&dd=y&inf=n&zm=n&country=KEN [Accessed 30 July 2018 2018].
Tigabu, A. 2017. Factors associated with sustained use of improved solid fuel cookstoves: A case study from Kenya. *Energy for Sustainable Development,* 41**,** 81-87.
Toth, F. L. & Videla, M. L. 2012. Energy for development: a key to long-term sustainability. *Energy for Development.* Springer.
United Nations 2013. United Nations Decade of Sustainable Energy for All: Report of the Secretary-General. United Nations General Assembly.
United Nations. 2017a. *The Sustainable Development Agenda* [Online]. United Nations. [Accessed 2 November 2017].
United Nations 2017b. The Sustainable Development Goals Report 2017. *In:* JENSEN, L. (ed.). New York: United Nations.
Urmee, T. & Gyamfi, S. 2014. A review of improved Cookstove technologies and programs. *Renewable and Sustainable Energy Reviews,* 33**,** 625-635.
Van Der Velden, M. & Mörtberg, C. 2014. Participatory design and design for values. *Handbook of ethics, values, and technological design.* Springer.
Watkins, D. & Gioia, D. 2015. *Mixed methods research*, Pocket Guides to Social Work R.
Wever, R., Van Kuijk, J. & Boks, C. 2008. User-centred design for sustainable behaviour. *International journal of sustainable engineering,* 1**,** 9-20.
Whitman, T., Nicholson, C. F., Torres, D. & Lehmann, J. 2011. Climate change impact of biochar cook stoves in Western Kenyan farm households: system dynamics model analysis. *Environmental science & technology,* 45**,** 3687-3694.
Zaretsky, M. 2011. Design from the Ground Up: Risks and Opportunities in Humanitarian Design. *In:* PARR, A. & ZARETSKY, M. (eds.) *New directions in sustainable design*
London;New York, NY;: Routledge.

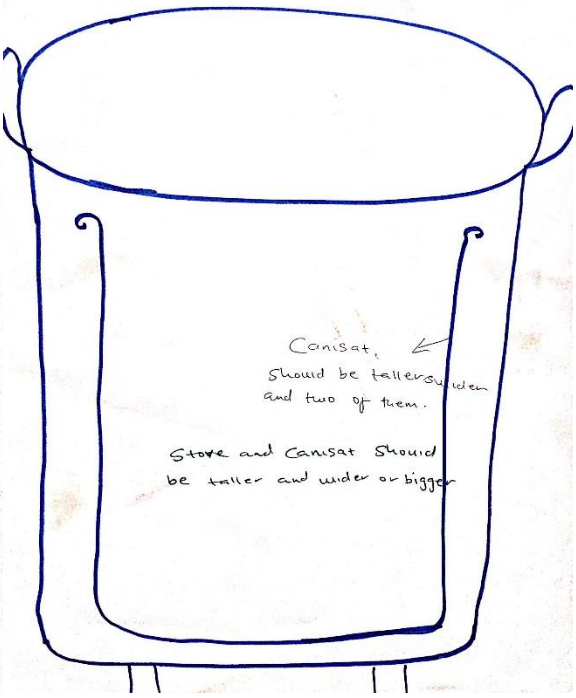
11. Appendix

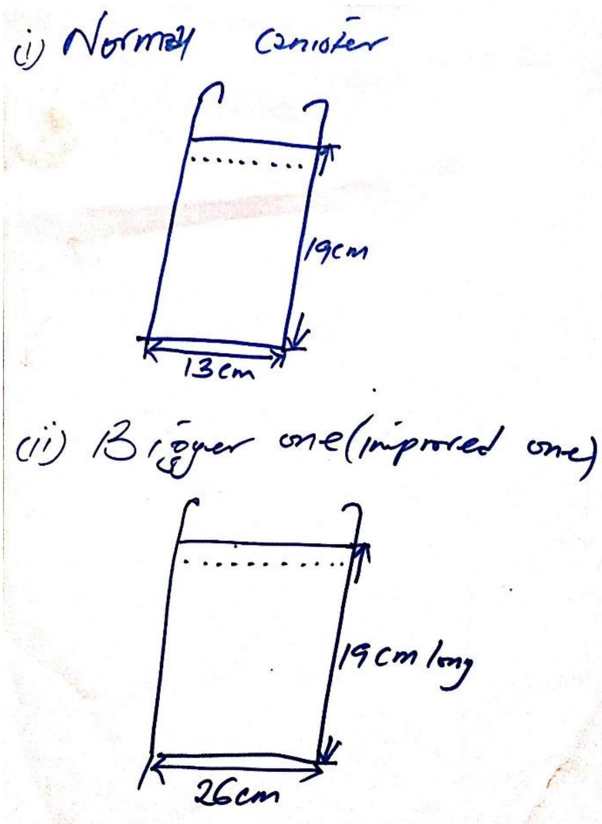
11.1. Observation checklist

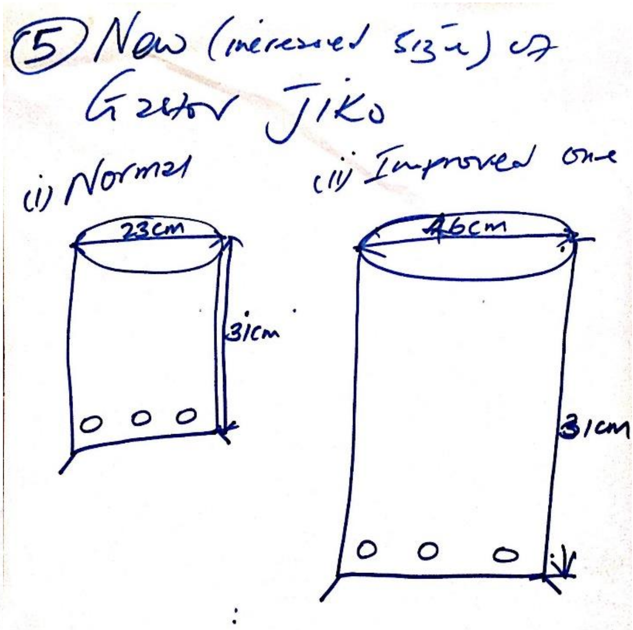
Date: ___/___/___	**Cooking Habit Observation**	Household # ____
Household name:	____________________	Cook name: ________________
Tools for cooking:	☐ GASTOV ☐ 3-stone open fire	Cook height: cm Gender: ☐ Male ☐ Female
Cook stove(s) in the house: **other than 3-stone open fire and GASTOV*	☐ Ceramic jiko ☐ Mud stove ☐ Paraffin stove	☐ LPG stove ☐ Biogas stove ☐ Saw dust stove ☐ Other: ________
Number of people in the household ________ members		
People involve in the cooking: ________ members		
Numbers of dish: _______ type(s)		
Pot size: Ø _____ x H ______ cm		
Pot weight: _____ gram		
Fuel type: ____________________	Fuel weight: _____ kg	
Routine:		

11.2. Focus group discussion result







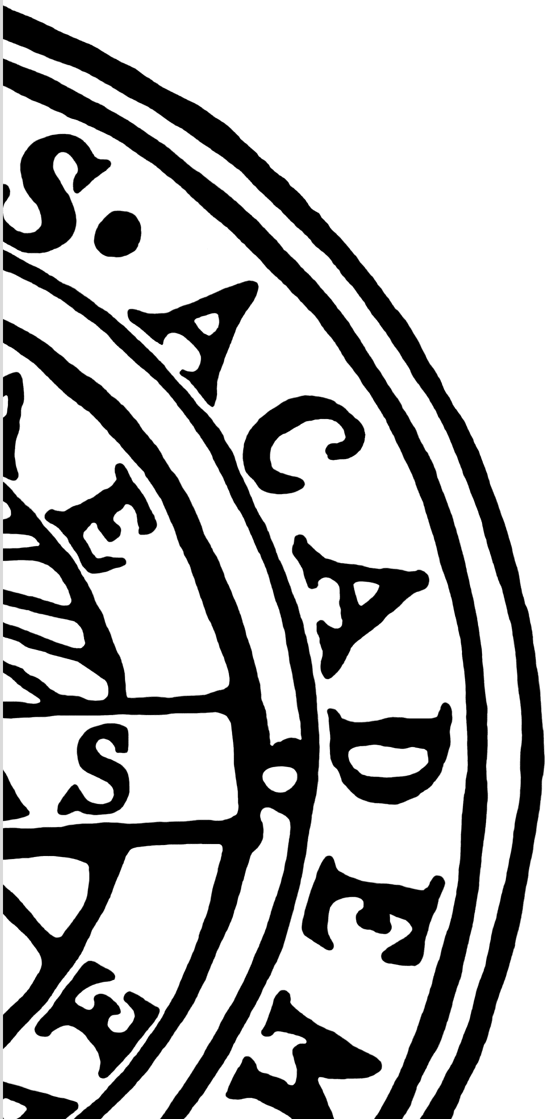


11.3. Interview questions guide

- (questions guide) From where do you source the material for each part of the TLUD stove?
- What should the customers do when their TLUD stove needs repairing (e.g. cracking on the ceramic lining)?
- Is it possible to have the gasifier manufactured and repaired locally?
- What were the considerations of having the TLUD stove on its current dimensions (ø23 x 32 cm) when a bigger stove can produce more biochar and cook more food for the household?
- From your manual, it is highlighted in one of the benefits “continuous cooking for two to three hours”, but this is possible when customer continues cooking using the biochar that they are producing. Does it mean that production of biochar is not encouraged to have longer cooking time?
- How much is the cost of current TLUD stove and what is the expected market price?
- Is there research ongoing to further improve the performance of the TLUD stove?
  - (If yes) What is the goal of this research (e.g. more efficiency, etc.)?
  - When do you expect that this improved model will be available to the market?
- According to the users’ aspirations in Kwale, they envisioned these improvements:
  - The length of canister handler is not sufficient because the flame often reaches their hand, is it possible to increase its length? Was there a specific reason to make it 30 cm long?
  - To have more flexibility in cooking time, they suggest having two canisters of different diameter (13, as current, and 26 cm) but the same height. In relation to this, the cookstove has to be adjusted in the railing (at the bottom of the stove). Will it be possible to do so and keep the combustion efficiency?
    - (If not) What about increasing the size of TLUD stove and canister in the next stove generation?
  - Skirting of the stove should be able to accommodate cooking with any pot size comfortably. Looking at this problem, what are the solutions that you can provide?

11.4. Transcript

Question	Response/Chunks
About your GASTOV project, I wonder whether you promote the charcoal produced from the gasifier to be used in cooking again, to be sold, or to be applied for farming purpose?	We did not design this particular gasifier for farming / TLUD stove is essentially made for cooking at home / for the agricultural part of charcoal, we have carbonizer
they also mentioned a suggestion on having two different sizes of canister but only using one stove. they proposed that the second canister is around 26 cm. Is it possible to do that?	Uhh….no, it is not possible to do that [2 sizes canister, 1 stove] / since they have to harvest the charcoal, it is good to have an additional canister.
can I have one which can accommodate the two [canisters]?	we normally give options to client / [fuel platform] is more innovative and uhm, cheaper in the long run because you are not going to need two canisters
What kind of goals is this TLUD stove…is this looking for more efficient in terms of using the firewood?	our goal has always been fuel efficiency / And uhm, reducing the smoke that is PM 2.5…especially those two
[asked about skirting] do you have any other way to provide that function but without giving the obstacle?	so they are not able to hold the suffuria when using the skirting? / according to our test it is good to have the skirting / you don't need to – you can remove it and use the stove without the skirting / there is a different design to hold the pot where you just hold the rim, you don't need to hold the side
do you also request a new handle, a longer one, for this canister? Because the current one is concise	There is a way for you to still use the current handler without getting burnt / maybe we can now design it in L-shape
Is there any way that they can repair it nearby where they are or how can they make it fixed?	it will not affect the efficiency of the stove because it is not possible for it to fall off / But if they want, so long as they take the stove to our repair centre, it can be fixed
Can we know where you sourced the material for TLUD stove?	here we sourced locally
you do your lab test before you sell your product, do you also test it in the household?	We do both; I'm going to show you at our lab where we do these tests
So, the ergonomic part such as the height of the stove and the weight is also considered during the development, or?	Those ones are not actually a consideration for us because we mainly look at the efficiency
Do you use GASTOV at your house?	I use it for cooking chapati, githeri, beans…it is easier to use the GASTOV instead of gas / gas is easier, but it is not easier to the pocket / I find that it is better to cook while standing than when you are sitting because of the emission will be as high as your face
how much is the cost of the TLUD stove that they are using in Kwale?	right now it is a bit expensive because it costs 5000 Kenyan shillings without the skirt, and with the skirt is 5500 shillings / for us the engineers, what we want to do is to mass produce the stove / As of now we are doing like a one-off job, which is very expensive / That is why when you do it in mass, you can improve it by at least 30%
When do you expect that it is ready to be mass-produced?	It depends on the demand of the stove project, so it is the parameter /
where is it sourced?	All the way from the producer of the steel? Like they use the ship from China, or whatever to get the steel to Mombasa then they use the train or trucks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