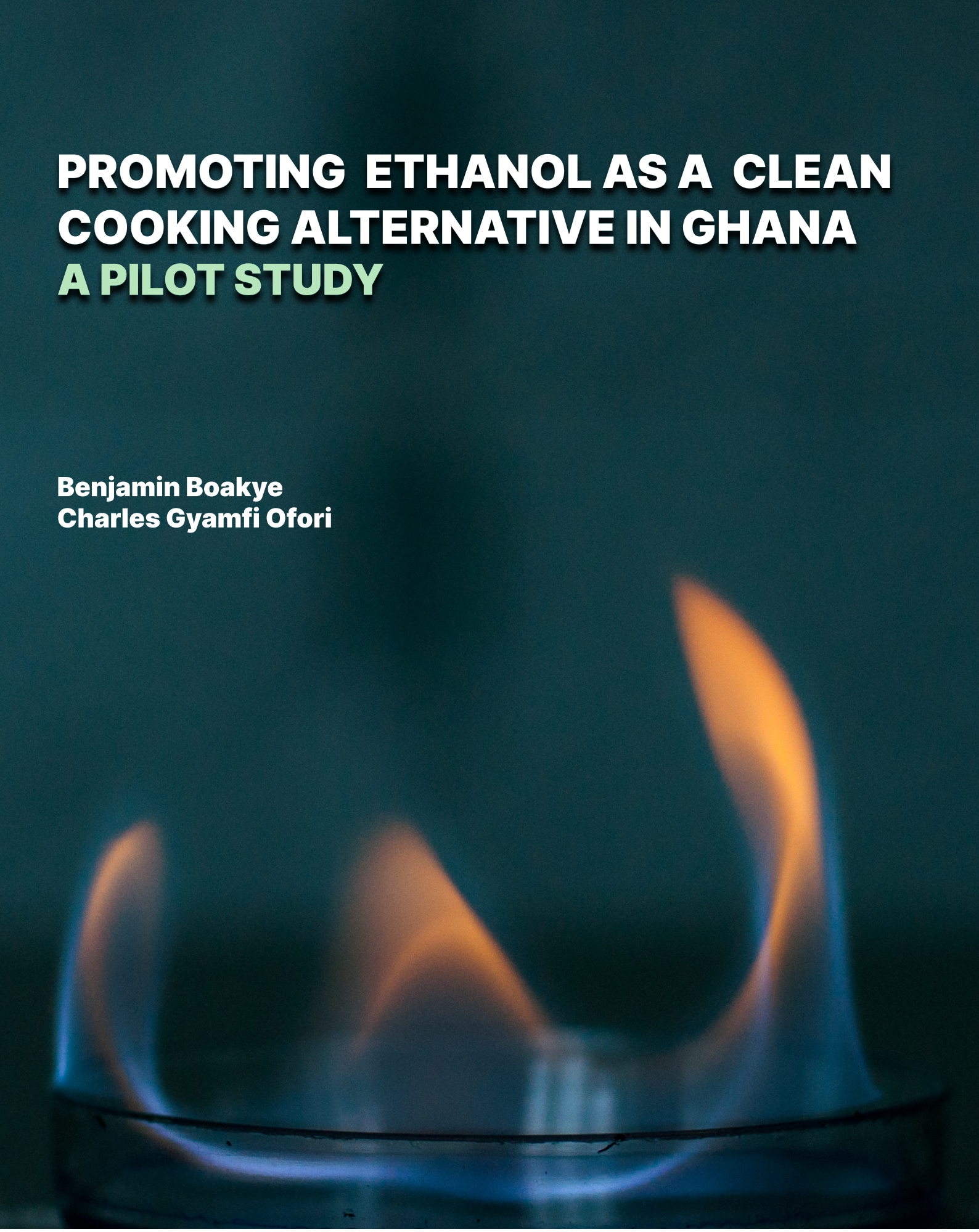
PROMOTING ETHANOL AS A CLEAN COOKING ALTERNATIVE IN GHANA
A PILOT STUDY

Benjamin Boakye
Charles Gyamfi Ofori



ACEP Africa Centre for Energy Policy

OXFAM

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ACKNOWLEDGEMENT

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ABBREVIATIONS

ACEP	Africa Centre for Energy Policy
CO	Carbon Monoxide
CO_2	Cardon Dioxide
GHS	Ghana Cedis
IRENA	International Renewable Energy Agency
LI	Legislative Instrument
LPG	Liquified Petroleum Gas
SDG	Sustainable Development Goals
UN	United Nations
UNSD	United Nations Statistics Division
WHO	World Health Organisation

EXECUTIVE SUMMARY

Clean cooking forms an integral part of Goal 7 of the Sustainable Development Goals (SDGs), which generally seeks to ensure universal access to reliable, affordable, sustainable, and modern energy by 2030. Polluting fuels such as wood fuels are major sources of household air pollution, particularly in developing countries. The World Health Organisation estimates that about 4 million deaths occur annually due to indoor air pollution-related diseases. These diseases include pneumonia, stroke, chronic obstructive pulmonary diseases, and lung cancer. Women and children are more exposed to these diseases due to their exposure to these gasses in their daily activities. Wood fuels do not only contribute to household air pollution but also deforestation, which affects the plant cover with its attendant impacts on the global ecosystem. The health and environmental impacts of these polluting fuels imply that more efforts must be channelled to switch towards cleaner sources that are accessible and affordable.

The government of Ghana has formulated policies and strategies to promote clean cooking technologies and fuels to reduce deforestation and indoor air pollution. A vital component of these strategies is the promotion of Liquified Petroleum Gas (LPG) and improved cookstoves for household and commercial uses. However, the current trend in growth suggests that the proportion of the population with access to clean technologies is about 51% short of the SDG 7 target. Therefore, an alternative fuel source is appropriate to complement the efforts of existing ones to accelerate Ghana's drive toward universal access to clean fuels.

Biofuels such as ethanol offer a cheaper alternative for clean cooking. Ethanol burns cleanly without harmful emissions, making it safe for humans and the environment. Studies across Sub-Saharan Africa on ethanol fuel utilisation show a high preference for ethanol-based stoves and fuels over traditional kerosene and charcoal stoves. However, ethanol-based stoves have not received the needed attention in Ghana. Results from the recent population and housing census indicate that about 0.04% of households in Ghana use alcohol-based fuels as a cooking source.

This study examined consumer behaviours towards using ethanol-based cookstoves and fuels in Ghana. The results are based on a pilot study in two peri-urban localities in Ghana – Ningo Prampram District and Akuapem North Municipality.

Generally, the study revealed that respondents showed positive attitudes towards ethanol-based cookstoves and fuels. A summary of the key findings is provided below.

1. **Stoves could be used to prepare various kinds of food:** The ethanol-based stoves were generally used for two primary forms of cooking; boiling and frying. In addition, the stoves were used to prepare several staple foods, although their relatively smaller size

introduced some perceived scepticism regarding their ability to prepare food for large family sizes.

2. **Key characteristic preference of ethanol stoves**: The ethanol stoves and fuel were preferred by consumers for three main reasons. First, using ethanol-based stoves had fewer risks of explosion and was safe to use by both adults and children. Second, ethanol-based stoves and fuels were portable and easy to convey from one point to another. The portability characteristic reduces associated costs of equipment handling and fuel transportation. Third, ethanol-based fuels did not produce excessive smoke, making them more environmentally friendly and ideal for reducing CO2 emissions.
3. **Key challenges experienced by consumers**: The foremost challenge associated with ethanol-based fuels was difficulties assembling and dismantling the stove. Secondly, some consumers faced challenges with fuel refilling while the stove was in use.
4. **Key customer preferences for the ideal cookstove**: The study identified durability, cost, fuel accessibility and efficiency, and variability in sizes as the key indicators that influence their choice of cooking stoves. Thus, manufacturers of clean cooking stoves and fuels must consider improving on these key customer preference indicators to improve their competitive power with other cookstoves.

The study proffers the following recommendations:

1. **Increase R&D in stoves' design**. Manufacturers and governments must heighten research on the most efficient ethanol-based cookstoves to replace the existing ones with design and operational flexibility challenges. Research and development must focus on improving the canister's design, the stove's strength and ease with refuelling.
2. **Government policy must focus on boosting the local production of ethanol**. The ethanol market is another sector that can boost the economy. Increased demand for ethanol for industry and cooking provides a supply potential with opportunities for income generation and job creation. Again, the government and producers must increase the R&D potential for ethanol production to create options to improve the efficiency of the ethanol production process, thereby minimising costs.
3. **Manufacturers of ethanol-based cookstoves must streamline production processes to reduce costs.** Manufacturers must have an efficient means of producing to minimise production costs, including lean systems, affordable power and bulk purchases and production.
4. **Fuel producers and stove manufacturers can consider the potential of receiving carbon credits to offset costs.** The clean nature of ethanol-based fuels provides a unique opportunity for producers to obtain carbon credits. These credits can be used to offset production costs to reduce the price of stoves and fuels on the market.

BACKGROUND

Clean cooking forms an integral part of Goal 7 of the Sustainable Development Goals (SDGs), which generally seeks to ensure universal access to reliable, affordable, sustainable, and modern energy by 2030. As of 2010, approximately 3 billion, representing about 42% of the world's population, had no access to clean cooking technologies.[1] The SDG target on clean cooking was to ensure that by 2030, the entire global population will have access to clean cooking fuels and technologies. Clean cooking fuels and technologies include electric, natural gas, Liquified Petroleum Gas (LPG), biogas, solar and alcohol-based fuel stoves. On the other hand, polluting cooking technologies include charcoal, firewood, crop waste, dung and kerosene, with devastating health and environmental impacts.[2]

Polluting fuels and technologies used for cooking are major sources of household air pollution, particularly in developing countries. They emit high volumes of air pollutants such as carbon monoxide, nitrous oxides, lead, and sulphur dioxide, among others. The World Health Organisation estimates that every year, about 4 million people die prematurely from indoor air pollution-related diseases like pneumonia, stroke, chronic obstructive pulmonary diseases, and lung cancer. Women and children are more vulnerable to these diseases due to exposure to these gasses in their daily activities.

Polluting fuels such as firewood and charcoal also contribute to deforestation affecting the plant cover with its attendant impacts on the global ecosystem. Forests act as important carbon sinks as they absorb more carbon dioxide. When the trees die or are destroyed, they release these gasses into the atmosphere. The Climate Council estimates that the global loss of forests contributes about 4.8 billion tonnes of carbon dioxide yearly.[3]

Realising the impacts of the use of solid biofuels, governments, development partners, NGOs, and other institutions have reiterated the call for using cleaner fuels for cooking. These calls have led to various technologies that either manage wood fuel utilisation or switch entirely to other cleaner technologies. However, the world continues to fall short of meeting the targets of ensuring universal access to clean fuels and technologies for cooking. It is estimated that, at the current pace, only 72% of the global population will have access to clean cooking fuels and technologies by 2030.[4]

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[1] Takada, M. (2019). *Sustainable Development Goal 7: First-ever universal goal on energy that calls to "ensure access to affordable, reliable, sustainable and modern energy for all".* UN Department of Economic and Social Affairs. Available at https://www.unescap.org/sites/default/files/Session%20I%20SDG7%20status%20and%20way%20forward%20%2819March2019%20at%20ESCAP%29%20Minoru%20Takada.pdf

[2] World Health Organization. (2014). *WHO guidelines for indoor air quality: household fuel combustion.*

[3] Dean. (2019). *Deforestation and Climate Change*. Climate Council. https://www.climatecouncil.org.au/deforestation/

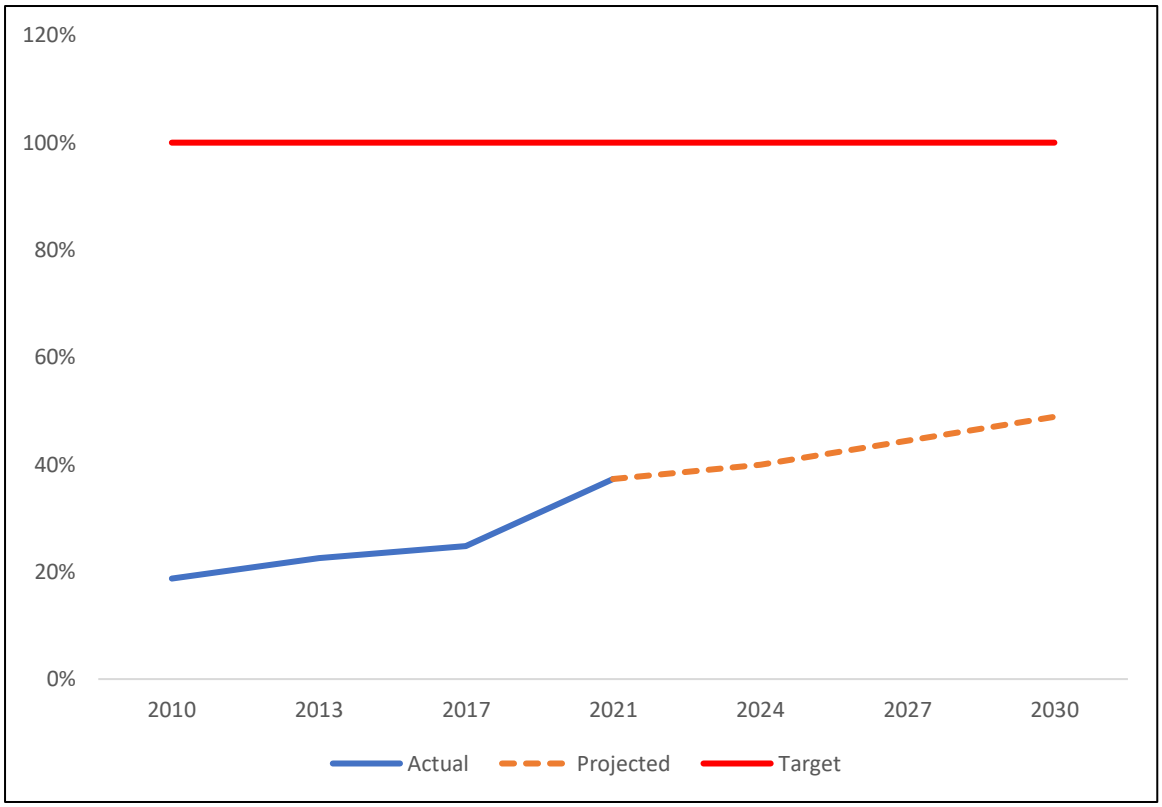
[4] EA, IRENA, UNSD, World Bank, WHO. (2021). *Tracking SDG 7: The Energy Progress Report*. World Bank, Washington DC.

The case of Ghana

The phenomenon in Ghana is not significantly different from the global situation. Over the past decade, the population primarily relying on clean fuels for cooking has increased marginally. The proportion of the population with access to clean cooking technologies has increased from 18% in 2010 to about 37% in 2021. This current trend in growth suggests that the proportion of the population with access to clean cooking technologies will be about 49% of the population by 2030, about 51% short of the SDG 7 target.

The 2021 population and housing census indicate that as of 2021, about 4.5 million households utilised polluting fuels and technologies for cooking, suggesting that approximately 18.4 million people[5] are exposed to these polluting fuels. Thus, over half of the Ghanaian population risk suffering from diseases caused by indoor air pollution from unclean cooking technologies and fuels.

Figure 1: Proportion of population with access to clean cooking technologies

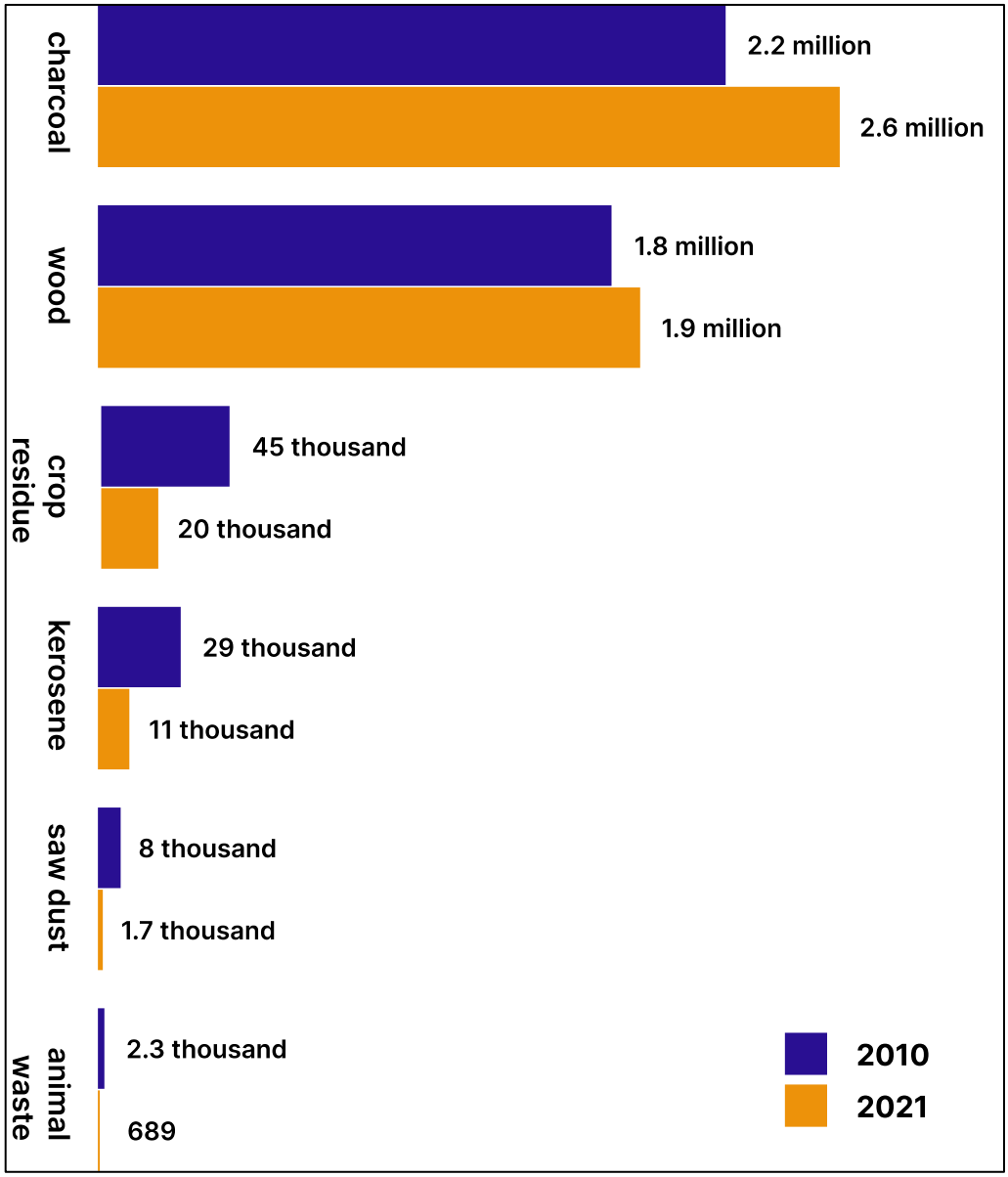


Source: Ghana Statistical Service Population and Housing Census (2010 & 2021 Censuses), Ghana Living Standards Survey (GLSS 6 & 7)

[5] Estimated average household size: 4 members per household

The use of animal waste, crop residue, kerosene and sawdust as cooking fuels declined by about 66% between 2010 and 2021. However, charcoal and firewood, the commonest sources of unclean fuels, increased by 5% and 18%, respectively (see Figure 1). As a result, there has been a net increase in households utilising unclean cooking fuels by about 10% (445 households), mainly influenced by firewood and charcoal utilisation. Therefore, Ghana must accelerate its actions toward clean cooking to meet the SDG 7 target by reducing wood fuels for cooking.

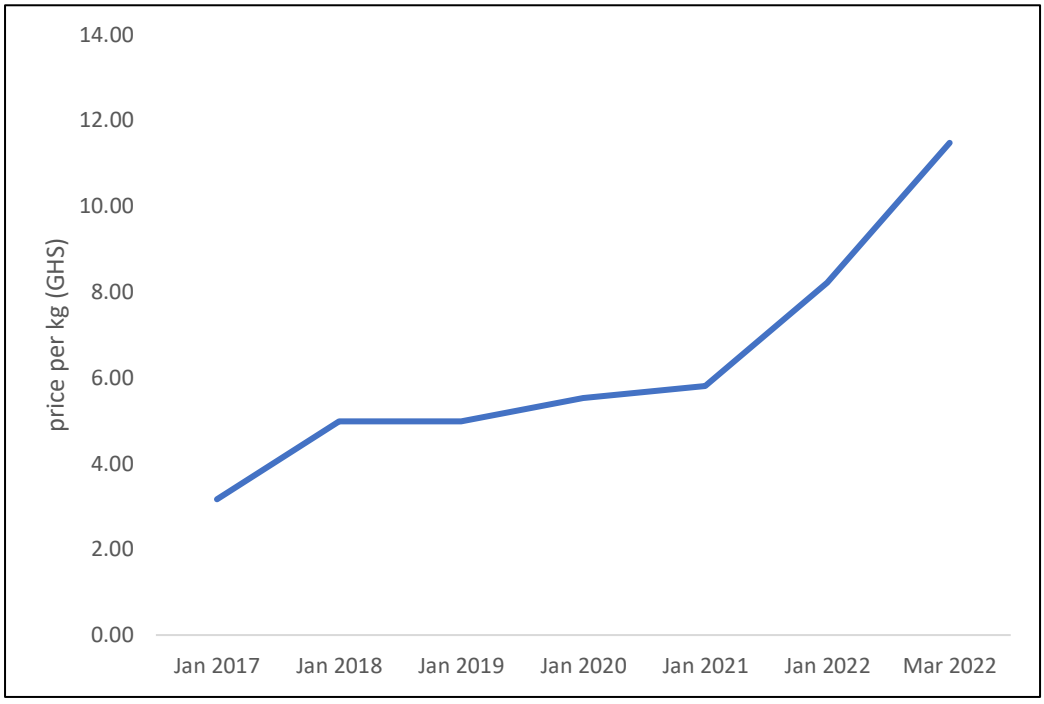
Figure 2: Households utilising various forms of polluting fuels in 2010 and 2021



Source: Ghana Statistical Service (2013; 2022)

The government of Ghana has formulated policies and strategies to promote clean cooking technologies to improve carbon sinks, reduce deforestation and reduce indoor air pollution. One of these key policy documents is "Sustainable Energy for All", which sought to enhance clean cooking by promoting LPG and improved cookstoves. Improved cookstoves reduce wood fuel consumption to some extent, but they do not eliminate the felling down of trees for charcoal. On the other hand, LPG eliminates the reliance on wood fuels and its attendant household air pollution. However, the increasing cost of LPG causes users to switch to charcoal and other polluting fuels. The average price of LPG increased from GHS 3.17 per kg in January 2017 to about GHS 11.5 per kg as of March 2022 (See Figure 2), affected mainly by rising crude oil prices and currency depreciation. Therefore, an alternative fuel source is opportune to complement the efforts of other clean fuels and accelerate Ghana's drive towards universal access to clean cooking fuels.

Figure 3: Average LPG prices between January 2017 to March 2022



Ethanol fuel as a cleaner alternative for cooking

Ethanol or alcohol-based fuels are either liquid or gel and do not produce smoke since they undergo complete combustion. Ethanol-based stoves and fuels have proven to be resilient technologies that can help reduce greenhouse gas emissions. For example, a study on the emissions reduction potential in Kenya showed that ethanol stoves reduced the climate impact of black carbon by 91% and 83% compared to kerosene and charcoal stoves, respectively.[6] Ethanol fuels are widely used in the eastern and southern parts of Africa. In

[6] Lefebvre, O. (2016). *Household air pollution study. Part 1: Black carbon emission factor measurement for ethanol, charcoal and kerosene stoves in Kibera, Kenya*. Climate Care.

Ethiopia, ethanol stoves are relatively cheaper than LPG-based stoves. Typically, the monthly cost of utilising ethanol stoves and fuels is about 52% less than the cost of using LPG stoves and fuels.[7]

In Ghana, ethanol-based fuels are used by a negligible proportion of households. The 2021 census indicates that about 0.04% of households use cooking gels such as ethanol as their primary fuel. Again, national policies on climate change and sustainable energy hardly promote ethanol-based fuels and stoves. A scan of the country's policies on clean cooking does not reveal a deliberate attempt to encourage the use of alcohol-based fuels and technologies, although they are also classified as clean fuels. Lastly, there is a dearth of research on the importance of ethanol stoves and their associated fuels. These issues have contributed to the limited focus on the potential of ethanol as a clean cooking alternative, resulting in the forgone social, economic, and environmental benefits.

Therefore, a study that seeks to understand customer behaviour toward ethanol-based fuels is appropriate, which is the focus of this study. This research results from a pilot study on ethanol fuels and stoves in two peri-urban localities in Ghana. The ensuing chapter provides an overview of ethanol fuels, the feedstock for ethanol production and the types of ethanol cookstoves available.

[7] Gaia Association. (2014). *Holistic Feasibility Study of a National Scale-up Programme for Ethanol Cook stoves and Ethanol Micro Distilleries (EMDs) in Ethiopia.* Gaia Association.

OVERVIEW OF ETHANOL FUELS AND ETHANOL-BASED COOKSTOVES

Ethanol is an oxygenated hydrocarbon and is made from various plant materials. It is a colourless fuel and can be used either wholly or blended with other fuels, especially diesel, to reduce the extent of air pollution.

Ethanol fuels and charcoal have relatively similar heating values. However, ethanol fuels have higher heating values than firewood and other crop residues. Whereas ethanol fuels have heating values between 27MJ/kg to 30MJ/kg, firewood and crop residue have heating values between 15MJ/kg to 17MJ/kg. The nature of ethanol fuels makes it a good and cleaner alternative to wood fuels and other forms of polluting fuels. Ethanol is not a naturally occurring substance, hence must be produced through an industrial process. Literature on ethanol production suggests three main processes; the hydration of ethylene, the fermentation of sugars, and the use of lignocellulosic materials.[8]

Ethanol-based cookstoves

Ethanol-based cookstoves are specially designed to accommodate ethanol fuels. Research has shown that ethanol fuels produce less smoke than charcoal and firewood, hence would reduce the impacts of household air pollution. Different kinds of ethanol stoves have varying design specifications and operation modes. This section discusses the pressurised alcohol stoves, the non-pressurised stoves, and the evaporative stoves.

Pressurised alcohol stoves

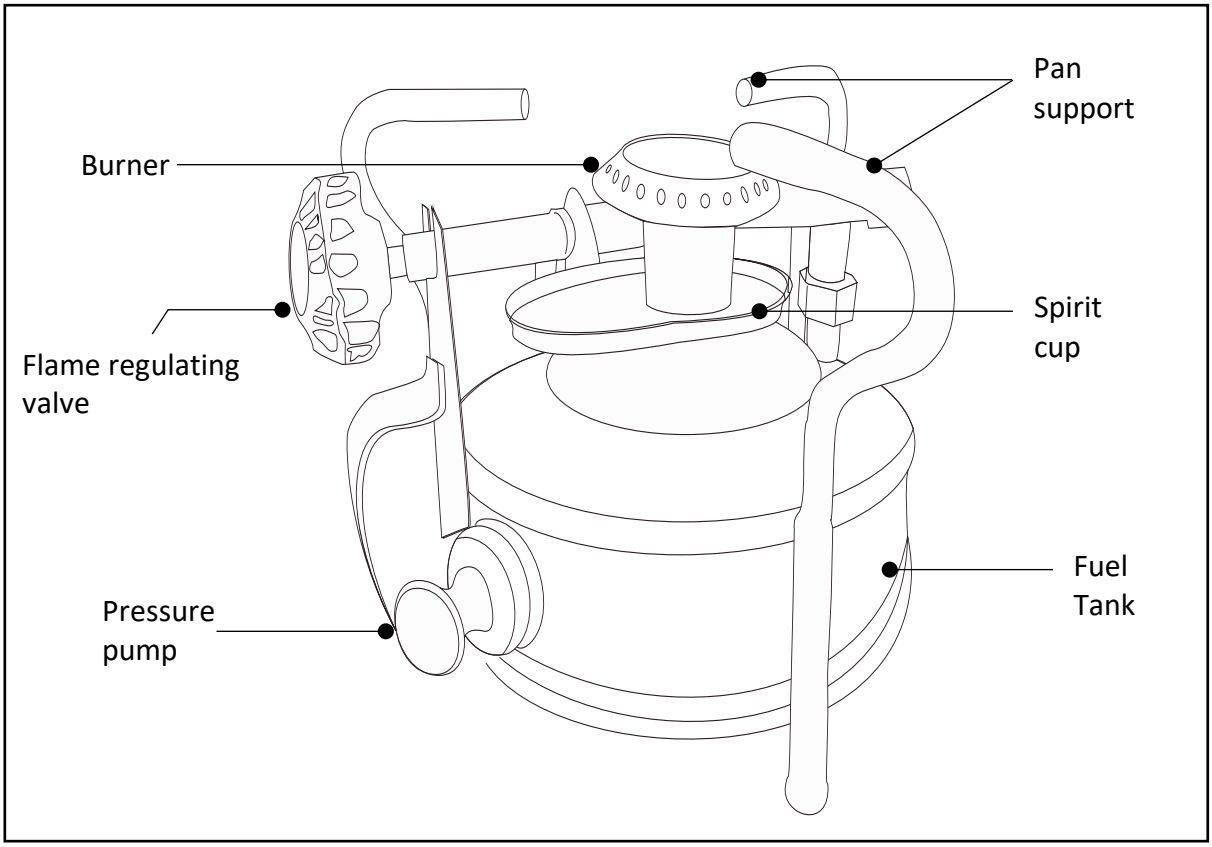
Pressurised alcohol stoves operate based on the mechanism of the old pressurised kerosine stove developed in the late 19th century. The stove's components include a fuel tank, a rising tube, a spirit cup, and a burner. The fuel tank is mainly located at the base of the stove. It has a hand pump where the user can easily apply pressure to increase the flame's intensity. The tank is connected to a rising tube fitted to a burner. The spirit cup is a preheating source between the burner and the base.

The user pours a small amount of alcohol onto the spirit cup and is primed to heat the burner area. Subsequently, pressure is mounted with the aid of the hand pump, which causes the fuel to rise through the tube to the preheated spirit cup and the burner. The heat from the spirit cup vaporises the liquid fuel at the burner to produce more heat at the burner, which lights up at the top ring. The base of the stove is pumped several times to maintain or increase the intensity of the heat.

[8]Hidzir, N. S., Som, A. S., & Abdullah, Z. (2014, August). Ethanol production via direct hydration of ethylene: A review. In *International conference on global sustainability and chemical engineering (ICGSE)*.

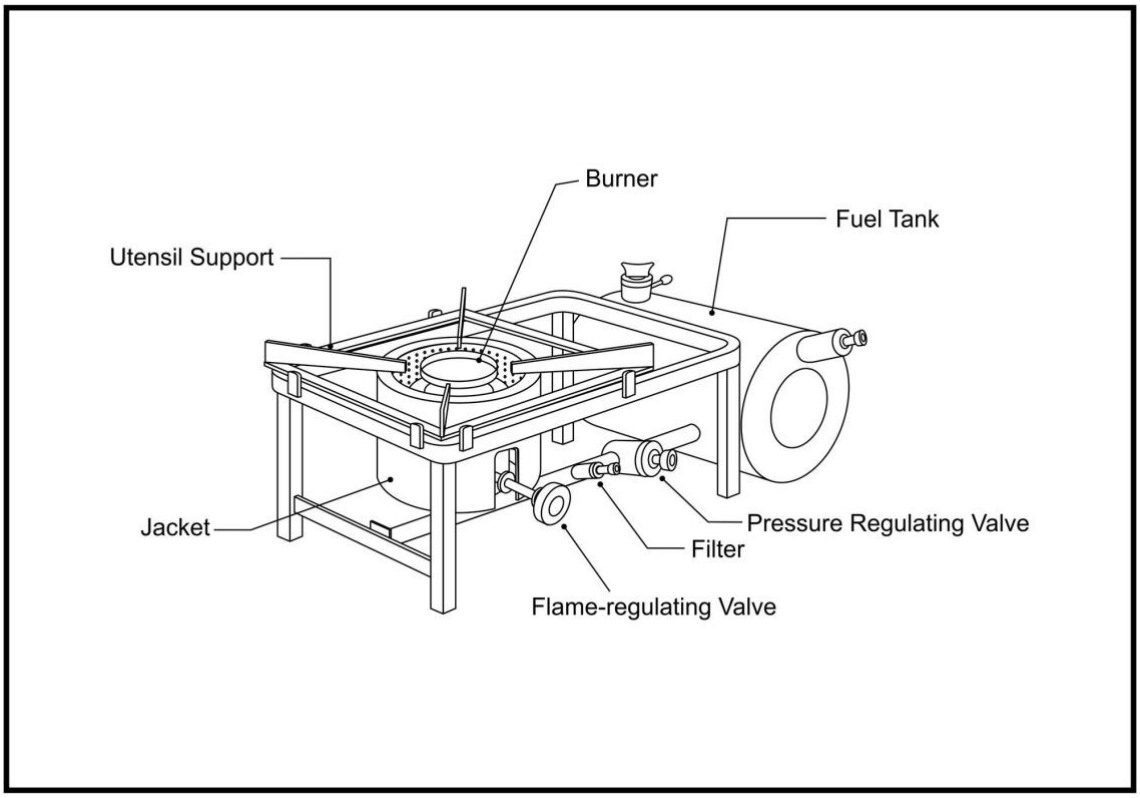
There are various brands of pressurised alcohol stoves with slightly different design specifications and modes of operation. While some brands have their fuel tanks attached to the burners, others have fuel tanks separated from the burner and connected by a hose. For example, the *Norma 25* pressure stoves have the fuel tank located at their base, as shown in Figure 4. For this brand of pressure stove, the function of pressure regulation and flame regulation are fused.

Figure 4: The main parts of the Norman 25 pressure alcohol stove



On the other hand, the NARI stove has the burner separated from the fuel tank. The stove has a regulating valve that controls the amount of heat that dissipates through the burner for cooking. However, it does not deviate significantly from the general operations of the pressurised alcohol stove. First, the NARI pressure alcohol stove requires a preheating step which vaporises the ethanol fuel before actual combustion occurs. Also, the pressure regulating valve regulates the fuel flow rate from the tank to the burner (see Figure 5).

Figure 5: NARI pressure alcohol stoves

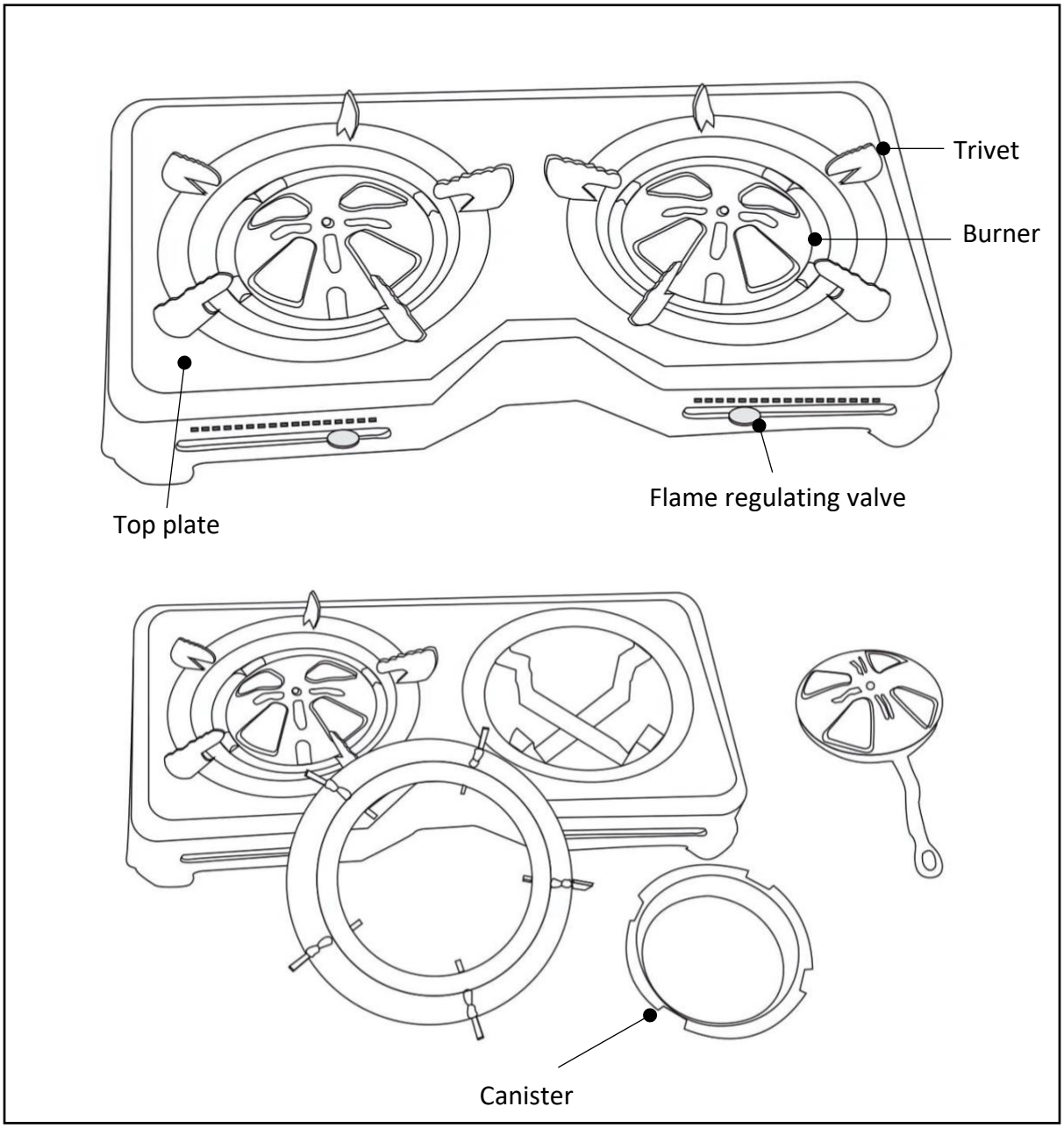


Source: Rajvanshi, A. K., Patil, S. M., & Mendoca, B. (2004). Development of Stove running on low ethanol concentration. *Nimbkar Agricultural Research Institute (NARI), Maharashtra, India*.

Non-pressurised alcohol stoves

Non-pressurised stoves hold the ethanol-based fuel in open containers, usually referred to as canisters. Most non-pressurised cookstoves have a top plate that firmly holds the other parts of the stove. The burner sits on the canister and is connected to a fire-controlling regulator, which controls heat from the canister to the burner. The burner contains pores that can be opened or closed to regulate heat transfer. A burner with completely opened pores allows maximum heat transfer from the canister to the top of the stove. A trivet is placed around the burner to hold the cooking pan firmly, protect direct contact between the hot pans and the stove, and allow adequate heat circulation. The stove is primed by lighting a match into the canister containing the ethanol fuel. The resulting flame is regulated with the fire controller handle.

Figure 6: The main parts of a non-pressurised stove



Non-pressurised cookstoves can use liquid or gelled ethanol, depending on the design specification. Gel fuels can be poured directly into the canister and burned to produce heat from the canister to the burner. The design of some non-pressurised stoves requires that the burner and the canister's cover are removed for fuel refilling. Liquid fuels may require a fibrous and porous medium (wick) in the container that absorbs the fuel and transports it through capillary action. This wick prevents excessive ethanol evaporation and ensures safety during the combustion process.

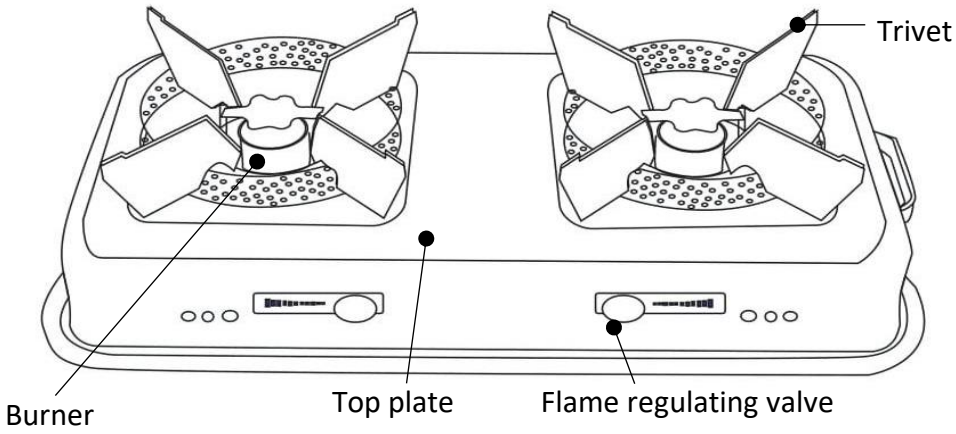
Evaporative stoves

The evaporative stove has a fuel storage and delivery system that transports fuel from the canister to the burner. Typical examples of such evaporative stoves include the *CleanCook* stoves and *Yazu* stoves. These stoves have similar features to many non-pressurised stoves, particularly the ones with the canister located at the stove's base. In addition, it has a top plate which holds the other parts of the system firmly and has a canister located at the base of the stove. The stove also has a trivet protecting contact between the hot pan and the burner.

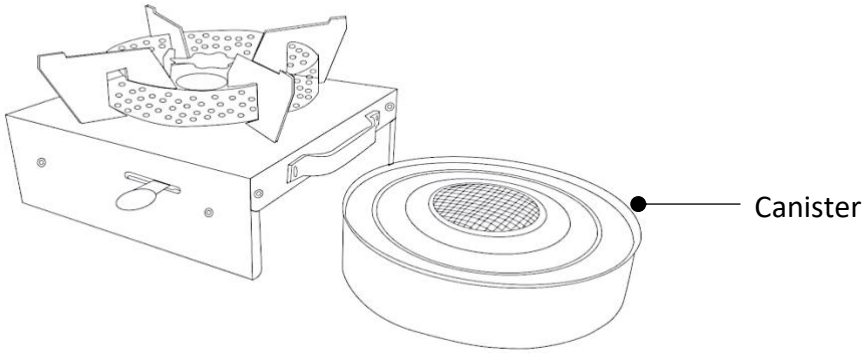
A distinct feature of the evaporative stove is its fuelling mechanism. First, the liquid ethanol is poured into the canister and absorbed by the wick. The liquid moves up the wick to an evaporative surface at the top of the burner, producing a flame when primed.

Figure 7: The main parts of an evaporative stove

Two burner evaporative stove



Single burner evaporative stove with canister



Evaporative and non-pressurised stoves are highly utilised among ethanol stove users in Africa. In Ghana, non-pressurised stoves are mainly used domestically to complement other cooking stoves. However, the evaporative stoves can be used in commercial settings, especially for those who prepare less energy-intensive or light foods such as noodles and omelette (locally referred to as *fried eggs*). The subsequent chapter provides the methodological approaches underlying the study and the behaviour of consumers towards ethanol-based cookstoves and fuels. The responses from respondents offer a base for advocacy and further development of the stove and fuel specifications that fit the needs of customers and advance the scale of utilisation.

METHODOLOGY

The pilot study was undertaken in two peri-urban districts in Ghana – Akuapem North Municipality and Ningo-Prampram District. Akuapem North Municipality is in the south-eastern part of the Eastern Region of Ghana. The municipality is characterised by the Akuapem hill range with a height of between 380 to 480 metres above sea level and covers about 450 sq. km. The municipality has about 20 communities, with Akropong as the district capital and the most populous community. Other major communities include Mampong, Larteh and Adukrom.[9]

Economic activity in the municipality is mainly agriculture and commerce. About 37% of the economically active population in the municipality is engaged in agricultural-related activities (agriculture, forestry, and fishing).[10] The main food crops cultivated by farmers within the municipality include cassava, plantain, cocoyam, maise, and vegetables. About 22% of the economically active population are involved in sales and service operations, whereas about 17% are engaged in craft and related trade.

The Ningo-Prampram district is in the Greater Accra Region, about 15km east of Tema and 40km from Accra. The communities that make up the Ningo Prampram district were initially part of the Shai Osudoku district until a legislative instrument, LI 2132, allowed new districts within the Shai Osudoku enclave. As a result, Ningo-Prampram was carved out of Shai Osudoku and has remained a district since 2012. The district has about 20 communities, with Prampram as the capital and the most populous community. Old Ningo, Dawhenya and Afienya are among the other most populous communities within the district.

Economic activity in the district is mainly agriculture which primarily involves crop farming and fishing. Farmers cultivate cassava, maise, banana, mango, and vegetable crops. The agriculture sector employs about 28% of the population, sales and services employ about 24%, and craft and related trades employ about 21% of the population. Ningo-Prampram district is also budding with various housing developments as vast land areas are available for construction.[11]

[9] Ghana Statistical Service. (2014). *District Analytical Report: Akuapem North Municipal*. Ghana Statistical Service.
[10] Ghana Statistical Service. (2014). *District Analytical Report: Akuapem North Municipal*. Ghana Statistical Service.
[11] Ghana Statistical Service. (2014). *District Analytical Report: Ningo-Prampram District*. Ghana Statistical Service.

Respondents' sampling

A sample of 34 respondents was selected from the study areas, of which 18 were from Akuapem North Municipality and 16 were from the Ningo-Prampram District. The local government authorities (district and municipal assemblies) in both places assisted with selecting the respondents for the study. ACEP wrote to the assemblies indicating the research's intent and requested their buy-in and support, especially in selecting study participants. The requirement was for each district to provide respondents who used the most popular cooking fuels (i.e., LPG, Charcoal, and firewood) for household or commercial purposes. Requirements for commercial utilisation included small-scale catering establishments (locally referred to as *chop bar* operators) and those who prepare and sell noodles, omelette, or fried plantain (locally referred to as *kelewele*). Participants were also required to be more observant regarding their fuel usage and expenditure and be able to communicate clearly in the local or English language.

Generally, there was more female representation than males. The study involved 27 females representing 79% of the total sample. This sample is representative since cooking duties, whether commercial or domestic, are mainly undertaken by women. Respondents from the Akuapem North Municipality were selected from various sub-communities within the district capital and had a female representation of about 78%. On the other hand, respondents from Ningo-Prampram were chosen from the surrounding communities, including Old Ningo, Prampram, Mobole, Tsopoli and Dawa. Like the respondents in Akuapem North Municipality, most of the respondents in Ningo-Prampram were females (81.3% of respondents).

In both study areas, most respondents used their cookstoves for domestic purposes. Generally, about 77% (78% from Akuapem North municipality and 81% from Ningo-Prampram district) cooked for domestic purposes. Table 1 describes the sample of respondents selected for the study.

Table 1: Characteristics of respondents

Variable	Akuapem North Municipality		Ningo-Prampram District	
	Number of respondents	percentage	Number of respondents	percentage
Gender				
Female	14	77.8%	13	81.3%
Male	4	22.2%	3	18.8%
Utilisation				
Domestic	14	77.8%	12	75.0%
Commercial	4	22.2%	4	25.0%
Main fuel used				
LPG	7	38.9%	7	43.8%
Charcoal	4	22.2%	4	25.0%
Firewood	2	11.1%	3	18.8%
LPG/Charcoal	5	27.8%	2	12.5%
Total	**18**	**100.0%**	**16**	**100.0%**

Stove distribution and data collection

The distribution phase of the stoves proceeded after the respondent selection phase. The research team met with respondents from the two districts at different times and carefully explained the study's intent. The team also demonstrated the use of ethanol-based cookstoves and responded to any questions during the discussions. Subsequently, the stoves were distributed to the respondents.

The non-pressurised cookstoves were given to respondents who utilised the stoves at the domestic level and some *kelewele,* noodles and omelette sellers. In addition, three evaporative stoves were distributed to some commercial-level operators – a *chop bar* operator, a caterer responsible for primary school children, and an omelette seller. These approaches were made to determine the design specifications of ethanol-based stoves that were fit for commercial purposes.

Respondents were asked to use the cooking stove for one month. In addition, there were occasional follow-up visits to the communities to examine any challenges with utilisation. Ethanol-based fuels were supplied free of charge throughout the study period through a local producer. This arrangement curtained any occurrence of fuel scarcity during the pilot study.

Two rounds of discussions were held to examine respondents' experience and behaviour towards the ethanol-based cookstoves. Respondents were classified into seven focus groups, with a maximum of six for each round of discussion. This approach allowed every respondent the opportunity to express themselves freely. The respondents were allowed to speak in any

language of their choice. Again, their consent was sought for the conversation to be recorded. The average duration of each focus group was approximately one and a half hours.

The first round of focus group discussion was held one week after the stoves were distributed to identify respondents' initial challenges with the utilisation and provide technical assistance where necessary. The discussions also obtained relevant information about respondents' experience with the stove and the fuel. The second round of discussions offered respondents the opportunity to provide additional details on their experience with the stove and fuel.

Data analysis

The recorded conversations from the focus group discussions were transcribed from audio to text. The data was analysed using *Atlas.ti* for qualitative data analysis. Atlas.ti is a qualitative analysis tool which provides a platform that consolidates large volumes of textual, pictorial, and audio-visual information for meaningful and easy analysis. In addition, it helps to identify and generate patterns and themes. It also groups the themes identified in qualitative data into higher levels of abstraction.

The field data was analysed thematically. First, after reviewing the transcript, themes and patterns were generated from the conversations. Next, similar emerging themes were put together to create mega-themes that form the basis for discussions of the results and their implications. Finally, the results from the field were also corroborated with additional information from desk reviews of prior studies and reports on issues related to clean cooking, environmental sustainability, climate change, and the production of ethanol fuels. The following section analyses the experiences of respondents regarding the use of ethanol-based fuels.

CONSUMERS' EXPERIENCE IN UTILISING ETHANOL-BASED FUELS

Using ethanol-based cookstoves meant that respondents would switch from their existing cooking stoves and fuels to newer cooking stoves and fuels. The switch presented new experiences on the part of the users that they could compare with the experiences they had using the existing fuel sources. This section documents the experiences of users. It forms the basis for recommending future design specifications and pricing schemes relevant to ensuring the competitiveness of ethanol-based stoves and fuels on the market. This analysis predominantly focuses on the non-pressurised ethanol stoves since they were the types that were mainly distributed to the respondents.

Foods prepared with ethanol-based stoves

The respondents indicated that the new ethanol-based stoves were used to prepare many kinds of foods, hence could be a good substitute for other existing cooking stoves and fuels. Ethanol-based cookstoves were used to undertake many forms of cooking, mainly boiling and frying. Respondents used the stove to cook tuber crops such as yam, cassava, cocoyam, and other cereals like rice. The stove was also ideal for frying fish, meat, yam and plantain, mainly requiring deep frying techniques. Also, omelettes, *tatale,*[12] and other basic foods that require shallow frying techniques were prepared with the ethanol-based stove.

For many Ghanaian staple foods, the type of food can determine the ideal stove that could be used for cooking. For example, foods that require much attention with continuous stirring or turning, such as *banku* and *kokonte,*[13] would mostly need a lowly elevated stove, especially for large-scale cooking. Those who prepare such foods prefer sitting and turning the dough when it hardens. Many charcoal stove users support the cooking pans with their legs placed on metal rods. The metal rods hold the saucepan firmly to ensure the effective turning of the dough. Generally, cooks within the household and commercial circles usually prefer to use charcoal stoves, especially for large-scale cooking.

There were mixed results on the utilisation of the cookstove in preparing these dough-like staple foods that require intensive stirring or turning. At first glance, some respondents indicated their scepticism about using ethanol-based stoves to prepare *banku* based on their judgement of the weight of the stove, its size, and the heating intensity of ethanol-based stoves.

[12] *Tatale* is a pancake style food that is prepared with ripe plantain. It acts as a main carbohydrate that accompanies beans sauce.
[13] *Banku* and *Kokonte* are traditional staple foods that are prepared with corn dough and cassava flour respectively. The result is a dough-like food that is mostly accompanied with soup.

"…I have not prepared banku with the stove because I have many children, and the size of the cookstove cannot support the saucepan I usually use …."

"…upon examining the stove's size and how the banku is prepared, I told my wife not to use it to prepare banku. She uses the Gyapa Stove[14] whenever she prepares banku. We used the [ethanol-based] cookstove to cook foods such as rice, yam and cassava. The stove is quite small, so I can't tell how effective it will work with bigger saucepans…."

On the other hand, respondents who confirmed their ability to prepare staple foods like *banku* indicated they prepared such foods in smaller quantities.

"…I can prepare all kinds of food with it, including banku. However, not in large quantities. We are only three…."

The ethanol-based cookstove can be used to prepare various foods and is ideal for the main cooking methods such as boiling and frying. In addition, the heating value of ethanol fuel is competitive with traditional firewood and charcoal. This property provides an assurance which could assuage consumers' fears of the stove's inability to cook heavy or dough-like food types. However, the size of the stove is an important characteristic that fuels consumers' perception of its ability to prepare foods in larger quantities. Generally, the findings on utilisation indicate consumers' perceived difficulties with cooking dough-like foods that require more attention and time. Therefore, the stove's design must allow for easier preparation of the main staple foods of the Ghanaian people.

Characteristic preferences of the ethanol-based stoves

The ethanol-based stove generated a new wave of eagerness toward utilisation. It has notable characteristic preferences which sustained respondents' willingness to utilise the stove for cooking. The preferred characteristics include reduced explosion risks, portability, and ethanol fuels as a cleaner alternative. These characteristics are further discussed in subsequent sections.

Reduced explosive risks

Fuel spillages are dangerous and can cause many hazards for most flammable fuels. The WHO estimates that about 180 thousand deaths are caused by burns every year. The exposure to household burn injuries is high among women and children because of their association with open fires and unsafe cookstoves. The WHO further indicates inadequate LPG and electricity safety mechanisms are additional risk factors for burns.[15] A study on the incidence of burns in Ghana shows that burns resulting from gas explosions formed about 51.6% of burn injuries

[14] Gyapa is a popular brand of improved charcoal stove in Ghana
[15] World Health Organisation. (2018). *Burns.* Accessed 12th June 2022 at https://www.who.int/news-room/fact-sheets/detail/burns

reported in one of the major teaching hospitals.[16] Therefore, less hazardous cookstoves can reduce the incidence and mortality rates of burns.

The field study results indicated that safety was the main characteristic of the stove that attracted respondents' preference. The ethanol cookstoves have stronger canisters that prevent spillages after the fuel is poured into the canister.[17] Further, the non-pressurised and evaporative cookstoves release the fuel under lower pressures and reduce the incidence of fuel explosion. As a result, there were no reports of accidents or injuries resulting from fuel spillages during the pilot study. Respondents who hitherto would not allow their children to use gas stoves because of their potential hazard were willing to allow their children to use ethanol-based stoves since any form of spillage does not result in greater damage.

"… The ethanol cookstove isn't dangerous; it is safe for children, and I prefer that."

"It is not dangerous; even kids can use it without any problem."

Cleaner alternative

The characteristic fuel in ethanol-based cookstoves undergoes complete combustion and does not emit smoke. The smokeless property of ethanol-based stoves has implications for reducing household air pollution, which is a significant contributor to many lung infections. On the other hand, wood fuels and charcoal stoves produce carbon monoxide (CO) because of their incomplete combustion. The reaction of carbon monoxide with other pollutants increases the amount of greenhouse gases in the atmosphere. Carbon monoxide exposure also has harmful health implications as it reduces the ability of the blood to carry oxygen.

Many respondents confirmed the smokeless characteristic of the ethanol-based cookstoves as a preferred characteristic of the stove. Generally, respondents noted that ethanol-based fuels did not emit smoke which has harmful health and environmental implications.

"... The fuel doesn't emit smoke compared to charcoal and firewood…."

Over time, cooking pans, mainly aluminium cookware and stainless-steel pans, produce a black discolouration at their base due to the continuous heat supply. The rate of discolouration is even faster when the pans are exposed to yellow flames from firewood. LPG stoves also produce discolouration when there is an uneven heat flow. Respondents indicated that the saucepans did not show any sign of discolouration within the time of utilisation. Although further technical studies are required to provide sufficient evidence to cement the

[16] Bayuo, J., Agbenorku, P., Amankwa, R., & Agbenorku, M. (2018). Epidemiology and outcomes of burn injury among older adults in a Ghanaian tertiary hospital. *Burns Open*, *2*(2), 98-103.
[17] Benka-Coker, M. L., Tadele, W., Milano, A., Getaneh, D., & Stokes, H. (2018). A case study of the ethanol CleanCook stove intervention and potential scale-up in Ethiopia. *Energy for Sustainable Development*, *46*, 53-64.

issue of non-discolouration, preliminary findings from this pilot study provide baseline information upon which further evidence can be sought.

"…Using the cookstove is less dangerous than using the gas. The saucepan doesn't discolour when using the [ethanol-based] cookstove…."

Portability

The ethanol-based stove is comparatively lighter in weight and can be fixed into a single unit, which makes it easy to convey from one point to another. LPG and charcoal stoves, on the other hand, require more peripheral materials. For example, LPG and charcoal stoves would require a gas cylinder and a bag of charcoal, respectively. However, ethanol-based stoves would only require the stove and the ethanol fuel, which can be placed in a 500ml container. The portable nature of ethanol-based stoves makes them ideal for trips where bulky stoves and fuels may cause general discomfort.

"I think the cookstove helps when I cannot travel with the cylinder… it will be best used in emergencies."

"This is not dangerous to use. I can travel with it because it is portable."

This characteristic of ethanol fuels can reduce the overall cost of obtaining the fuel. In addition, ethanol-based fuels can be sold at shops near households, reducing commuting time and transportation costs. On the other hand, LPG stoves incur charges in transporting the cylinders to and from the refill point, which increase significantly for households that reside farther away from such refill points.

Challenges with utilising ethanol-based stove and fuels

The general challenges with the stove's utilisation emanated mainly from its size and engineering. The challenges include, among others, difficulties in assembling the stoves and challenges with fuel refilling. Improving the stove's engineering would engender public support and compete better with existing products.

Difficulties in assembling and dismantling the stoves

The non-pressurised stove used for the study has canisters which must be removed occasionally for either refilling or canister cleaning. This process requires that stoves are dismantled and reassembled. Some respondents complained of difficulties they experienced assembling or disassembling the stove. In many cases, canisters were not well fitted, which impacted the stove's performance. Consequently, there are difficulties with regulating heat flow from the canister to the saucepan.

"…On the fourth day, I struggled to remove the canister for cleaning..."

"…If you dismantle and don't arrange it well, there will be spaces in between. Sometimes the pores do not allow the fire to quench after turning it off…."

Comparatively, the other main cooking alternatives do not require dismantling at the magnitude of ethanol-based fuels. For example, LPG stove burners are dismantled when the user wants to clean the stove, and its reassembling is not difficult. This striking difference in the ease of disassembling and reassembling contributed to some respondents' continual preference for LPG-based stoves.

"For me, I cannot stop using gas because of the difficulty in dismantling the new cookstove."

This difficulty, however, was not experienced by respondents who were given the evaporative stoves. The evaporative stove's canister is fitted behind the stove, and dismantling involves a single step compared to the non-pressurised stoves. In addition, the evaporative stove's canister easily snaps to fit at the base of the stove upon a single turn. Thus, it provides more comfort and ease for reassembling.

Refilling challenges

It is essential to ensure that the fuel can support the cooking from start to finish. LPG stoves offer a constant heat supply from the gas cylinder without taking the cooking pan off the stove. In the case of charcoal stoves, the user must take the cooking pan off the stove for refilling without necessarily quenching the heat from the stove. The non-pressurised stove, on the other hand, would require that the fire is turned off and the stove is possibly dismantled before the fuel is refilled. Generally, an associated heat transfer from the burner to various parts of the stove makes immediate dismantling and reassembling difficult. The evaporative stove, which uses liquid ethanol, also requires that the canister is removed before the fuel is refilled and has similar inconveniences as the non-pressurised stove. A short-term solution to prevent occasional dismantling would be to fill canisters with adequate fuel before any significant cooking.

The tasks of quenching, dismantling, reassembling, and re-igniting the stove for refilling purposes were described by respondents as tedious steps that discouraged the user. Some recommended that a design that allows refilling to be made without dismantling the stove would be more appropriate for the consumer.

"…this drew my attention to the kerosene stove. Again, the kerosene can be poured into it from the side when it finishes, but this time, I had to quench the fire before I could refill the canister with the gel…."

Size of stove and canister

Generally, households in Ghana cook in larger quantities, especially in rural and peri-urban communities. Cooking for a larger household size demands a stove whose size supports the saucepan and provides an even distribution of heat around the cooking pan. Some respondents indicated that the non-pressurised cookstove was small to support their cooking with large cooking pans and thus recommended that the stove comes in various sizes to provide options for the consumer. In addition, the size contributed to some respondents' inability to prepare dough-like staples such as *banku* and *kokonte.* The small size of the canister meant that the refill time was shorter, which has implications for cooking time and ease of cooking.

"...I didn't find any difficulties at all. I am okay with the usage, but the only problem concerns the size..."

Fuel residue

Ethanol fuels do not produce smoke. However, some respondents indicated that it left residue after they were completely burnt. The ethanol residue remained stuck at the base of the canister. Respondents indicated several coping mechanisms for dealing with the residue. While some scrapped the residue with cleaning materials such as a sponge, steel wool and foams, others used knives and metallic spoons to remove the residue. Again, other respondents soaked the canister in water to soften the residue, which was wiped with a foam sponge.

"… the fuel gets stuck around the walls of the canister, and it is difficult to remove them. This has caused most people to use the silver shine [steel wool] to wash the canister..."

"…When the fuel residue gets stuck in the canister, I soak the canister in water and wash it off with a sponge..."

"…I use a spoon to take the residue out. It is not difficult for me to remove it with the spoon…"

Removing residue with steel wool and knives can increase the wear and tear of the canister. Although the residue from the fuels does not pose much danger concerning the stove's utilisation, respondents wished that there was little or no residue left at the base of the canister.

General expectations for cookstoves

The choice of the ideal stove for cooking depends on several factors. Therefore, customers' expectation of the kind of stove is critical in designing or manufacturing alternative cookstoves. This section examines the characteristics of customers' preferred cooking stoves and fuel. It forms the basis for mapping the general indicators for preferred cookstoves and the identified advantages of using ethanol-based cookstoves. These expectations will inform the engineering and design of clean cookstoves to ensure competitiveness in the market.

Quality of stove

The concept of quality examines the extent to which the cookstove is free from defects constraining effective utilisation. This study examines quality through the lens of durability, which was one of the significant factors influencing the choice of cookstoves. Respondents preferred stoves engineered with durable products that withstand harsh cooking or environmental conditions.

Generally, dough-like foods such as *Banku* and *Kokonte* require additional pressure through stirring, which can destroy fragile stoves. Similarly, cooking for larger household sizes or commercial utilisation may require stoves that can withstand the pressure of heavy saucepans and the weight of the food being prepared. In addition, cookstoves absorb excessive heat as they directly interact with flames of different characteristics. Thus, the stove must withstand rising temperatures that can cause wear and tear and possibly rust.

"…I look out for the quality of the stove and how durable it is. The stove must be strong…."

"…First of all, I check whether the stove is of good quality; it must also not be prone to rust…."

Cost

Cost is a multidimensional concept that encompasses production and consumption. Generally, it is a major determining factor of product choice for many customers. This section examines the costs of the stove and fuel as indicators for selecting the preferred cookstove.

Cost of ethanol-based stoves

Next to quality, respondents indicated the cost of the stove as an essential characteristic that affects their purchasing decision. Typically, the buyer would compare the prices of various stoves and brands before making a purchase.

At the time of the study, the average cost of non-pressurised cookstoves was about GHS200, while evaporative stoves ranged between GHS450 and GHS500. The initial cost of obtaining

ethanol-based stoves competes favourably with some LPG stoves. For instance, the price of a table-top LPG stove ranged between GHS200 to GHS300, depending on the number of burners and the brand of stove. LPG stoves would require gas cylinders with an average cost of about GHS300 for a 14kg gas cylinder, increasing the total cost to range between GHS500 to GHS600. However, evaporative and non-pressurised cookstoves may not compete well with the complete LPG stoves. Complete LPG stoves are usually 6kg gas cylinders with a burner on top of the cylinder, with an average price of about GHS150.

Improved charcoal stoves also range between GHS50 to GHS80, while traditional iron charcoal stoves range between GHS50 and GHS70, which are lower than evaporative and non-pressurised ethanol-based stoves. These price differences among charcoal, LPG and ethanol-based stoves make cost reduction strategies in producing ethanol-based stoves essential to drive down the price of the stove on the market.

"...I consider the price and whether it [the stove] lasts longer...."

The cost of fuel

Purchasing the characteristic fuel is a significant operational cost element. Expensive fuels increase household expenditure costs and lower commercial catering operators' profitability. This contributes to many households' preference for cooking stoves with cheaper fuel costs. Respondents also corroborated this assertion and noted that fuel cost was a major determinant in their selection of stoves for cooking. The field survey revealed that some respondents have switched from LPG to traditional charcoal stoves because of the difference in fuel costs.

"...I check for one whose fuel price is less...."

The pilot study found that the cost of a bag of charcoal varies and ranges between GHS 60 to GHS 75. A bag of charcoal for an average household size of five can last for approximately one month, depending on the type of food being cooked. Charcoal can be purchased in smaller quantities to benefit poor households that cannot afford to buy in bulk. The price of charcoal could range from GHS 2 to GHS 5, which could be enough for a single meal for a household size of about five.

As of March 2022, the average retail price of a kg of LPG was about GHS11. Although LPG can be purchased in smaller quantities, the minimum amount payable is significantly higher than the amount payable for charcoal. A scan of LPG vendors indicates that the minimum amount of LPG ranges between GHS15 and GHS20. In addition, LPG has heating values of about twice as much as ethanol fuels, suggesting that the cost of ethanol fuels must be between GHS5 to GHS6 per kg to make it competitive with LPG.

Fuel efficiency and stove performance

Fuel efficiency is another characteristic that affects the operational cost of stoves. Respondents indicated their preference for fuel that would last longer before running out. For example, charcoal stove users generally prefer hardwood charcoal. Although these types of charcoal may be more difficult to prime compared to the lighter ones made of softwood, they last longer before wasting away into ashes. Anecdotal arguments from respondents indicated that hardwood charcoal has a lifespan twice as much as softwood charcoal.

The speed and the time-saving advantage that LPG offers allow for utilisation in many commercial cooking settings. Although some traditional catering establishments utilise charcoal as a primary fuel source, LPG utilisation has increased in many commercial catering establishments. Some respondents confirmed the performance of LPG for commercial cooking.

"…I have used it for three days. I used it to prepare indomie and fried eggs as well. If I compare the cookstove to LPG, the LPG works faster..."

Ethanol may have lower heating values compared with LPG. However, it competes effectively with wood fuels and charcoal. Thus ethanol-based stoves can perform better, resulting in minimum cooking time. Therefore, besides being a cleaner alternative, ethanol-based fuels would provide an additional advantage over charcoal stoves and traditional wood fuels. However, adulterated ethanol fuels would reduce their heating value and the overall efficiency of the fuel. Therefore, producers of ethanol-based fuels must ensure that the correct composition of ethanol is used in the fuel's preparation to sustain its effectiveness and competitive advantage.

Variability in sizes

Stoves for commercial purposes are more significant in size, accommodate larger saucepans, and ensure equitable heat distribution. Respondents indicated that size is an essential indicator for selecting the ideal cookstove. Household users of cookstoves with smaller family sizes may opt for smaller cookstoves as a cost-cutting approach. Similarly, households with larger sizes and commercial users of cookstoves would generally opt for larger cookstoves to ensure effectiveness in cooking.

"To me, the size matters. I prefer the bigger size, but mine is too small. I wish I could get a bigger one…."

Currently, the non-pressurised ethanol stoves exist as either single or double-burner stoves. On the other hand, the evaporative stove is also relatively bigger in size and heat distribution and are stoves are relatively fit for household consumption. Ethanol stoves that offer a variety

of sizes will prove competitive on the market. This is particularly essential if manufacturers want to be competitive within commercial cooking circles.

Fuel accessibility

Fuel is a significant component of any cooking stove. Thus, the unavailability of fuels would make the stoves redundant. Fuel accessibility has resulted in many failed attempts to increase the use of clean cooking alternatives, particularly in rural areas. In 2013, the government of Ghana launched the Rural LPG program to contribute to the country's goal of increasing LPG access to at least 50% of the population by 2020. The program had distributed about 150,000 LPG stoves to rural households by November 2017. However, further interrogation regarding utilisation showed that about 58% of the households had never refilled their gas cylinders nine months after receiving filled cylinders. It was also revealed that only 8% still used their LPG 18 months after distribution. In addition to cost, beneficiaries cited the distance to gas refill points as a primary challenge.[18]

Similarly, an organisation began an ethanol cookstove project to promote its utilisation in Mozambique in 2012. The project started with heightened promotion and sales of ethanol-based stoves and the associated fuel, which garnered public interest and affection. However, the lack of accessibility to fuel contributed to the beneficiaries' decision to quit using ethanol-based stoves and revert to charcoal stoves.[19]

Ethanol fuels must be accessible to allow them to remain competitive. The portability feature of ethanol fuels can help improve their accessibility. Unlike LPG, ethanol fuels do not require special transportation equipment or investment in storage tanks. Ethanol fuels can be sold over the counter in department stalls and supermarkets of all sizes. However, safety must never be compromised in the preparation and sale of the fuels. Thus, the storage medium or packaging must protect the fuel from leaking and have the appropriate warning or cautionary signals.

Other characteristics

Additional characteristics that did not receive wider mention compared to the traits mentioned above were considered secondary criteria for selection. For example, the respondents rarely mentioned safety concerns, although it is essential for preventing accidents. The few respondents who indicated safety as a criterion argued based on the safety of children. Generally, these respondents considered charcoal safer than LPG. Also, their

[18] Asante, K. P., Afari-Asiedu, S., Abdulai, M. A., Dalaba, M. A., Carrión, D., Dickinson, K. L., ... & Jack, D. W. (2018). Ghana's rural liquefied petroleum gas program scale up: A case study. *Energy for Sustainable Development*, 46, 94-102.
[19] Mudombi, S., Nyambane, A., von Maltitz, G. P., Gasparatos, A., Johnson, F. X., Chenene, M. L., & Attanassov, B. (2018). User perceptions about the adoption and use of ethanol fuel and cookstoves in Maputo, Mozambique. *Energy for Sustainable Development*, 44, 97-108.

experience with ethanol fuels showed that its fuels provided a safer alternative than the other cooking alternatives.

"I also use both charcoal and LPG. But honestly, I use charcoal more often than the LPG because of the safety of my children."

Again, the ease or convenience of cooking was one of the rarely mentioned factors. The study observed that if convenience were a major yardstick, the use of charcoal stoves would have reduced to a large extent. Although charcoal is difficult to prime, other qualities, such as the affordability and accessibility of fuel, make it a better option for many consumers. Other characteristics, such as aesthetics and portability, were secondary criteria for selecting a stove.

Mapping customer expectations with an identified preference for ethanol stoves

The pilot study identified the characteristic preferences for ethanol-based cookstoves based on safety, portability/convenience, and its potential as a clean cooking alternative. However, these preferences must align with customers' expectations to ensure competitiveness. Therefore, it is vital to map the general expectations on cooking stoves and fuels with identified advantages of ethanol-based cookstoves.

The mapping indicates that customers' primary expectations are generally outside the stove's characteristic preferences. The main qualities of ethanol-based cookstoves identified in the pilot study include less explosive risks, cleaner alternative, and portability. These qualities are highly linked to general expectations of safety and convenience. However, they relate loosely with the general indicators for customer preferences for the choice of a cooking stove.

The identified advantages of ethanol fuels had no substantial linkage with durability. As noted in the previous sections, respondents were sceptical about the strength of the non-pressurised cookstove, which prevented them from using it to prepare some staple foods. Again, the portability characteristic, particularly for non-pressurised stoves, provides a good case for small household sizes. The portability of ethanol-based fuels can improve fuel accessibility and minimise transportation costs incurred for buying fuels. However, varying sizes are required to meet the needs of commercial consumers.

Like other fuels, ethanol fuels are reusable, and this quality increases its level of efficiency. However, performance characteristics such as the high heating values are other core customer preferences that require the attention of fuel producers.

Table 2: Mapping general expectations of stoves with a characteristic preference for ethanol cookstoves

Characteristic preference for ethanol stoves	**Customer expectations for cooking stoves**						
	Primary factors					**Secondary factors**	
	Durability	Cost	Fuel efficiency	Variable sizes	Access to fuel	Safety	Convenience
Less explosive risks						**H**	
Cleaner alternatives						**H**	
Portability		**M**		**L**	**M**		**H**
Fuel reusability			**M**				

Key: H – High (A best fit for the factor); M – Moderate (A moderate fit for the factor); Low (A low fit for the factor)

The main characteristic preferences of ethanol-based stoves are mainly secondary to the general expectations of customers. However, this does not undermine the importance of the distinctive features of ethanol-based stoves. For example, safety is a highly essential characteristic for fuels and cooking stoves to prevent the incidence of explosions resulting in severe injuries and the destruction of lives and properties. In addition, the clean nature of the energy provided by ethanol-based fuels and stoves is vital for health and environmental sustainability. Ethanol-based stoves and fuels do not produce smoke and can prevent the incidence of household air pollution and its attendant health impacts. However, given that customers' preferences would affect the competitiveness of the stoves on the market, it is essential for the stove's characteristics to also conform to what consumers have identified as their preferred indicators for an ideal cookstove. It is interesting to note that consumers generally would not compromise on the quality of the stove and ensure a good trade-off between quality and cost but would hardly consider the widespread environmental and health impacts of polluting stoves.

The design specifications of ethanol-based stoves and fuels must also examine consumers' expectations of cookstoves. The critical characteristic preferences of safety, convenience and environmental sustainability can become additional qualities that make ethanol-based stoves stand out among other alternatives, offering them a more competitive advantage.

RECOMMENDATIONS FOR IMPROVING ETHANOL-BASED COOKSTOVES AND FUELS

Ethanol-based cookstoves are good alternatives for clean cooking. The results from the pilot study show that the cookstove competes effectively on safety, convenience and environmental sustainability compared to other cooking forms such as LPG stoves and charcoal stoves. Again, ethanol has higher heating values than traditional firewood and charcoal, making it more effective. Large-scale production and wide acceptance of ethanol-based stoves can be essential to reducing the number of trees felled for firewood and charcoal, making it a critical contributor to reducing greenhouse gas emissions from solid fuels.

Despite the essential features and preferences for ethanol stoves and fuels, the design and production specifications must also meet the general expectations of consumers. Safety and environmental sustainability alone cannot ensure the competitiveness of ethanol-based stoves on the market. As shown in earlier sections of the text, consumers' preferences for stoves are based on the quality of the stove, fuel accessibility and cost competitiveness. Therefore, governments and producers of ethanol-based fuels must consider these recommendations for improvement to build on their competitive power, where environmental sustainability and convenience will become the indicator that makes such technologies stand out among the other forms of cooking.

1. **Increase R&D in stoves' design**. Manufacturers and governments must heighten research on the most efficient ethanol-based cookstoves to replace the existing ones with design and operational flexibility challenges. Research and development must focus on improving the canister's design, the stove's strength and ease with refuelling.
2. **Government policy must focus on boosting the local production of ethanol**. The ethanol market is another sector that can boost the economy. Increased demand for ethanol for industry and cooking provides a supply potential with opportunities for income generation and job creation. Again, the government and producers must increase the R&D potential for ethanol production to create options to improve the efficiency of the ethanol production process, thereby minimising costs.
3. **Manufacturers of ethanol-based cookstoves must streamline production processes to reduce costs.** Manufacturers must have an efficient means of producing to minimise production costs, including lean systems, affordable power and bulk purchases and production.
4. **Fuel producers and stove manufacturers can consider the potential of receiving carbon credits to offset costs.** The clean nature of ethanol-based fuels provides a unique opportunity for producers to obtain carbon credits. These credits can be used to offset production costs to reduce the price of stoves and fuels on the market

Africa Centre for Energy Policy (ACEP)
No. 26 Lemming St.|North Legon
Digital Address: GM-058-1968
P. O. Box CT 2121|Cantonments|Accra
Tel: +233(0) 302 900 730
Email: info@acep.africa
Website: http://www.acep.africa