Pilot Evaluation of the Diffusion and Use of Clean Cooking Technologies in Lagos, Nigeria (PEDUCCT): Results Brief

July 2018

Study Introduction

A consortium of Nigerian private sector partners, anchored by Project Gaia Partners Limited (Project Gaia) and Shell Nigeria Exploration and Production Company (SNEPCo), is exploring how to promote ethanol-methanol fuel for cooking in West Africa, with a pilot project designed to roll out as a commercial start-up in 2018-19. An initial 2,500 CleanCook stoves (see box) and 15,000 alcohol-fuel canisters will be sold in selected neighborhoods of Lagos. The consortium also includes Forte Oil, a leading fuel sales and distribution company with over 500 retail outlets, and UNIKEM Industries Ltd. In order to support the commercial scale-up of the CleanCook stove and ethanol-methanol fuel blend, an assessment, entitled **Pilot Evaluation of Diffusion and Usage of Ethanol Clean Cooking Technology (PEDUCCT)**, was launched in 2017 with funding from the African Development Bank.

The CleanCook Stove

The alcohol-fueled CleanCook stove has 2 burners, a stainless-steel body, and an expected lifespan of 8 to 10 years. It is currently manufactured in Durban, South Africa, and has a factory cost of ~24,000 Naira. The ethanol-methanol fuel is delivered to the burners through a system of fiber-filled adsorptive canisters that allow the user to adjust the heat level while eliminating the risk of burns or fuel ingestion.

Study Approach

Objective	Method Details
This early-stage observational study aimed to collect the data necessary to explore and improve the potential for successful ethanol technology scale-up, including information on cooking patterns, customer perceptions, and willingness to pay.	In-home field assessments were undertaken in an experimental sample of 30 households for up to 6 months.
	A combination of sensor-based stove-use measurements, canister refill monitoring, and household surveys were used to measure uptake, use, and acceptability of the CleanCook.
	The evaluation also included performance testing of both the CleanCook with the ethanol-methanol fuel and a local kerosene stove conducted at the National Center for Energy Research and Development (NCERD) laboratory at the University of Nigeria, Nsukka, to estimate emission factors/rates and fuel efficiency.
	Although the original study design also included a parallel study of early purchasers, this component could not be completed as the assessment period concluded prior to the CleanCook's market launch, which is still awaited.

Note that a complete description of the methods is presented in Annex 1.

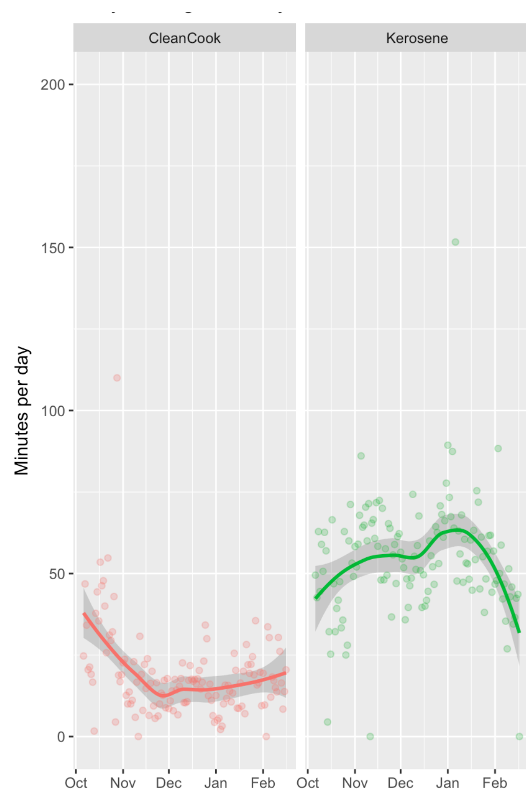
Key Findings

Key results are presented below, while the complete set of findings is presented in Annex 1.

Stove Usage

Stove use monitor (SUM) and self-reported data show usage patterns that suggest consistent but incomplete adoption of the CleanCook stove.

- 4-5 months after receiving the stove, 65% (n=17) of participants reported that the CleanCook was the stove they 'used most of the time.' Six of these homes reported to use it exclusively.
- Just over one-third of participants (38%, n=10) reported to use their CleanCook stove 7 days per week, with most of these (90%, n=9) using it for 2 or more meals.
- Self-reported data appears to over report CleanCook stove usage. SUMs results showed the overall highest average cooking events per day was on the kerosene stove (1.26, SD=0.88). The CleanCook (n=28) and the LPG (n=5) stoves, were used on average 0.72 (SD=0.58) and 0.53 (SD=0.39) times per day, respectively.
- The kerosene stoves also had the highest average minutes of use per day (93 minutes, SD=73) followed by the CleanCook (26 minutes, SD=20) and then the LPG stoves (19 minutes,



CleanCook and kerosene stove use over time

SD=16)[1].

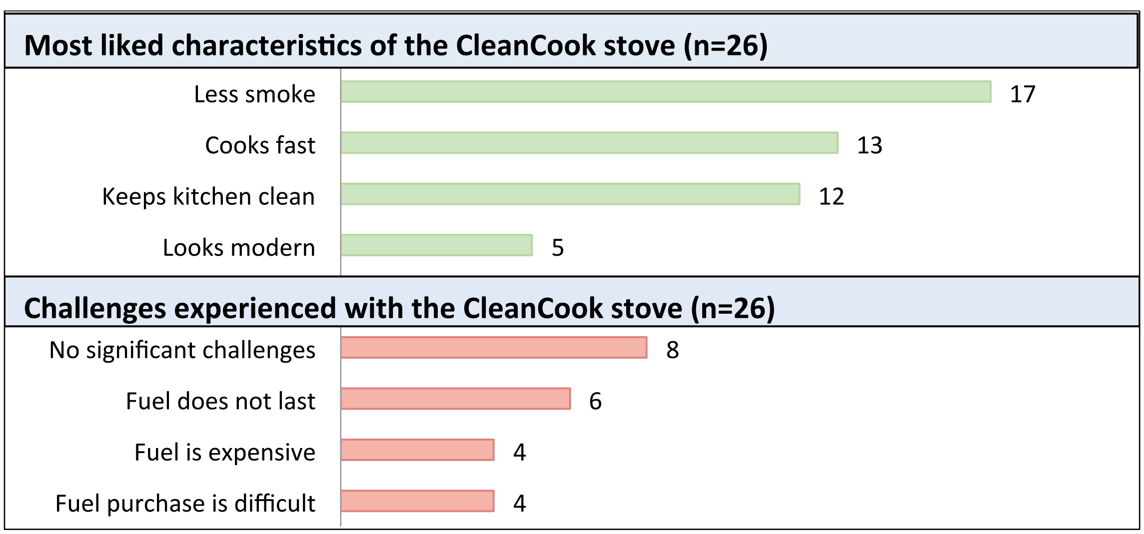
- SUMs data from the CleanCook over the course of the study shows that usage was relatively consistant after the initial 'honeymoon' period (see figure), though kerosene continued to be the predominant fuel used.
- Homes that purchased the CleanCook after the study concluded (n=10)[2] showed a more intensive pre-purchase CleanCook usage pattern than those that decided not to buy: 0.87 events (SD=0.49) and 31 minutes (SD=20) of cooking per day versus 0.63 events (SD=0.63) and 23 minutes (SD=20).
- Stove use data showed no change in the use of the CleanCook stove before and after purchase (p=0.76)

Emissions and Climate Impacts

- Based on the amount of cooking done on the CleanCook, during the study, determined by SUM data, study homes were estimated to reduce their long- and short-term climate emissions by approximately 15 to 20%, as measured by carbon dioxide-equivalent and black carbon-equivalent, respectively.
- The bulk of the climate-forcing emissions came from the production and use of kerosene, as this was the primary fuel used even after the CleanCook was introduced into the households.
- If households were to switch entirely to ethanol/methanol stove use, then it is estimated they would reduce their carbon dioxide-equivalent and black carbon-equivalent emissions by approximately 70 and 80%, respectively, suggesting substantive climate impacts could be achieved with more complete displacement of current cooking technologies in urban Nigeria.

Participant perceptions of the CleanCook Stove

- 4-5 months after receiving the CleanCook stove, all participants stated that they would recommend the stove to friends and family.
- The most liked features as well as the most significant challenges reported by users are presented below.



[1] Note: the LPG stove sample size is very small, meaning the results should be interpreted with caution. Homes with high LPG use were excluded from the study by design as we did not seek to collect data on LPG users.

[2] These homes had taken part in the full experimental arm of the study and had either purchased as part of the willingness to pay (WTP) exercise or after the study had finished.

CleanCook fuel access and affordability

- Percent of participants agreeing or disagreeing with statements related to the perceived usability of the CleanCook fuel are presented below.

	Strongly agree	Agree	Disagree	Strongly disagree
I can afford to cook with CleanCook fuel (n=25)	36% (9)	64% (16)	0% (0)	0% (0)
CleanCook fuel is a safe fuel to cook with (n=26)	58% (15)	39% (10)	4% (1)	0% (0)
CleanCook fuel is a clean fuel to cook with (n=26)	61% (16)	39% (10)	0% (0)	0% (0)

- Fuel canisters were sold at an average rate of 2.3 canisters per household/month. This rate provides approximatively one-third of the estimated amount of fuel that a typical Lagos household requires to meet all their cooking needs.
- 58% (n=15) reported that fuel canisters were not always available when needed, although only 4 participants said this had happened more than once over the duration of the study. When canisters were unavailable, participants cooked with a different stove.

Willingness to pay for the CleanCook stove

- A willingness to pay exercise was conducted with 37 households. 94.6% (n=35) were interested in purchasing the stove.
- Participants were told that the stove was 'worth' N24,000 (the approximate factory price), but they could purchase it for a discounted N19,000. If this offer was declined, participants were invited to make up to three bids for the stove, with any bid over N15,000 being accepted.
- 30% (n=11) purchased the CleanCook stove at an average price of N15,909 (SD 1300).
- Participants with higher levels of education were more likely to purchase the CleanCook stove (p=0.02). There was no relationship seen with other possible predictors such as current LPG ownership, age, or home-ownership status.

Conclusions and Program Learnings

Taken together, the multiple approaches used in this assessment generate an encouraging picture of ethanol as a likeable and affordable household fuel.

The ethanol-methanol cooking experience delivered sufficient benefits to the participants that they were willing to continue to procure the fuel even though the purchase experience was sometimes inconsistent and challenging.

Even with incomplete household adoption and continued cookstove stacking, an ethanol-methanol initiative could deliver significant regional reductions in climate-damaging pollutants.

Monetizing the climate benefits through some form of carbon finance to subsidize the capital cost of the cookstove would help it better compete with LPG and other cooking fuel options.

The findings of the PEDUCCT study, while rich and interesting in their own right, are limited in their scope due to the fact that only an experimental study could be undertaken during the timeframe of the research contract.

The full market launch of the CleanCook stove, which would have allowed for the evaluation of an authentic customer experience, was delayed indefinitely due to challenges with permitting and constructing the fuel supply storage and blending facilities. This deferral further underscores the challenges of trying to assess customer satisfaction with the fuel procurement system, which is central to adoption of the CleanCook in an urban market-based program, before the actual supply chain has been established.

In this case, where only the study stoves use the fuel type and the fuel can only be purchased from limited sources, canister refill data appears to be a cost-effective and reasonably accurate way to measure adoption.

Unlike self-reported data, canister sales are not affected by recall or over-reporting biases. The canister refill data provides a good counterpoint to survey data that is much less invasive and labor-intensive than stove use monitoring.

Project Context

The Project Gaia/SNEPCo initiative is motivated by an overarching social responsibility goal to "promote a safer cooking system in Nigeria as part of efforts to encourage access to a better source of energy" (SNEPCo, 2015). It builds on a recently completed randomized controlled study in Nigeria that transitioned pregnant women from traditional cooking fuels to ethanol and demonstrated improved pregnancy outcomes in mothers and children (Alexander et al., 2017; Alexander et al., 2018; Dutta et al., 2017; Northcross et al., 2016; Olopade et al., 2017). The commercial pilot also offers the opportunity to explore alternatives to methane gas flaring, which poses health and environmental risks in the Niger Delta, and support the government of Nigeria's interest in displacing biomass and kerosene as primary household.

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Pilot Evaluation of the Diffusion and Use of Clean Cooking Technologies in Lagos, Nigeria (PEDUCCT):

Acknowledgements

July 2018

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This project was funded by the African Development Bank and implemented by the many colleagues listed above. Additional funding was kindly given by the Susan and Richard Kiphart Family. We are especially grateful to the local leaders and kind study participants who allowed us into their communities and homes.

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Pilot Evaluation of the Diffusion and Use of Clean Cooking Technologies in Lagos, Nigeria (PEDUCCT)

Results Brief Annex 1

Berkeley Air Monitoring Group

July 2018

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Acronyms

Project Gaia Partners Limited (PGPL)
Shell Nigeria Exploration and Production Company (SNEPCo)
Pilot Evaluation of Diffusion and Usage of Ethanol Clean Cooking Technology (PEDUCCT)
Willingness to pay (WTP)
Water boiling test (WBT)
National Center for Energy Research and Development (NCERD)
Global warming potentials (GWPs)
Fuel Analysis, Comparison & Integration Tool (FACIT)
Liquid petroleum gas (LPG)
Black carbon equivalent (BCe)
Organic carbon (OC)
Carbon monoxide (CO)
Carbon dioxide (CO_2)
Carbon dioxide equivalent (CO_2e)
Methane (CH_4)

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1. Introduction

A consortium of Nigerian private sector partners, anchored by Project Gaia Partners Limited (PGPL) and Shell Nigeria Exploration and Production Company (SNEPCo), is exploring how to promote ethanol-methanol fuel for cooking in West Africa, with a pilot project designed to roll out as a commercial start-up. An initial 2,500 CleanCook stoves and 15,000 alcohol-fuel canisters will be sold in selected neighborhoods of Lagos. The consortium also includes Forte Oil, a leading fuel sales and distribution company with over 500 retail outlets, and UNIKEM Industries Ltd,. The commercial pilot is motivated by an overarching social responsibility goal to "promote a safer cooking system in Nigeria as part of efforts to encourage access to a better source of energy" (SNEPCo, 2015).

Specifically, the pilot aims to introduce the CleanCook stove and its canister fuel system into the Nigerian market. To enable commercialization, the consortium focused on developing a commercial fuel supply chain that could safely and profitably blend methanol into the ethanol fuel and deliver it to the customer in a secure and user-friendly canister. It sought to establish a system that enabled consumers to visit designated retailers to return empty fuel canisters and purchase newly refilled replacements. Finally, it also aimed to identify and characterize the target market for the new cooking system, establish effective promotional activities, and determine the correct price for the stove and fuel.

1.1 CleanCook Stove

The two-burner stove CleanCook Stove has a stainless-steel body. It is currently produced in Durban, South Africa, and the factory cost is about 60-70 USD. The expected lifespan is 8 to 10 years.

The CleanCook stove has a unique, fiber-filled adsorptive fuel canister that retains the ethanol-methanol mix inside the canister (see Figure 1). Because ethanol and methanol have extremely low surface tension, they spread out on and cling to the surface of the fiber in the canister. This is a process of adsorption, as distinct from absorption. As it does not adhere to itself, the alcohol will not form droplets and leak out of the canister, even when the canister is put upside down, struck or shaken, or the fiber is depressed. The canister was designed to exploit this unique physical property of the simple alcohols. The mouth of the canister, which is protected by a rigid stainless-steel wire mesh, and from which the alcohol will evaporate when the mouth is open, is sealed by a sliding plate on a control arm when inside the stove. The stove operator adjusts this arm. When the plate is closed, the stove is turned off. Neither alcohol gas nor vapor evaporate from the mouth of the canister when the stove is turned off. When the plate is slid to open the mouth of the canister, alcohol fuel evaporates into the stove's combustion chimney and may be lit with a match or spark igniter. If the plate is only partially slid from the mouth of the canister, less gas is released into the combustion chimney, which will produce a smaller flame. As the alcohol vapor burns in the combustion chimney, the fuel mixes with air drawn in from the sides by natural convection, which is important for obtaining complete combustion.

The fuel canister and combustion chimney with sliding regulator plate insure safe containment of the alcohols and a fuel delivery system that will not leak or spill fuel and is not pressurized and cannot be made to pressurize. The adsorptive alcohol fuel canister is somewhat analogous to an LPG cylinder, but without resort to pressure and a closed containment vessel. When outside of the stove, the canister is closed by use of a pliable elastomer lid, which is snapped on, or, alternatively, a peel off seal. The lid or seal is removed when the canister is placed in the stove. The lid, seal and sliding plate all work on a simple principle to contain alcohol within the canister. They form a vapor barrier in the void between the fiber and the cover. When this vapor barrier is equalized in saturation or vapor pressure with the vapor in the fiber, all evaporation ceases and the alcohol remain in place. This vapor pressure is very low and is safely contained by the lid, seal or plate. If the canister were to become heated to the boiling point of alcohol and sufficient pressure were to build in the canister, the lid or seal is designed to release this pressure harmlessly, as will the sliding plate, which is on a flexible spring steel arm. When alcohol evaporates from the canister, it cools the alcohol remaining in the canister because heat is transferred from the liquid to the vapor phase of the alcohol and thus, as with any substance, thus creates a cooling effect. Thus, unless the canisters are stored in a hot area, they are unlikely to become hot enough to release vapor.

The stove has been used in several countries, leading to an accumulation of operational data that allows it to be evaluated for safety. For example, no fires or burns were observed during the 3-year ethanol randomized control trial in Nigeria (Alexander, et al., 2018). Similar results have been achieved in Ethiopia, Haiti and elsewhere. Alcohol fuels do, however, pose exposure and consumption risks, which are mitigated by prefilling the canisters for distribution to eliminate direct consumer contact with the fuel. As an additional precaution, the fuel is also denatured with denatonium benzoate (Bitrex).

Figure 1: CleanCook 2-Burner Stove (left) and model showing the adsorptive canister (right).

1.2 Ethanol-Methanol Fuel Blend

In the commercial pilot, an ethanol-methanol blend is being promoted. Methanol, one-carbon alcohol, adds both hydrogen and oxygen to ethanol, enabling it to burn more completely. Ethanol often contains distillation impurities in small amounts, 4-, 5- and 6-carbon alcohols, which can produce soot when burned, but can be mitigated by adding methanol. Methanol can also be inexpensively produced from natural gas and, if cheaper than ethanol, can be mixed with ethanol to bring the price down. Moreover, use of methanol diversifies the supply of alcohol fuel available for cooking, enabling cooking with alcohol to go to scale (Zhao et al., 2018).

Ethanol is produced from sugars and starches, while methanol is manufactured inexpensively from natural gas. Methanol may also be produced from other carbon sources, including biomass. Methanol is being used in China as a clean-burning alternative to coal and fuel oil in industrial boilers, in generator sets for power, and for commercial and institutional cooking (Zhao et al. 2018). In Nigeria, both fuels are being imported but Nigeria has the capacity to produce both alcohols in enormous quantity domestically (Ohimain., 2012). A 5,000 tons per day (6.35 million liters per day) methanol plant has been operating in Equatorial Guinea since 2001 (Atlantic Methanol Production Company, 2018).

2. Study Design and Methods

2.1 Study overview and objectives

In order to support the commercial scale-up of the CleanCook stove and ethanol-methanol fuel blend, the assessment, entitled Pilot Evaluation of Diffusion and Usage of Ethanol Clean Cooking

Technology (PEDUCCT), was launched in 2017. PEDUCCT aims to collect the data necessary to explore and improve the potential for successful ethanol technology scale-up including establishment of willingness to pay (WTP). It is an early-stage observational study that is not a substitute for a future full program evaluation. PEDUCCT had four primary components, two of which were designed to occur prior to the commercial launch of the CleanCook stove in Lagos, Nigeria, and two immediately following it. Prior to the launch, an experimental sample of 30 households was recruited for an in-home assessment of consumer preferences, cooking patterns, and WTP for the CleanCook and its fuel canisters. Laboratory testing of baseline and project stoves was conducted by the National Center for Energy Research and Development (NCERD), University of Nigeria, Nsukka in Nigeria to estimate emission factors/rates and fuel efficiency using local kerosene and charcoal as well as the particular commercial pilot ethanol-methanol fuel blend. Following the launch of the commercial pilot, the PEDUCCT team planned to conduct a street-intercept rapid survey exploring the impact of commercial pilot's promotional materials within the target population. Finally, the research team intended to recruit up to 30 additional households who were early purchasers of the CleanCook fuel system to conduct an in-home assessment similar to the one conducted in the experimental sample. Together these four components were expected to deliver rich insights to both improve the outcomes of the commercial pilot and describe its potential role in Nigeria's energy future.

PEDUCCT had the following six specific research aims:

1. Assess the emissions performance of the CleanCook stove relative to current baseline technologies and with respect to international climate and health benchmarks;

2. Assess consumer preferences, particularly comparing their satisfaction with the CleanCook stove and blended ethanol and methanol canisterized fuel compared to charcoal, kerosene, and LPG;

3. Measure consumer adoption of the CleanCook stove, investigate usage patterns including use alongside other cooking technologies and fuels ("stacking"), evaluate correct and safe operation, and identify facilitators of and barriers to sustained widespread adoption;

4. Identify successful components within the project promotional activities by estimating reach and ability to move the target populations along the consumer journey (awareness, familiarity, initial consideration, purchase, loyalty);

5. Provide an estimate of the target markets' willingness to pay for the CleanCook stove and fuel after an extended period of use; and

6. Estimate potential national-level impacts on climate with well-established modeling approaches.

IRB approval was granted before the study and informed consent was obtained for all participants.

2.2 Study timelines and limitations

The data collection activities were launched in September 2017 and concluded in March 2018. Several factors meant that the PEDUCCT study did not run according to the anticipated timeline. Firstly, the field activities were originally scheduled to begin in June 2017 but were postponed due to a delay in the administration of the grant and difficulties obtaining Institutional Review Board approval. Secondly, the planned market launch of the Cleancook stove, which was expected to occur midway through the study, was significantly delayed. This interruption was due to challenges in the permitting of the commercial-grade facility to house fuel storage tanks, blending equipment, and the canister refilling station, which were circumstances well beyond the project team's control. These factors impacted on the timeline as well as which components of the study could be implemented. Additionally, the study design was sometimes compromised by conflicting priorities created by a situation where the implementing team were also the ones collecting the study data. The original study design is presented below with deviations from the plan noted after each section.

2.3 Fuel Accessibility for Study Households

An important element of the PEDUCCT study was to assess the participants' perceptions of the convenience of ethanol-methanol fuel. The full commercial fuel supply system required the construction of some industrial scale tanks, which took longer to permit and erect than originally anticipated. Therefore, a limited short-term system that mimicked the envisioned commercial system was installed to safely and efficiently fill the fuel canisters for the households in the experimental study arm. Study participants could take their empty fuel canisters to a Forte Oil filling station within two kilometers of their homes and purchased newly refilled replacements.

Over the course of the experimental study, the fuel suppliers repeatedly adjusted the composition and packaging details of the fuel in response to the participant's likes and dislikes, even though these adjustments were not included in the study methodology. (Ideally in an impact assessment, all exogenous factors would be held constant during the full study in order to isolate and understand the household behavior over time.) In response to participant complaints about the fuel smell, the suppliers changed the fuel blend and provided plastic shrink-wrapping around each canister. In response to concerns that the fuel runs out too quickly, the volume of ethanol-methanol fuel per canister was increased from 1 liter to 1.2 liter with no change in cost. All changes were documented and tracked closely.

In the final month of data collection in the experimental sample, some participants reported a glitch in the supply of ethanol/methanol fuel canisters at one of the Forte Oil filing stations. Although the canisters were for sale at this location, they could only be sold by a particular sales agent who was frequently away. This caused an artificial barrier to purchase and may have impacted cookstove usage for some households.

2.4 Household Recruitment for In-Home Assessments

The study was conducted within the catchment areas of three Forte Oil gas stations located within three local government areas of urban Lagos, which represent the target customer segments of the commercial pilot: Mushin (low income), Shomolu (low-medium income) and Akoka (upper-middle income) (Figure 2).

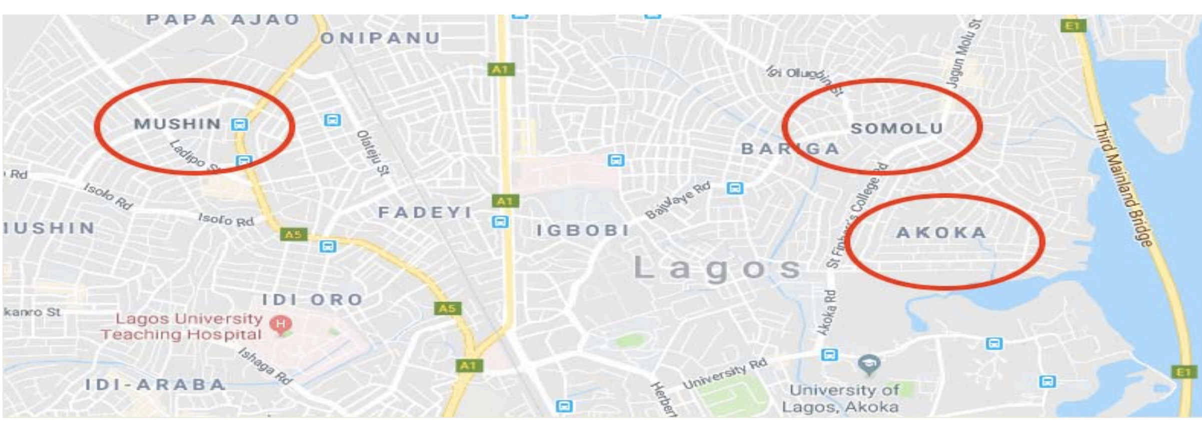

Figure 2: The three selected study sites, representing the target customer segments of the

2.4.1 Experimental Sample

An experimental sample of 30 households was randomly selected, with ten from each of the three catchment areas. All the households in the experimental sample were given a CleanCook stove free of charge for the duration of the study. At the end of the study, they were given an option to purchase the stove for a reduced price during the WTP exercise. Participants also received two fuel canisters filled with the blended ethanol-methanol at the study start, with the expectation that they were responsible for depositing empty canisters and purchasing refilled ones at the local Forte Oil filling station. Households were located within a two-kilometer radius of a Forte Oil filling station so that participants had access to fuel throughout the study period.

The following criteria were used to select study participants:

- Used charcoal and/or kerosene as their primary cooking fuel;
- Had minimal use of LPG;
- Unlikely to migrate in the next 3-5 months;
- Did not engage in commercial cooking;
- Household size was within the average range for Lagos (2-7 people);
- Did not have a maid; and
- Person who made decisions about cooking and fuels was between the ages of 23 and 50.

There were some irregularities in the way the households were recruited, with some fieldworkers not following the standard study protocol. The resulting sample had clumps of households located relatively close together, creating the concern that inter-subject communication could create changes in behavior or biases. Further, upon reviewing the baseline data, it was discovered that 11 households recruited into the experimental sample did not meet the selection criteria due to excessive use of LPG at baseline. In order to achieve the study aims, it was important that the participating households relied at baseline on more polluting and health-damaging fuels than LPG. However, it was challenging for the field team to identify upper-middle income homes that did not rely entirely or nearly entirely on LPG. After exploring multiple options, the team decided to leave the CleanCook in these 11 homes so as not to bias them against the market launch of the CleanCook, but to cease to collect or analyze data from them and remove their baseline data from the analysis. 11 replacement homes with a conforming fuel profile were subsequently selected and inducted into the study one month after the initial recruitment.

2.4.2 Willingness to Pay Sample

The households invited to take part in the WTP exercise at the end of the experimental arm of the study were made up of all 30 experimental homes plus the 11 households that had been removed at baseline due to excessive LPG consumption. The WTP is the only part of the experimental arm study that included data collected from these 11 HH.

2.4.3 Purchaser Sample

For the second study arm, up to 35 early purchasers were to have been recruited from the point of sale for the CleanCook stoves during the first three months of the commercial sales. Customers showing interest in the CleanCook at any of the participating Forte Oil filling stations would have been approached and invited to participate in the in-home assessment of early adopters. In return for their participation, these early purchasers would have been offered the stove at the lowest price point.

The evaluation of early purchasers could not be implemented as part of PEDUCCT as there were no commercial sales of the CleanCook stove during the project period due to significant unforeseen delays beyond the study team's control. Instead a purchaser group was created from the participants who purchased the Cleancook during the WTP exercise and consented to post-purchase monitoring. This group was joined by additional households who purchased the Cleancook after the WTP exercise was over, following some non-standardized unplanned communication with the implementer, Project Gaia. The final sample of 18 post purchase households were monitored for an additional month to see if their cooking patterns and perceptions of the Cleancook stove changed after they spent their own resources to acquire the ethanol-methanol cooking system.

2.5 Data Collection Process

In the 30 experimental households, data was collected over a 5-6 month period. The stove use monitoring began at baseline and continue for the full monitoring period. During this time a baseline survey, and three follow up surveys were conducted. Intermittent visits were also made to the homes to download the data from the stove use monitors. 27 households were available for and completed baseline and end line surveys plus at least one of the two interim surveys. Two of the three HH that dropped out were removed from the study because they relocated beyond the boundaries of the gas stations selling the CleanCook fuel canisters.

The final follow-up monitoring was conducted at the same time in all the study homes, regardless of when they enrolled in the study, even though this resulted in a variation in the overall monitoring duration between the participants recruited in the original campaign and those enlisted as replacements for the homes with non-conforming fuel use patterns. This schedule allowed the WTP negotiation to be carried out at the same time in all experimental group households (original and replacement), minimizing the chance of any of the households discussing the outcome of the WTP before the exercise was complete and thereby potentially threatening the integrity of the results.

After the WTP negotiation concluded, an additional month of stove use monitoring and one additional follow-up survey were conducted within the purchaser sample (see 2.4.3) in order to see if/how their usage patterns and perceptions varied from those documented previously once they committed their own resources to the CleanCook and following the adjustments to the fuel mix and canister packaging.

2.6 Measuring Stove Use and Adoption

A combination of methods and indicators were used to gather information on the extent to which households adopted and correctly used the CleanCook, and the manner in which they integrated it into their kitchen activity patterns over the study period. The approach seeks to validate self-reported stove use data with objective stove use monitoring. Given the PEDUCCT timeline and resource constraints, it was not feasible to follow a subgroup long enough to measure sustained adoption rates. Our assessment, however, includes stove use measurements up to five months post-acquisition, which provides a good indication of acceptance beyond the initial 'honeymoon' period.

Stove use monitoring (SUMS) was conducted using iButtons (model DS1922T, Maxim, USA), which measure temperature as a proxy for the number and duration of usage events. SUMS iButtons were placed on the CleanCook stove and all stoves/cooking devices that had been used in the home within the prior month. When aggregated, these data provide an objective assessment of cooking patterns, including the presence and nature of any stove stacking

Although stove use monitoring was planned to start as soon as a household was recruited into the study, not all of the stove-use monitors were initially installed in all homes due to concern that these instruments could prove unsettling to the participants if they were mistaken for listening devices or small cameras. Therefore, the field team opted to wait until the second visit to install them, when a more trustful relationship between the fieldworker and the cook had been established.

Monthly data on the frequency of canister exchanges was also collected by location to provide information on energy cost per household and the number of canisters that will be needed in circulation to supply the 2,500 homes in the commercial pilot.

2.7 Cookstove/Fuel Performance Testing and Climate Impacts

Cookstove performance testing for the commonly available kerosene and CleanCook ethanol/methanol stoves was conducted for this project by the National Center for Energy Research and Development (NCERD), University of Nigeria, Nsukka, using the Water Boiling Test (WBT Technical Committee, 2014). The tests were carried out using a local kerosene stove (Original Wheel) and the CleanCook stove and ethanol/methanol fuel supplied by Project Gaia. Potential for climate impacts were estimated by combining stove usage estimates with emissions performance and global warming potentials (GWPs), as well as factoring in emissions associated with the production and distribution of the various fuels. LPG performance was based on data from Shen et al. 2018. For more information on the methods uses for emissions testing please see Annexes 2 and 3.

2.8 Household Surveys and Kitchen Observations

Potential opportunities and barriers to scale were assessed with surveys focusing on participants' acceptance and preferences of the CleanCook stove, the canisterized fuel system, and the ethanol/methanol blended fuel. Questions also collected data to identify drivers and barriers to proper and consistent stove and fuel use, as well as to understand household stove use patterns, including any 'adoption niche' (31) that has occurred. Each follow-up survey also collected observational data on the configuration of any cooking underway at the time of the visit and the condition of the household's kitchen, cookstove, and fuels.

Surveys were written in English and translated by an independent translator into Nigerian Pidgin before being piloted. The survey was administered in either Pidgin or English according to the participants preference. A variance from study protocol occurred at the end of the study, when the final follow-up survey and the willingness to pay script were only administered in English. As only a handful of households requested that the study be conducted in Pidgin, the enumerators decided to translate the questions and responses in real time.

2.9 Willingness to Pay Negotiation

In March 2018, at the end of the in-home assessment, the PEDUCCT team conducted a WTP negotiation, based on methodologies developed and successfully piloted by USAID's WASHplus program (32). A standard bargaining script was adapted to local cultural practices, and the enumerators received in-person and remoted training on performing this activity in the experimental sample homes. The participants were given the opportunity to purchase the study stoves at market rates in a bargaining exercise designed to mimic as much as possible the sales and financing techniques to be used in the commercial pilot.

At the beginning of the negotiation, the surveyor explained that the stove was 'worth' ₦24,000[1] (the approximate factory price), but by participating in the study, they could purchase it for a discounted ₦19,000. Participants who did not opt to purchase at this price were then asked to name a price they would be willing to pay for the stove. For the purposes of the WTP exercise, a minimum bid of ₦15,000 was established but not disclosed to the participants. If they offered over ₦15,000, their bid was accepted. If their bid was less than ₦15,000, they were asked to make another offer. A total of three offers were permitted. This minimum bid was set just above the lowest price that Project Gaia anticipates they can offer customers, taking into account all possible subsidies, including carbon financing and profits from fuel sales.

[1] At the time the negotiation was conducted, 1 Naira = $.0028 USD

Once the WTP exercise had been completed in all homes, those participants with successful bids were informed that they would only need to pay ₦14,500, regardless of the price they had negotiated. Participants who “purchased” a stove during the negotiation were given a week to assemble the payment and/or discuss with other family members and renege if needed. This money was collected one week after the WTP exercise, at which point the participants took ownership of the stove. The CleanCook stoves were also collected from the non-purchaser households at this point.

Some HH that declined to purchase the CleanCook during the WTP exercise made contact with the Project Gaia team or were contacted by the Project Gia team some days later. The conversations during these calls lead to further purchases of the stove. As this does not follow the WTP protocol, these purchasers were not included in the WTP data. These households were however invited to be part of the purchaser sample.

2.10 Identifying Effective Promotional Activities: Approach and Methods

Rapid street-intercept surveys were to be carried out in each of the three study locations. The survey was to be used to measure recall and recognition of specific promotional messages and collateral marketing pieces disseminated to the public through various marketing channels. As the promotional activities may also have created a community dialogue, we would have asked about diffusion effects, such as ‘word of mouth’. Accurate knowledge would have been pre-defined, so that responses to knowledge items could be dichotomized into accurate or inaccurate knowledge. Finally, we intended to explore with any participants who have been exposed to the CleanCook campaign where they were on the consumer journey: awareness, consideration, or purchase and what barriers prevented them from progressing on that path.

Due to the delay in the commercial launch of the Cleancook, no promotional activities occurred during the timeframe of the study, and we were thus unable to conduct this component of the evaluation.

3. Results

3.1 Stove Use Monitoring

Analysis of the iButton data showed that the kerosene stoves (n=28) had the highest mean cooking events per day (1.26, SD=0.88). The stoves used as secondary cooking devices, the CleanCook (n=28) and the LPG (n=5) stoves were used on average 0.72 (SD=0.58) and 0.53 (SD=0.39) times per day, respectively (Figure 3).

The kerosene stoves had the highest mean minutes of use per day (93 minutes, SD=73) followed by the CleanCook (26 minutes, SD=20) and then the LPG stoves (19 minutes, SD=16). It is important to note that the LPG stove sample size is very small, meaning the results should be interpreted with caution (Figure 4). These results are similar to those found in the final follow-up survey in which the majority of participants (38%) reported to use their CleanCook stove 7 days per week and the majority of those participants (56%) reported cooking 2 meals per day.

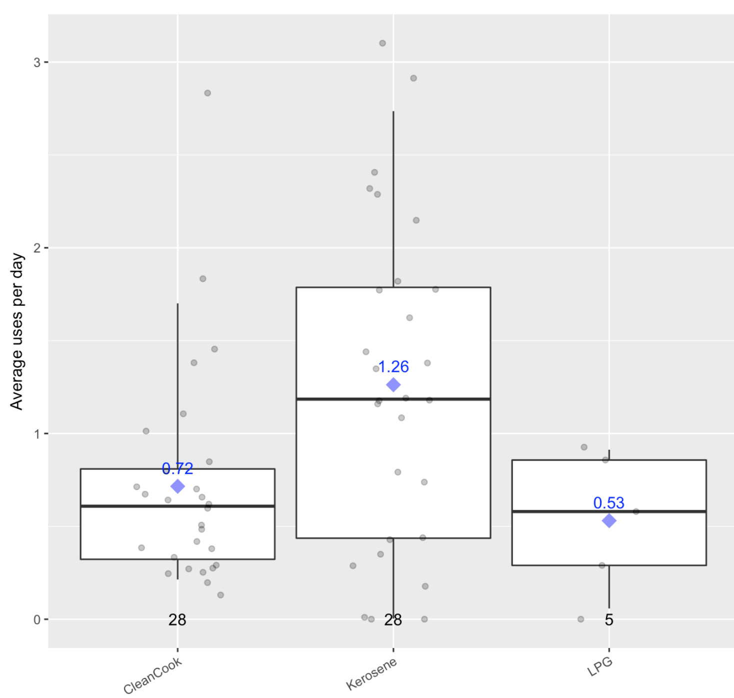

Figure 3: Box plot showing average events per day for each stove type by location. Medians are the central line, box ends represent the 25th and 75th percentiles, whiskers the 5th and 95th percentiles. Means are represented by the blue dot. The black number below each box shows the number of households contributing data.

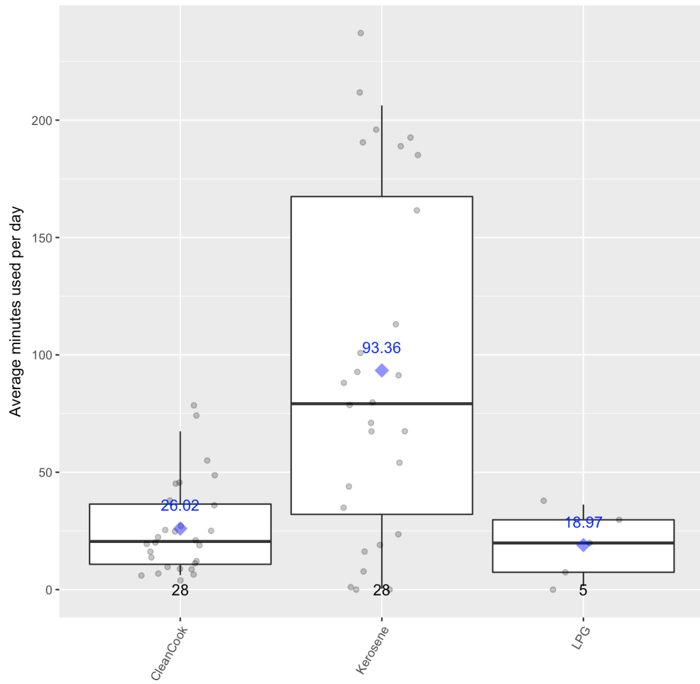

Figure 4: Box plot showing average cooking time (min) per day for each stove type. Medians are the central line, box ends represent the 25th and 75th percentiles, whiskers the 5th and 95th percentiles. Means are represented by the blue dot. The black number below each box shows the number of households contributing data.

Analysis of iButton data by location showed that use of the CleanCook stove was similar in all study locations. Homes in Akoka (n=9) and Shomulu (n=10) were more likely to use the CleanCook stove (0.75 average events per day (SD=0.88) and an average of 24 minutes per day (SD=24) and 0.71 average events per day (SD=0.46) and an average of 25 minutes per day (SD=20, respectively). Homes in Mushin (n=9) also used their CleanCook stove, but likely less frequently with 0.69 average events per day (SD=0.36) and an average of 29 minutes per day (SD=17). The kerosene stove appeared to be the primary stove in every location in terms of minutes per day and events per day in every location but was sued the most heavily in Mushin (1.71 average events per day (SD=0.80) and an average of 126 minutes per day (SD=72) compared to Akoka and Shomulu (0.96 average events per day (SD=0.82) and an average of 73 minutes per day (SD=72) and 1.12 average events per day (SD=0.93) and an average of 83 minutes per day (SD=74), respectively) (Figure 5 and Figure 6).

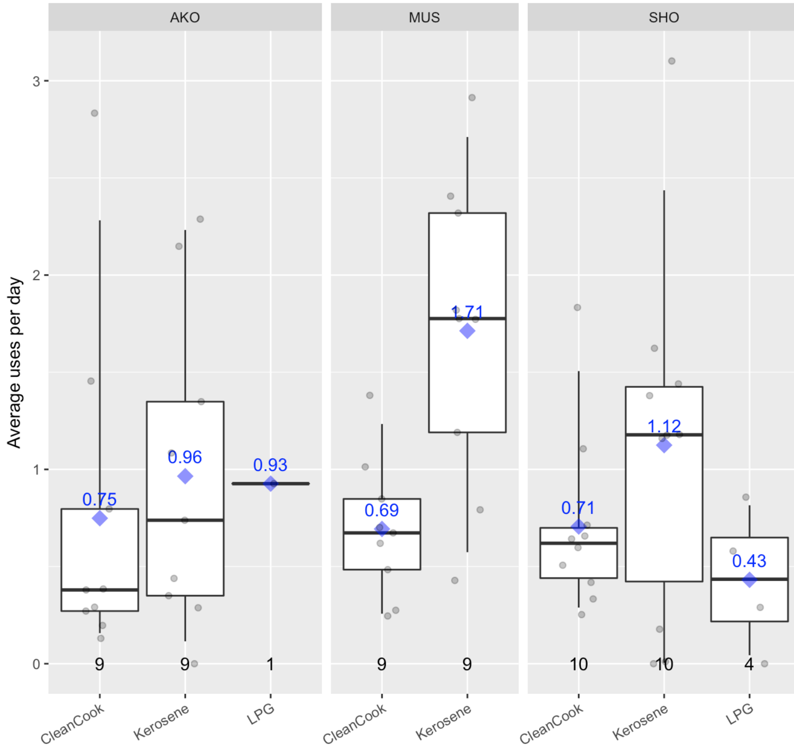

Figure 5: Box plot showing average cooking events per day for each stove type by location. Medians are the central line, box ends represent the 25th and 75th percentiles, whiskers the 5th and 95th percentiles. Means are represented by the blue dot. The black number below each box shows the number of households contributing data.

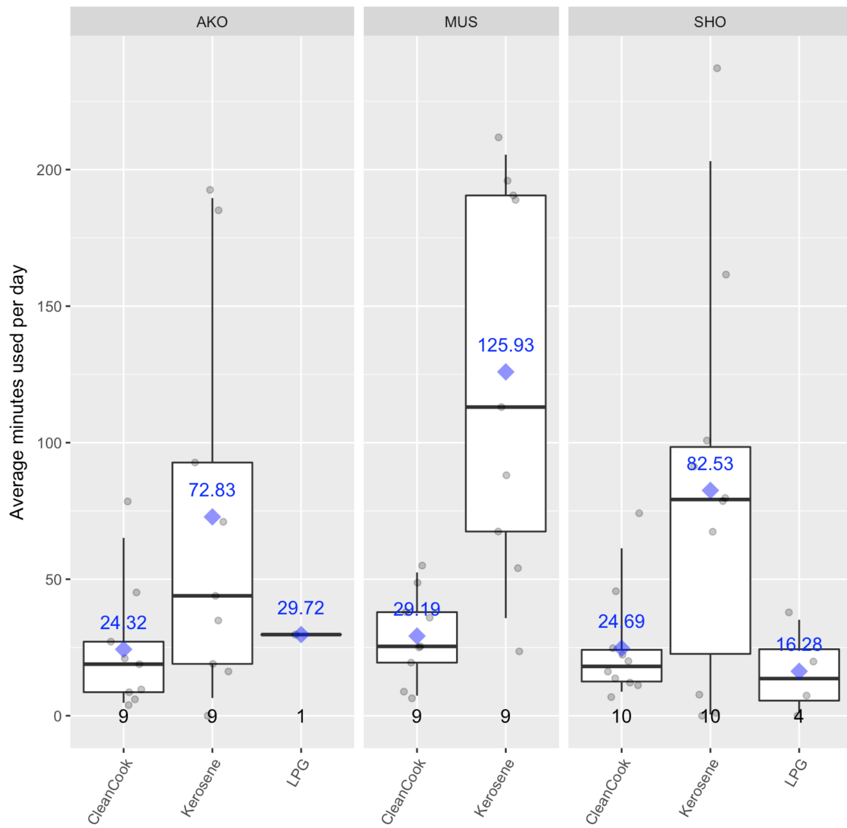

Figure 6: Box plot showing average cooking time (min) per day for each stove type by location. Medians are the central line, box ends represent the 25th and 75th percentiles, whiskers the 5th and 95th percentiles. Means are represented by the blue dot. The black number below each box shows the number of households contributing data.

CleanCook usage data over the course of the study shows that adoption was consistant but incomplete, as there was stacking with kerosene stoves[2]. Use of the CleanCook was highest at dissemination, followed by a steep drop in (likely as the intital excitement waned) and then leveled out for the duration of the study (Figure 7).

[2] There was also some stacking with LPG stoves on a much smaller scale.

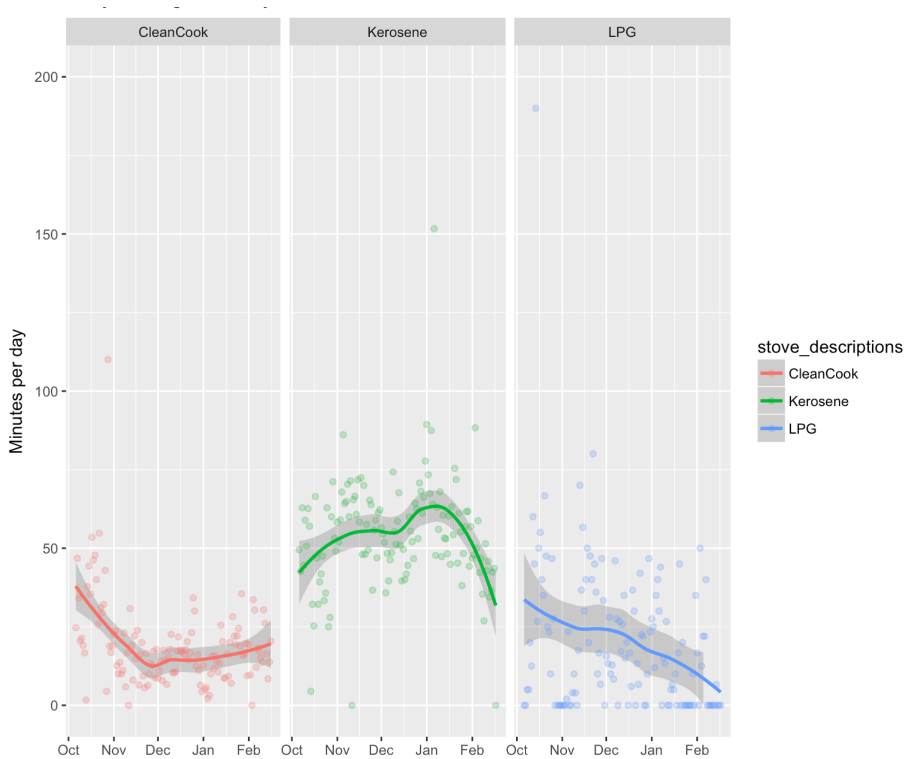

Figure 7. Scatterplots for all stove types (CleanCook left, Kerosene middle, and LPG right) showing mean minutes per day over the course of the study (from October 2017 to February 2018).

Homes who purchased the CleanCook after the study had finished (n=10[3]) showed a more intensive pre-purchase CleanCook usage pattern than those that decided not to buy (0.87 (SD=0.49) events and 31 minutes (SD=20.1) of cooking per day verses 0.63 (SD=0.63) events and 23 minutes (SD=19.9).

3.2 Climate Impacts

Potential for climate impacts were estimated by combining stove usage estimates with emissions performance and global warming potentials (GWPs), as well as factoring in emissions associated with the production and distribution of the various fuels. Stove performance for the kerosene and CleanCook ethanol/methanol stoves was primarily measured for this project by the National Center for Energy Research and Development (NCERD), University of Nigeria, Nsukka, using the Water Boiling Test (WBT Technical Committee, 2014). Those tests were

[3] These homes had taken part in the full experimental arm of the study and had either purchased as part of the willingness to pay (WTP) exercise or after the study had finished.

carried out using a local kerosene stove (Original Wheel) and the CleanCook stove and ethanol/methanol fuel supplied by Project Gaia (for the full emissions testing report, please refer to Annex 2 and 3). LPG performance was based on data from Shen et al. 2018. Additional performance estimates not directly measured for this study (e.g. CH_4 emissions) were supplemented with studies referenced below (Shen et al., 2018) and (Climate Solutions Consulting, 2016, NCERD, 2018b; USEPA, n.d.).

Table 1 shows the fuel-based emission factors, which were applied to the amount of fuel estimated to be used before and after introduction of the CleanCook stove. The amount of fuel used was estimated by multiplying the amount of time each stove was used by the firepower of the respective stove, and then converting the total energy used to mass via the energy density of the fuel (see Table 2). The total emissions of CO_2, CH_4, and CO were then multiplied by their respective 100-year GWPs[4] to estimate CO_2-equivalent (CO_2e) emissions (IPCC, 2013). Black carbon equivalent (BCe) was estimated by using the BCe conversion factors[5] from the Gold Standard methodology for quantifying short-lived climate pollutant emissions from cookstoves (Gold Standard, 2015). Finally, the CO_2e and BCe associated with the production, processing, and distribution of the different fuels (simplified to "production" from here on), were calculated based on the estimates provided by the Fuel Analysis, Comparison & Integration Tool (FACIT)[6]. The FACIT database included Nigeria-based production CO_2e and BCe estimates for LPG and ethanol, but no production CO_2e or BCE estimates were available for kerosene in Africa, and thus those production emission factors were sourced from FACIT's data on India.

Table 1: Emission factors used for modeling CO_2e and BCe impact.

	CO_2 (g/kg)		**CO (g/kg)**		**CH_4 (g/kg)**		**BC (g/kg)**		**OC (g/kg)**		**Production CO_2e (g/kg)**	**Production BCe (g/kg)**
	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD		
Kerosene	3054	145	14	11	0.29	0.16	0.47	0.47	0.74	0.74	144	0.074
LPG	3302	144	19	15	0.15	0.25	0.01	0.01	0.03	0.03	2733	0.180
Ethanol/ methanol	346	17	10	3	0.03	0.02	0.07	0.10	0.19	0.26	175	-0.016

Sources: Kerosene stove emissions performance: (Climate Solutions Consulting, 2016; NCERD, 2018a; Smith et al., 2000)
LPG stove emissions performance: (Shen et al., 2018)
Ethanol emissions performance: (Climate Solutions Consulting, 2016; NCERD, 2018b; USEPA, n.d.)

[4] 100 year GWPs: CO_2 = 1; CH_4 = 28, CO = 3.
[5] BCe conversion factors: BC = 1; OC = -0.1.
[6] http://cleancookstoves.org/technology-and-fuels/facit/#

Production factors: http://cleancookstoves.org/technology-and-fuels/facit/#

Table 2: Stove performance and energy content for the different fuel/stove technologies.

	Firepower (W)	Thermal Efficiency (%)	Lower heating value (MJ/kg)
Kerosene	900	42%	39.7
LPG	1200	59%	44.7
Ethanol/ methanol	1100	49%	23.6

Sources: (NCERD, 2018b, 2018a; Shen et al., 2018; WBT Technical Committee, 2014)

CO_2e emissions per home per day estimates are shown in Figure 8 and Table 3. The potential CO_2e reductions are relatively modest (16%) for the measured intervention scenario. These modest reductions are primarily a result of the limited displacement of the kerosene stoves in homes as the CleanCook only accounted for approximately 20% of the cooking. Thus, the graph clearly shows that kerosene emissions (both from the stove and production) are the dominant source of CO_2e in the intervention scenario. Given that this pilot study was only a step towards scaling ethanol towards a more extensive market change in household fuel consumption, we also calculated the potential impact assuming exclusive use of the ethanol/methanol fuel. Under this more idealized scenario, the impact is much greater, reducing CO_2e by 76%.

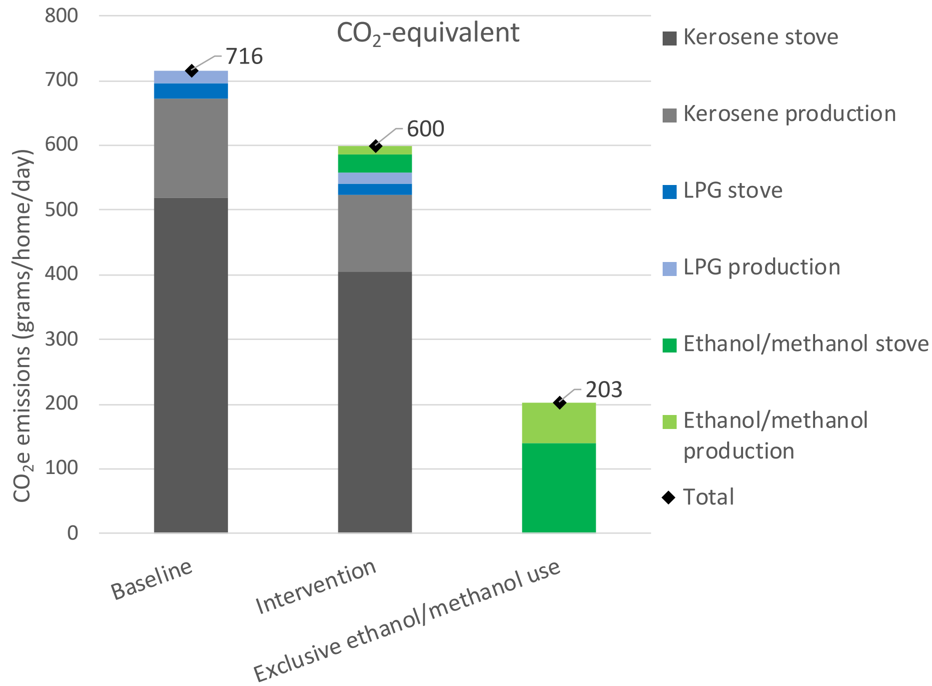

Figure 8: CO_2e emissions associated with the different fuels and sources estimated for the study baseline, and intervention, and an idealized 100% ethanol/methanol use scenario.

Table 3: CO_2e emissions associated with the different fuels and sources estimated for the study baseline, and intervention, and an idealized 100% ethanol/methanol use scenario.

	Baseline	**Intervention**	**Exclusive ethanol/ methanol use**
Kerosene stove	520	404	0
Kerosene production	153	119	0
LPG stove	24	19	0
LPG production	19	15	0
Ethanol/methanol stove	0	29	139
Ethanol/methanol production	0	13	64
Total	716	600	203
Percent reduction		**16%**	**72%**

BCe emissions per home per day estimates are shown in Figure 9 and Table 4. These results largely mirror those for CO_2e, suggesting that the short-term climate benefits are marginal given the pilot study scenario (18% reduction in BCe), for which kerosene stove emissions the dominant source of BCe. Assuming complete displacement with the ethanol/methanol blend, however, again shows that there is substantial potential for benefits as the BCe would be estimated to be reduced by approximately 80%.

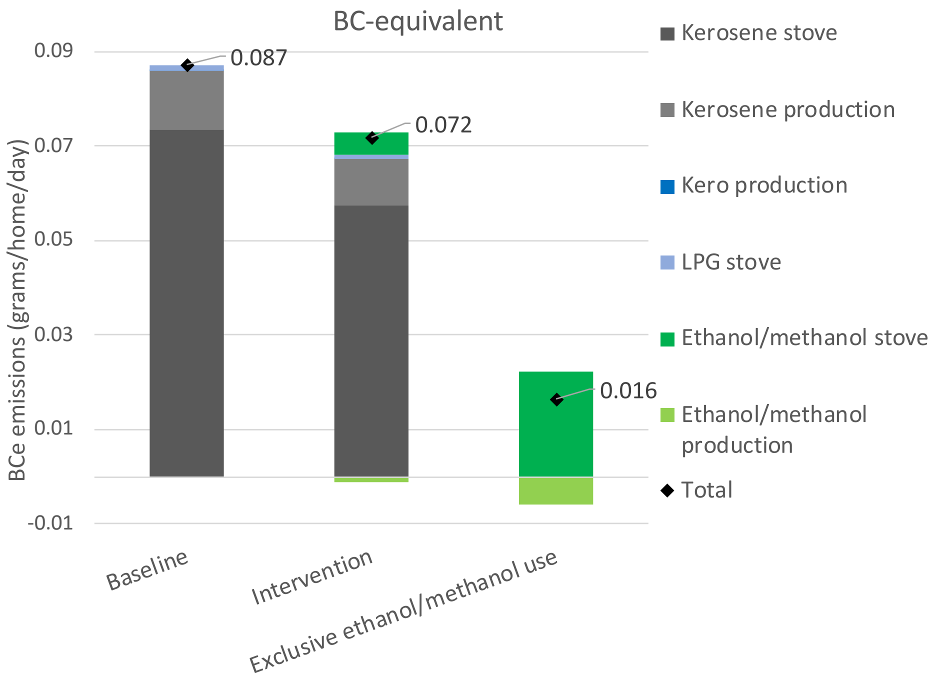

Figure 9: BCe emissions associated with the different fuels and sources estimated for the study baseline, and intervention, and an idealized 100% ethanol/methanol use scenario.

Table 4: BCe emissions associated with the different fuels and sources estimated for the study baseline, and intervention, and an idealized 100% ethanol/methanol use scenario.

	Baseline	**Intervention**	**Exclusive ethanol/ methanol use**
Kerosene stove	0.0736	0.0577	0
Kerosene production	0.0124	0.0096	0
LPG stove	0.0000	0.0000	0
LPG production	0.0013	0.0010	0
Ethanol/methanol stove	0.0000	0.0047	0.0222
Ethanol/methanol production	0.0000	-0.0012	-0.0058
Total	0.0872	0.0718	0.0164
Percent reduction		**18%**	**81%**

Overall, this analysis shows that substantive climate-relevant benefits are possible as ethanol burns relatively cleanly and is produced from renewable fuels. Complete displacement of kerosene and/or LPG with the ethanol/methanol blend could reduce shorter and longer-term climate emissions by three fourths or more, suggesting that efforts to more fully transition households towards this fuel could yield large climate benefits.

3.3 Survey Results

3.3.1 Baseline

3.3.1.1 Demographics of the study sample

A total of 30 households were recruited to the study during September/October 2018. All main participants were women between the ages of 23-50 (See Table 5).

Table 5: Age groups of main participants.

Age group of main participant (n=30)	% (n)
23-25	3% (1)
26-30	17% (5)
31-35	13% (4)
36-40	20% (6)
41-45	17% (5)
46-50	30% (9)

Average household size was 5.1 (SD 1.5), which is slightly higher than the 2016 average for Nigeria urban households, which stands at 4.9[7]. The average baseline household crowding index, defined as the total number of people per household, excluding newborn infants, divided by the total number of rooms was 2.68 (SD 1.93.) 23% (n=7) of participants owned their homes.

All heads of households were male, excepted in three cases where the participant was widowed. Table 6 below shows education levels and occupations for both the primary cooks and the heads of households.

Table 6: Education levels and occupations for both primary cooks and heads of households during the baseline survey.

Education	Primary Cook (n=30) % (n)	Head of Household (n=30) % (n)
Completed secondary school	40% (12)	23% (7)
Completed post-secondary (certificate/diploma)	7% (2)	23% (7)
Completed university/higher national diploma	33% (10)	43% (13)
Occupation	Primary Cook	Head of Household

[7] http://www.nigerianstat.gov.ng/nada/index.php/catalog/51

	% (n)	% (n)
Full time Homemaker	10% (3)	0% (0)
Professional/Technical/Managerial	27% (8)	23% (7)
Sales and Services	40% (12)	37% (11)
Skilled Manual	20% (6)	30% (8)
Other	3% (1)	14% (4)

3.3.1.2 Cooking Patterns at Baseline

As per inclusion criteria 93% (n=28) of the participants used kerosene stoves as their primary cooking device. 63% (n=19) own just one of their primary cookstove type, and 11 households own two of that type. 27% (n=8) use another stove type in addition to their primary stove. 4 of these households use a secondary LPG stove, 2 of these households use a secondary kerosene stove, and 1 each use a metal charcoal stove and a ceramic charcoal stove.

Of the 8 cooks who regularly use more than one stove, half of them (n=4) use the stoves simultaneously. The main reason for this is to cook more quickly when in a rush or to make more than one dish or drink at the same time.

Table 7 below shows location of cooking when the baseline was carried out.

Table 7: Primary cooking location.

Primary Cooking Location	% (n)
Inside main house, in main living space	3% (1)
Inside main house, in separate kitchen area	50% (15)
Inside building separate from main house	30% (9)
On veranda or porch	17% (5)

3.3.1.3 Perceptions of Baseline Stoves

The participants were asked what features if any they liked and disliked most about their primary stove. Figure 10 and Figure 11 below shows the responses given, multiple responses were allowed.

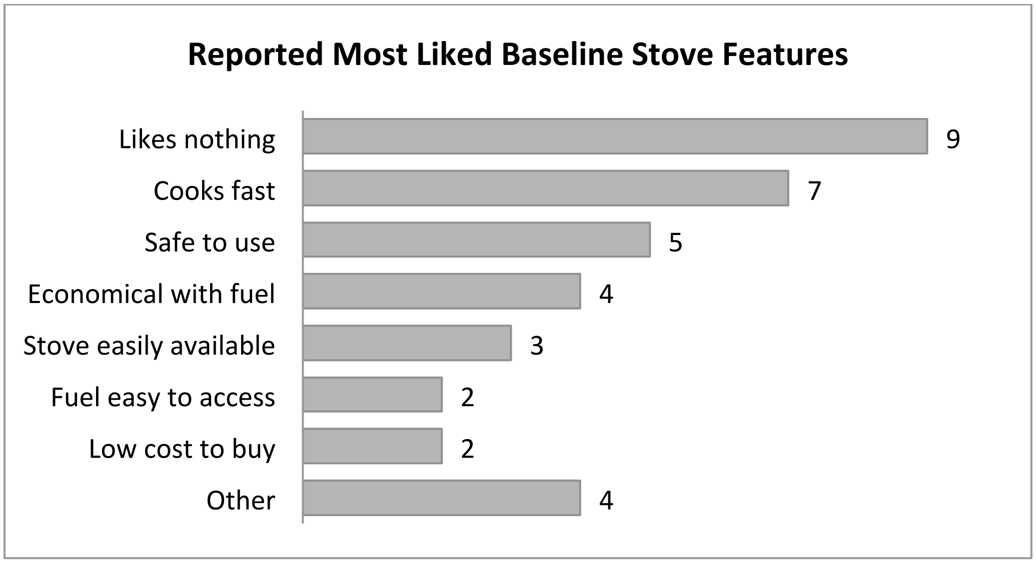

Figure 10: Features primary cooks reported liking most about their baseline stoves.

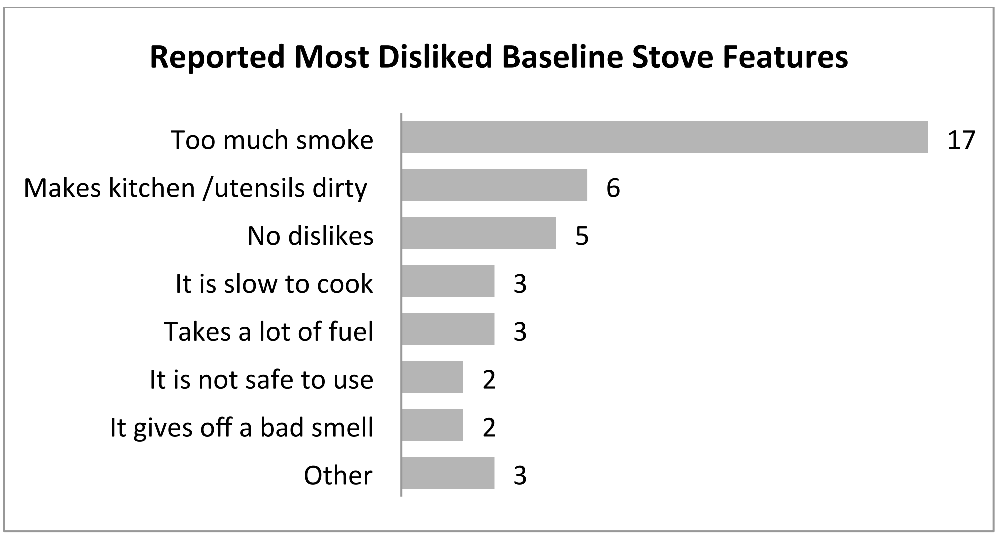

Figure 11: Features primary cooks reported disliking most about their baseline stoves. Multiple answers allowed.

Figure 12 below shows the key drivers for choosing kerosene fuel (n=28). The reasons given for choosing LPG was because it 'burns hot' and familiarity with the fuel (n=2).

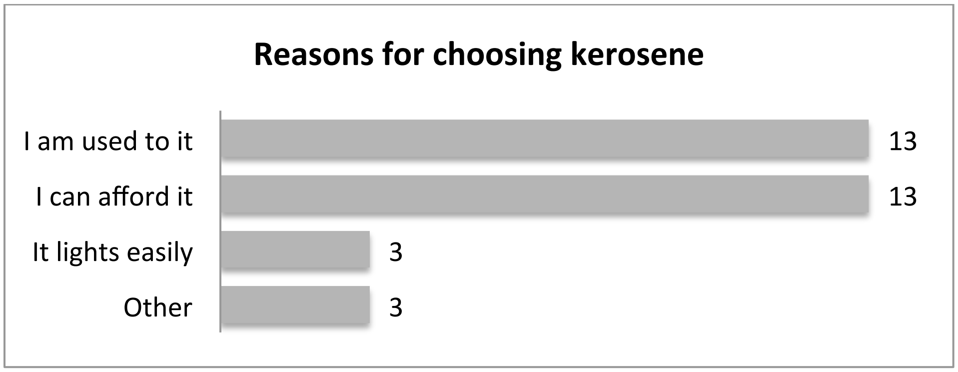

Figure 12: Reasons primary cooks reported for choosing kerosene fuel.

Participants were asked to estimate their weekly fuel expenditure. Table 8 below shows mean amounts spent on various fuels for each study location.

Table 8: Average (mean) amounts spent on each fuel type per week, by study location.

Fuel Type	MUSHIN			SHOMULU			AKOKA		
	Mean (Naira)	SD	n	Mean (Naira)	SD	n	Mean (Naira)	SD	n
Charcoal	N/A	N/A	0	N/A	N/A	0	300	141	2
Kerosene	895	370	10	800	362	10	950	363	10
LPG	N/A	N/A	0	625	312	4	1000	N/A	1

43% (n=13) thought that their baseline cookstoves caused problems for them or their families. 86% (n=12) of these believed that their kerosene stove caused problems, and the two participants with LPG stoves said that their LPG stoves caused health problems. Figure 13 shows the perceived kerosene stove problems. One LPG stove user said that her stove could cause a house fire.

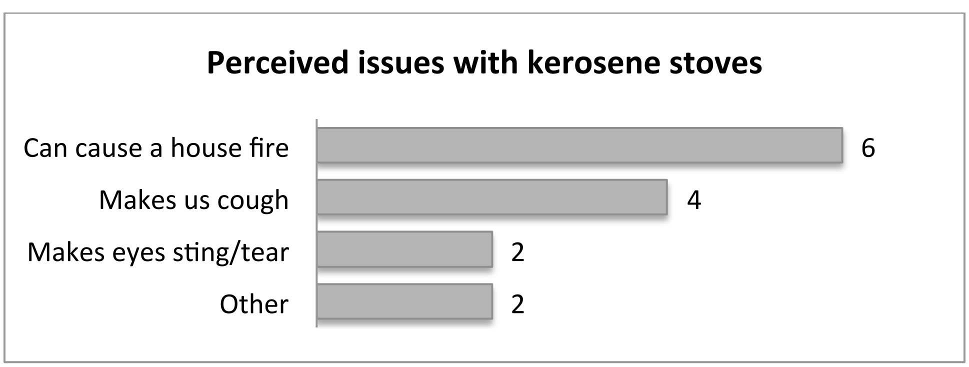

Figure 13: Reported issues that participants perceived their baseline kerosene cookstoves could be causing.

3.3.1.4 Stove Purchase Patterns

To understand the drivers and barriers to stove purchase in the study community the participants were asked about their most recent stove purchase. Figure 14 shows the stove features that drove stove purchase decisions, Figure 15 shows who the participant made the purchasing decision with, and Figure 16 shows who may have influenced the participants decision-making process.

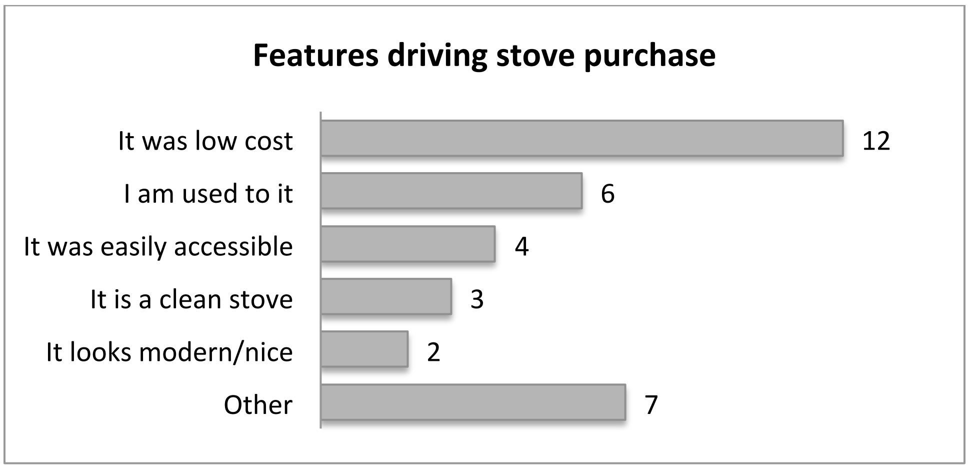

Figure 14: Stove features reported to drive the primary cook's stove purchase decisions. Multiple answers allowed.

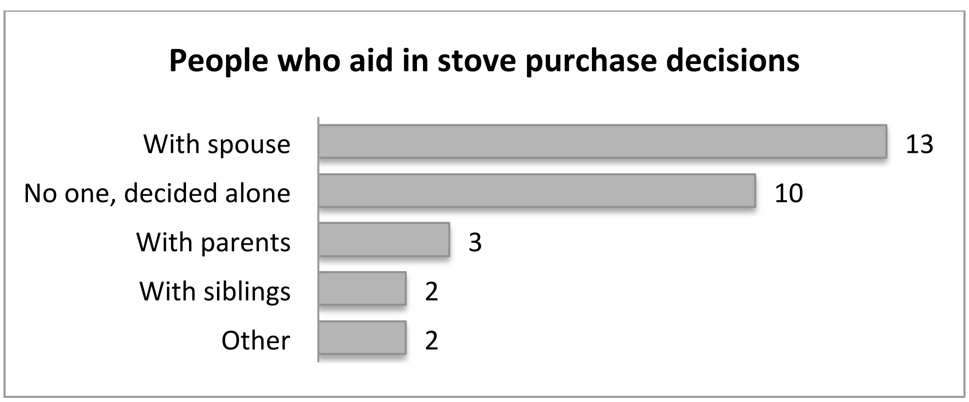

Figure 15: People with whom the primary cook reported to make their stove purchase decisions with.

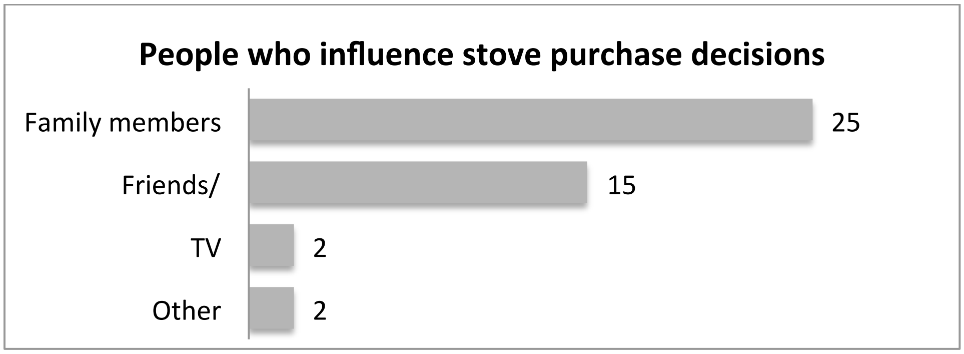

Figure 16: People whom the primary cook cited as influencing their stove purchase decisions.

3.3.1.5 Knowledge and Use of Clean Cooking Fuels.

To explore barriers to the use of clean cooking fuel the study participants were asked what has prevented them from using LPG fuel as their main cooking fuel. Their responses are presented in Figure 17 below (multiple responses were allowed).

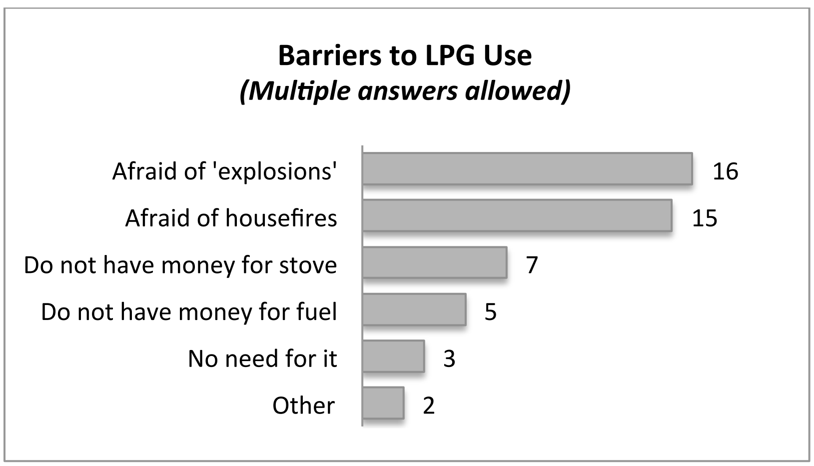

Figure 17: Reported barriers to using LPG as primary cooking fuel.

No participants had 'ever heard of or were familiar with ethanol as a fuel for cooking' prior to the study commencement.

3.3.1.6 Initial Perceptions of the CleanCook Stove Cost.

After having the CleanCook stove demonstrated to them but not yet having used it, the participants were asked 'If this was to be sold in the stores/market what is the highest price you would consider paying for it?' Table 9 below shows the average (mean) amounts in Naira[8] participants would be consider paying by study location.

Table 9: Average amounts in Naira participants would consider paying for the CleanCook stove after initial demonstration by study location (mean (SD))

	Average amount in naira (MEAN (SD))
ALL (n=30)	10,033 (4.4)
Mushin (n=10)	9,700 (3.9)
Shomolu (n=10)	11,200 (5.7)
Akoka (n=10)	9,200 (3.7)

3.3.2 Interim Follow-up Surveys

Two brief interim surveys were conducted at one and then two months after providing he CleanCook stove. During these visits surveyors conducted a direct observation of the cooking area on arrival at the home. Figure 18 shows the stoves observed by surveyors during the first and second follow-up survey visits.

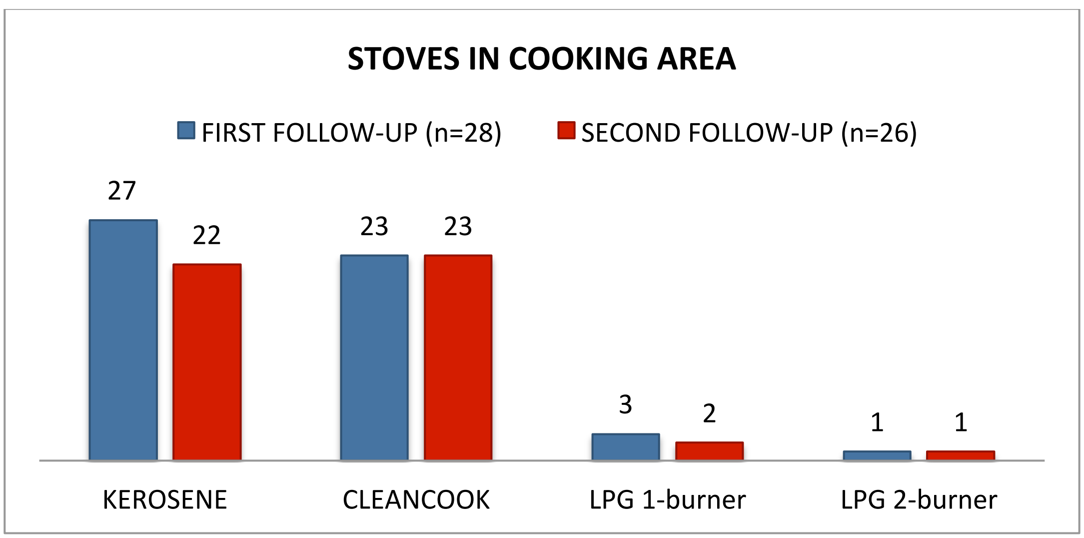

Figure 18: Stoves observed in the kitchen area by surveyors during the first and second follow-up survey visits.

Participants were asked what, if anything, they liked about the CleanCook stove. Figure 19 below shows participant answers for both the first and second follow-up survey visits.

[8] At the time of report writing 1 USD= 360 Naira

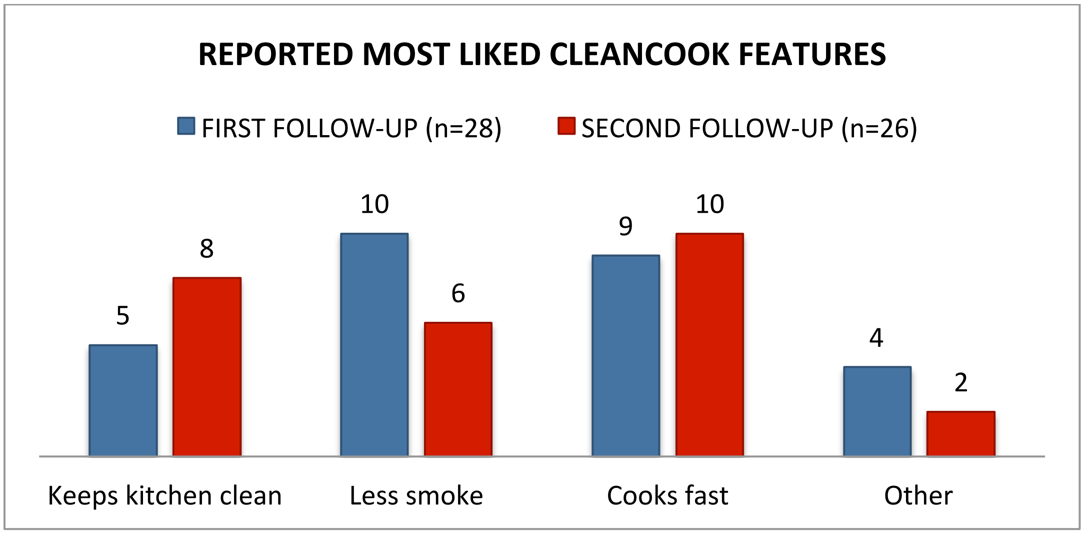

Figure 19: The features primary cooks reported liking the most about the CleanCook stove on the first and second follow-up survey visits.

Participants were also asked about any challenges presented by the CleanCook stove. Figure 20 shows participant responses on both the first and second follow-up survey visits.

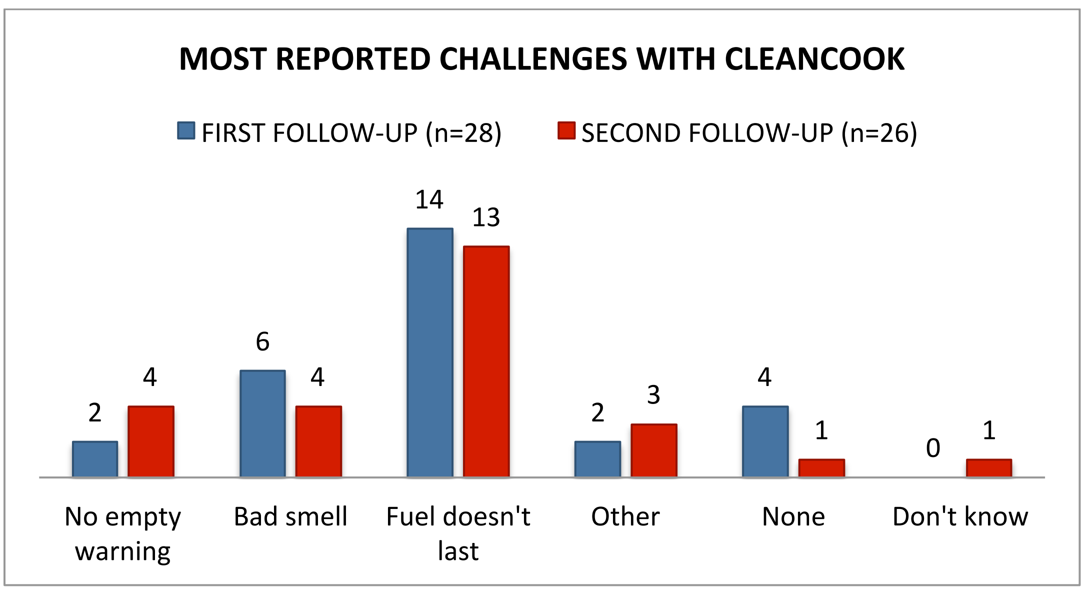

Figure 20: The aspects primary cooks reported to be most challenging about the CleanCook stove on the first and second follow-up survey visits.

One month after receiving the stove, participants were asked about the speed of cooking, ease of lighting, and cleanliness of the CleanCook stove compared to their primary baseline stove. Table 10 below shows their responses.

Table 10: Reported comparisons of speed of cooking, ease of lighting stove, and cleanliness of stove between participant's previous baseline stoves and the CleanCook stove.

Speed of cooking meals		Ease of lighting stove		Cleanliness of stove	
Much faster	75% (21)	Much easier	86% (24)	Much cleaner	89% (25)
Slightly faster	11% (3)	Slightly easier	4% (1)	Slightly cleaner	0% (0)
Same	7% (2)	Same	7% (2)	Same	11% (3)
Slightly slower	4% (1)	Slightly more difficult	4% (1)	Slightly more sooty/smoky	0% (0)
Much slower	4% (1)	Much more difficult	0% (0)	Much more sooty/smoky	0% (0)

One month after receiving the stove, participants were also asked to compare the convenience and cost of the CleanCook fuel to their previous baseline fuel. Table 11 shows their responses.

Table 11: Reported comparisons of convenience and cost of CleanCook fuel compared to participant's previous baseline fuels.

Convenience of purchasing fuel		Cost of fuel	
Much more convenient	43% (12)	Much cheaper	29% (8)
Slightly more convenient	18% (5)	A little cheaper	14% (4)
Same	18% (5)	Same	11% (3)
Slightly more difficult	14% (4)	A little more expensive	29% (8)
Much more difficult	7% (2)	Much more expensive	14% (4)
Don't know	0% (0)	Don't know	4% (1)

3.3.3 Final Follow-up Survey

26 households were available for the final survey. During the final survey, surveyors were asked to report on the appearance of the CleanCook stove in the participant's homes. Table 12 shows the surveyor observations.

Table 12: Surveyor reports on the appearance of the CleanCook stove during the final survey visit.

Appearance of CleanCook stove	% (n)
Used and well cared for	89% (23)
Used but dirty and not well cared for	8% (2)
Not recently used and covered in dust/cobwebs	0% (0)
No signs of recent use and clean	4% (1)

The reported primary and secondary stoves are shown in Table 13 below.

Table 13: Reported primary and secondary stoves at the final survey visit.

	Primary stove	Secondary stove(s)
CleanCook	65% (17)	27% (7)
Kerosene	27% (7)	50% (13)
LPG 1 burner	4% (1)	0% (0)
LPG 2 burner	0% (0)	4% (1)
Electric	4% (1)	0% (0)

Don't know	0% (0)	4% (1)

35% of respondents (n=9) said they cooked with two stoves simultaneously Table 14 below shows their reasons for doing so.

Table 14: Reported stove types used simultaneously during the final survey visit and reported reasons for doing so.

Reason	% (n)
To cook more quickly	67% (6)
Food requires different techniques	11% (1)
Cooking more than one item at a time	56% (5)

Of the respondents who reported to be using a stove in addition to the CleanCook (n=22), 32% (n=7) said that they preferred to carry out tasks such as cooking beans or other slow-cooking foods with their kerosene stoves because the flame both burned hotter and lasted longer.

3.3.3.1 Perceptions of the CleanCook Stoves

As with the interim surveys, the participants were asked which features, if any, they liked most about the CleanCook stove and which features presented the biggest challenges. Table 15 shows the most reported features for both questions. Multiple responses were allowed.

Table 15: Features primary cooks reported to like most about the CleanCook stove and those that presented the biggest challenges.

Most liked characteristics of the CleanCook	% (n)
Less smoke	65% (17)
Cooks fast	50% (13)
Keeps kitchen clean	46% (12)
It looks modern	19% (5)
Characteristic of the CleanCook that presented the most challenges	% (n)
No significant challenges	31% (8)
Fuel does not last	23% (6)
Fuel is expensive	15% (4)
Fuel purchase is difficult	15% (4)

3.3.3.2 Perceptions of CleanCook Fuel

Participants were asked whether they agreed or disagreed with a range of statements regarding the CleanCook fuel’s affordability, safety, and cleanliness. Table 16 shows participant responses ranging from ‘Strongly agree’ to ‘Strongly disagree’.

Table 16: Participant's responses to statements regarding CleanCook fuel affordability, safety, and cleanliness from 'Strongly agree' to 'Strongly disagree'. Shown by %(n).

	Strongly agree	Agree	Disagree	Strongly disagree	Other
I can afford to cook with CleanCook fuel	35% (9)	62% (16)	0% (0)	0% (0)	4% (1)
CleanCook fuel is a safe fuel to cook with	58% (15)	38% (10)	4% (1)	0% (0)	0% (0)
Clean cook fuel is a clean fuel to cook with	62% (16)	38% (10)	0% (0)	0% (0)	0% (0)

Lastly, participants were also to rate the convenience, cost, and ease of purchasing, cooking with, and refueling with CleanCook fuel as compared to their previous fuel. The results are shown in Tables 17-19 below.

Table 17: Reported convenience of purchasing CleanCook fuel as compared to buying previous fuel during the final survey visit.

Buying CleanCook fuel	% (n)
Much more convenient	42% (11)
Slightly more convenient	23% (6)
Same	15% (4)
Slightly more difficult	15% (4)
Much more difficult	4% (1)

Table 18: Reported affordability of cooking with CleanCook fuel as compared to previous fuel.

Cooking with CleanCook fuel	% (n)
A lot more expensive	4% (1)
Slightly more expensive	31% (8)
Same	19% (5)
Slightly less expensive	19% (5)
A lot less expensive	27% (7)

Table 19: Reported ease of changing the CleanCook canister as compared to refueling their previous stove.

Changing CleanCook canister vs. refueling previous stove	% (n)
Much easier	46% (12)
Easier	50% (13)
The same	0% (0
More difficult	4% (1)
Much more difficult	0% (0)

3.3.4 Purchaser Follow-up Survey

A follow up survey was conducted on 18 study participants who elected to buy the CleanCook stove one month after purchase. As with other visits, surveyors were asked to report on the appearance of the CleanCook stove in the home. Table 20 shows how surveyors reported the CleanCook's appearance in the home during the purchaser follow-up survey visit.

Table 20: The reported appearance of the CleanCook stove according to surveyors during the purchaser follow-up survey visit.

CleanCook appearance	% (n)
No signs of recent use and clean	6% (1)
Used and well cared for	89% (16)
Used but dirty and not well cared for	6% (1)

Participants were asked which stove they consider their primary stove following the purchase of the CleanCook stove. Table 21 shows participant responses when asked which was their primary stove.

Table 21: Reported primary stoves according to the primary cook during the purchaser follow-up survey visit.

Primary Stove	% (n)
CleanCook Stove	50% (9)
Kerosene Stove	22% (4)
LPG 2 burner	17% (3)
Electric	6% (1)
LPG 3 burner	6% (1)

61% (n=11) of participants reported using more than one stove at a time while cooking. Table 22 below shows which stoves these participants reported to use when using more than one stove at a time.

Table 22: Stove types participants reported to use when using more than one stove at a time, allowed to provide multiple answers.

Stove Types used for Simultaneous Use	% (n)
CleanCook Stove	91% (10)
Kerosene stove	45% (5)
LPG 1 burner	18% (2)
LPG 2 burner	36% (4)
Electric	18% (2)

3.3.4.1 Perceptions of the Stove Post Purchase

All participants reported to be pleased that they had gone ahead with the purchase of the CleanCook stove for reasons including not wanting to lose the stove after becoming accustomed to it and it offers a safer, cleaner cheaper to use alternative to their previous stoves.

When asked 'How likely are you to recommend the stove to a friend or neighbor, if 5 is extremely likely and 1 is not at all likely?' Over 80% (n=15) reported a 4 or more.

3.3.4.2 Cannister procurement post purchase

Participants were also asked a series of questions about procuring CleanCook fuel. Table 23 shows how many canister refills participants reported purchasing per month, and how many canisters they reported purchasing during those refills, Table 24 shows the distance in kilometers each participant must travel to the refill station, and Table 25 shows their reported methods of transport.

Table 23: Reported number of canister refills purchased per month and reported number of canisters purchased per refill.

Canister refills/month	% (n)
0	6% (1)
2	18% (3)
3	18% (3)
4	47% (8)
5	6% (1)
6	6% (1)
Number of canisters purchased each trip	% (n)
1	12% (2)
2	88% (15)

Table 24: Time taken to get to the refilling point.

Time (mins) to canister refill	
Mean	6.3
SD	4.5
n	18

Table 25: Reported method of travel to the canister refill point.

Travel to refill station	% (n)
Walking	89% (16)
Public transport solely for fuel	11% (2)

Participants were then asked about their experiences purchasing CleanCook fuel canisters, including questions about the availability of fuel and the convenience of purchasing fuel. Table 26 shows participant responses to the question, "Have there been canisters available each time you have been to purchase them?", and Table 27 shows participant responses when asked about the convenience of purchasing CleanCook fuel on the provided scale.

Table 26: Participant responses when asked, "Have there been canisters available each time you have been to purchase them?"

Canisters available?	% (n)
Yes	67% (12)
No	33% (6)

Table 27: Participant's responses when asked about the convenience of purchasing CleanCook fuel as compared to their previous fuel during the purchaser follow-up survey visit.

Purchasing CleanCook fuel	% (n)
Much more convenient	78% (14)
Slightly more convenient	6% (1)
Same	6% (1)
Slightly more difficult	11% (2)
Much more difficult	0% (0)

3.4 Canister Refill Rates

Households in the experimental sample were able to purchase additional fuel at a nearby filling station once their initial supply was exhausted. A full fuel canister required the return of an empty one together with a payment of 250 Naira (approximately 0.70 USD). The canister sales records for the duration of the PEDUCCT experimental study (October 2017 through February 2018) are presented in Figure 23.

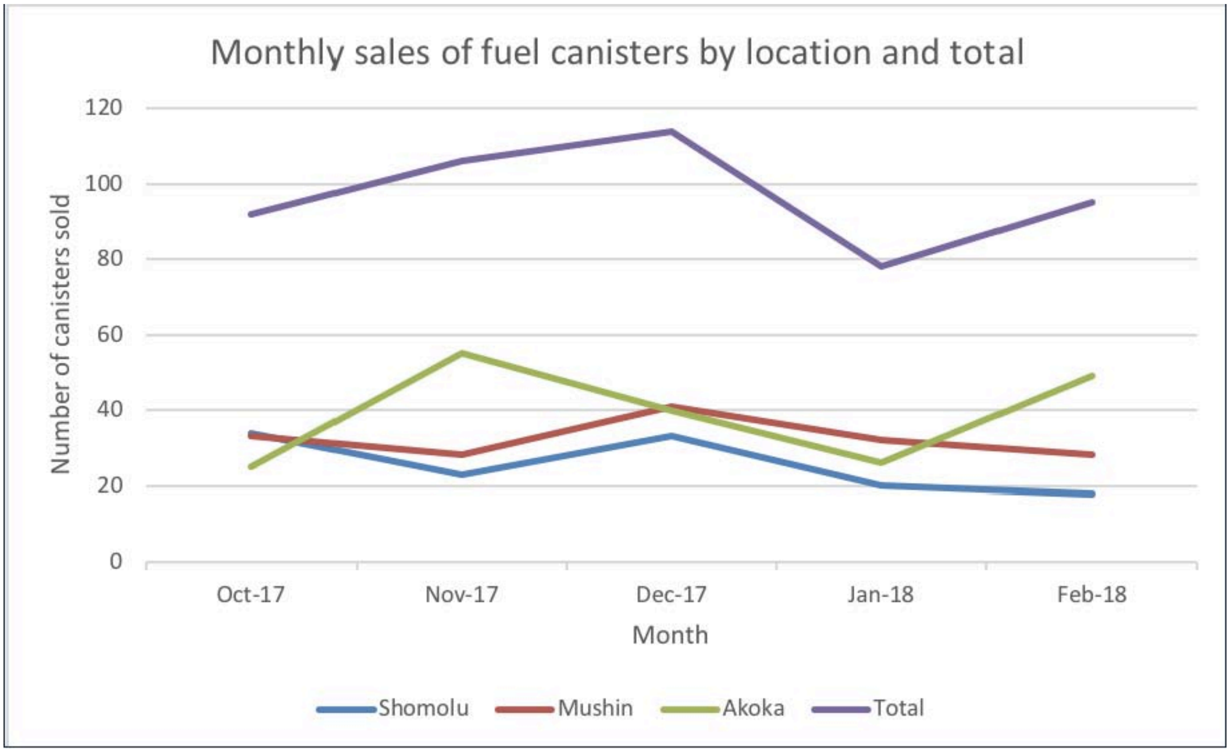

Figure 21: Monthly sales of fuel canisters by location and total.

The total average monthly canister sales was 97 units (SD 14), from a pool of 42 CleanCook stoves deployed in Lagos during the study period, giving an average of 2.3 canisters per household/month. Project Gaia estimates that a typical Lagos household requires about 8 canisters of fuel per month to meet all their cooking needs. Further analysis of stove use monitoring and household survey data will clarify stove stacking patterns and the extent to which the CleanCook stove displaced the baseline cooking methods.

3.5 Willingness to Pay

A total of 37 households were available to take part in the WTP exercise, during which 30% (n=11) purchased the CleanCook stove. When participants were offered the opportunity to buy the stove and asked if they would like to find out more, 94.6% (n=35) stated they did. One participant agreed to purchase the stove at this opening price of ₦19,000.

The remaining 34 HH were then asked to name a price they would be willing to pay for the stove. For the purposes of the WTP exercise, a minimum bid of ₦15,000 was established but as per the WTP protocol, this was not disclosed to the participants. If they offered over ₦15,000, their bid was accepted. If their bid was less than ₦15,000, they were asked to make another offer. A total of three offers were permitted. This minimum bid was set just above the lowest price that Project Gaia anticipate they could offer participants, taking into account all possible subsidies, including carbon financing and profits from fuel sales. The outcomes from each these rounds of negotiations are outline in Table 28 below.

Table 28 shows that the average bid increased between rounds, as those who opted to stay in the negotiation became more invested. The average bid increased 10% between rounds 1 and 2 and 42% between rounds 2 and 3. The average final bid made for the stove, irrespective of round, was ₦15,909 (SD 1300 n=11). The distribution of final bids is presented in Figure.

Table 28: Summary of WTP results

	Accepted opening price of ₦19,000		Outcome
n	35		1 accepted the opening price of ₦19,000. 34 wanted to continue to the negotiations.
	First Offer		Outcome
n	34		5 offered a price the same as or more than the minimum bid. 12 offered below and then decided to stop bargaining. 16 offered below and then continued. 1 decided not to make an offer.
Mean (SD)	₦8,742 (3531)		
	Second Offer		Outcome
n	17		1 offered a price the same as or more than the minimum bid. 10 offered below and then decided to stop bargaining. 6 offered below and then continued.
Mean (SD)	₦9,853 (3445)		
	Third Offer		Outcome
n	6		5 offered a price the same as or more than the minimum bid. 1 offered below and stopped bargaining.
Mean (SD)	₦14,000 (4472)		
	Cumulative		Outcome
n	11		A total of 11 households purchased the CleanCook stove during the WTP exercise.
Mean (SD)	₦15,909 (1300)		

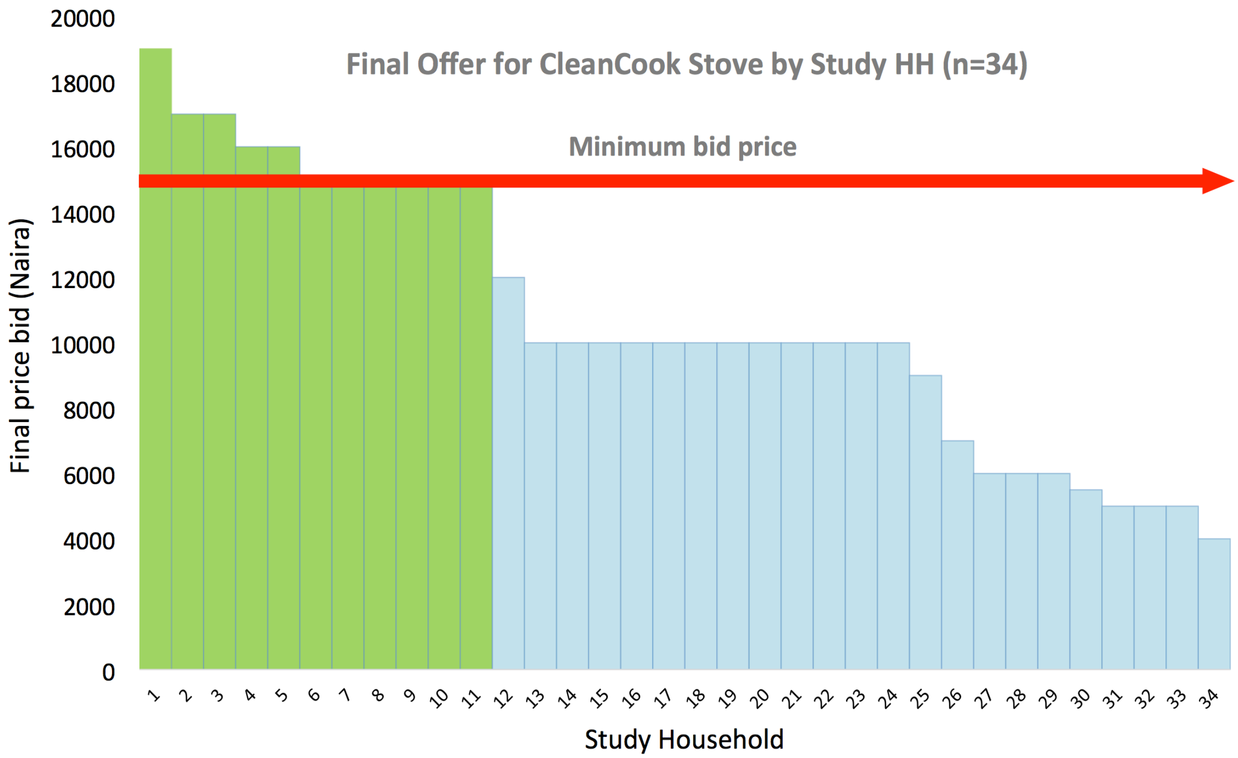

Figure 24: Distribution of final bids for CleanCook stove, regardless of round

Further analysis looking at the characteristics of those participants that went ahead and purchased during the WTP exercise and those that did not purchase showed a relationship between an increased level of education of the main cook and increased likelihood of buying. (p= 0.02 chi-squared test). There was no relationship seen with other possible predictors of purchase such as current LPG ownership, age or home ownership status.

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ENERGY COMMISSION OF NIGERIA
(The Presidency)
NATIONAL CENTRE FOR ENERGY RESEARCH AND DEVELOPMENT
UNIVERSITY OF NIGERIA, NSUKKA
NATIONAL STOVE ELIGIBILITY LABORATORY

TITLE: CLEANCOOK STOVE

Date: June 13th, 2018

The Cleancook Stove was received at the National Stove Eligibility Laboratory, National Centre for Energy Research and Development University of Nigeria, Nsukka on May 29th, 2018 for testing in accordance with the International Organization for Standardization (ISO) International Working Agreement (IWA) using the Water Boiling Test (WBT) version 4.2.2. The stove is made of all-metal body.

The Stove was tested using the Water Boiling Test, WBT4.2.2, in accordance with the ISO International Working Agreement (IWA). The Water Boiling Test includes three phases - a Cold Start, Hot Start, and Simmer. During the Cold and Hot Start phases, the tester brings the stove to a boil operating the fire at a constant rate. For Charcoal stoves, the Hot Start is not usually carried out. The Simmer phase requires the operator to maintain the water temperature three degrees below boiling temperature, assuring the water does not fall six degrees below boiling temperature. The test was conducted with 1 L of water in a 4.5 L capacity flat bottom pot, with **no** pot skirt. The fuel used was anhydrous ethanol/methanol mix with a heating value of 23.580 MJ/kg and moisture content of 0.5%. The WBT was carried out five (5) times for statistical validity.

Overview of Reporting Metrics:

The International Organization for Standardization (ISO) International Workshop Agreement (IWA) testing and rating system of the IWA was approved in February 2012 at an international workshop held in The Hague, Netherlands. The rating system defines "tiers" of performance in the areas of fuel efficiency, emissions of fine particulate matter (PM 2.5) and carbon monoxide (CO), and safety. Each area is ranked separately on a scale of Tier 0 – Tier 4, Tier 0 being the baseline or unimproved stove, and Tier 4 being the aspirational goal. Definitions of the Tiers are found below in *Detailed Test Data*.

Fuel Efficiency -- For the fuel efficiency metrics, the high power thermal efficiency is the ratio of the energy absorbed by the water in the pot to the energy released by the fuel consumed during the test. If a Cold Start and Hot Start are both performed they are averaged to find the high power result. For low power, the ISO IWA reports specific fuel consumption as fuel consumed divided by water remaining after the duration of the simmer phase.

Emissions – Emissions measured are carbon monoxide (CO) and particulate matter less than 2.5 µm ($PM_{2.5}$). Two categories of metrics are reported for each, total emissions and indoor emissions. For high power total emissions, the metrics are based on energy delivered to the cooking pot. For low power total emissions, the metrics are specific to the amount of water remaining and the length of the simmer period. Indoor emissions are displayed in emissions rates - mass of pollutant over time.

IWA Performance Metrics	units	Test 1	Test 2	Test 3	Test 4	Test 5	Average	Standard Deviation	Coefficient of Variation (COV),%
High Power Thermal Efficiency	%	49.5	45.3	50.4	50.6	50.4	49.24	2.2434	4.56
Low Power Specific Consumption	MJ/min/L	0.067	0.058	0.098	0.086	0.07	0.0758	0.0160	21.12
High Power CO	g/MJ$_d$	1.25	1.46	1.66	1.77	2.01	1.63	0.2908	17.84
Low Power CO	g/min/L	0.021	0.042	0.031	0.032	0.026	0.0304	0.0078	25.75
High Power PM	mg/MJ$_d$	77.5	95.3	90.5	69.1	75.1	81.5	10.9790	13.47
Low Power PM	mg/min/L	0.8	1.34	1.2	0.56	0.6	0.9	0.3533	39.25
High Power Indoor Emissions CO	g/min	0.06	0.11	0.07	0.08	0.08	0.08	0.0187	23.39
High Power Indoor Emissions PM	Mg/min	1.6	1.46	1.84	2.2	0.87	1.594	0.4924	30.89

IWA Tiers	Tier	Tier	Tier	Tier	Tier	Average
High Power Thermal Efficiency	4	4	4	4	4	4
Low Power Specific Consumption	0	0	0	0	0	0
High Power CO	4	4	4	4	4	4
Low Power CO	4	4	4	4	4	4
High Power PM	3	3	3	3	3	3
Low Power PM	4	3	3	4	4	4
High Power Indoor Emissions CO	2	0	1	1	1	1
High Power Indoor Emissions PM	4	4	4	3	4	4

Standard Performance Measures		Test 1	Test 2	Test 3	Test 4	Test 5	Average	Standard Deviation	Coefficient of Variation (COV), %
Fuel to Cook 5L (850/1500)	g	857.3	898.1	1153.7	1056.3	877.1	968.5	130.0802	13.43
CO to Cook 5L (20)	g	1.28	1.4	2.4	1.8	1.6	1.696	0.4405	25.98
PM to Cook 5L (1500)	mg	440	612.4	508.5	427.8	600	517.74	86.524	16.71
Energy to Cook 5L (15,000/25,000)	kJ	19084	13386	25681	21353	19629	19826.6	4434.9669	22.37
Time to Boil	min	8.7	9.3	8.0	9.4	9.7	9.02	0.6760	7.49
CO2 to Cook 5L	g	1214.9	1513	2086.5	2170.2	2324.3	1861.78	474.2489	25.47

Summary

The Cleancook Ethanol stove was received at NSEL on May 29th 2018 for testing in accordance with the International Organization for Standardization (ISO) International Working Agreement (IWA) using the Water Boiling Test (WBT). Testing was carried out using a flat bottom pot. It was carried out five (5) times to ensure statistical accuracy. The high power thermal efficiency of the stove averaged **49.24%.** Most of the metrics were within the recommended 25% CoV.

Dr. C. N. Anyanwu
Director, NSEL

ENERGY COMMISSION OF NIGERIA
(The Presidency)
NATIONAL CENTRE FOR ENERGY RESEARCH AND DEVELOPMENT
UNIVERSITY OF NIGERIA, NSUKKA
NATIONAL STOVE ELIGIBILITY LABORATORY

TITLE: ORIGINAL WHEEL KEROSENE STOVE

Date: June 13th, 2018

The Original Wheel Kerosene Stove was received at the National Stove Eligibility Laboratory, National Centre for Energy Research and Development University of Nigeria, Nsukka on May 29th, 2018 for testing in accordance with the International Organization for Standardization (ISO) International Working Agreement (IWA) using the Water Boiling Test (WBT) version 4.2.2. The stove is made of all-metal body.

The Stove was tested using the Water Boiling Test, WBT4.2.2, in accordance with the ISO International Working Agreement (IWA). The Water Boiling Test includes three phases - a Cold Start, Hot Start, and Simmer. During the Cold and Hot Start phases, the tester brings the stove to a boil operating the fire at a constant rate. For Charcoal stoves, the Hot Start is not usually carried out. The Simmer phase requires the operator to maintain the water temperature three degrees below boiling temperature, assuring the water does not fall six degrees below boiling temperature. The test was conducted with 1 L of water in a 4.5 L capacity flat bottom pot, with **no** pot skirt. The fuel used was anhydrous ethanol/methanol mix with a heating value of 23.580 MJ/kg and moisture content of 0.5%. The WBT was carried out five (5) times for statistical validity.

Overview of Reporting Metrics:

The International Organization for Standardization (ISO) International Workshop Agreement (IWA) testing and rating system of the IWA was approved in February 2012 at an international workshop held in The Hague, Netherlands. The rating system defines “tiers” of performance in the areas of fuel efficiency, emissions of fine particulate matter (PM 2.5) and carbon monoxide (CO), and safety. Each area is ranked separately on a scale of Tier 0 – Tier 4, Tier 0 being the baseline or unimproved stove, and Tier 4 being the aspirational goal. Definitions of the Tiers are found below in *Detailed Test Data*.

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Emissions – Emissions measured are carbon monoxide (CO) and particulate matter less than 2.5 µm ($PM_{2.5}$). Two categories of metrics are reported for each, total emissions and indoor emissions. For high power total emissions, the metrics are based on energy delivered to the cooking pot. For low power total emissions, the metrics are specific to the amount of water remaining and the length of the simmer period. Indoor emissions are displayed in emissions rates - mass of pollutant over time.

IWA Performance Metrics	units	Test 1	Test 2	Test 3	Test 4	Test 5	Average	Standard Deviation	Coefficient of Variation (COV),%
High Power Thermal Efficiency	%	40.1	43.6	41.5	42.5	41.2	41.78	1.3293	3.18
Low Power Specific Consumption	MJ/min/L	0.156	0.096	0.121	0.085	0.134	0.1184	0.0286	24.19
High Power CO	g/MJ_d	2.02	1.51	1.66	2.7	1.65	1.908	0.4812	25.22
Low Power CO	g/min/L	0.06	0.04	0.08	0.08	0.06	0.064	0.0167	26.15
High Power PM	mg/MJ_d	470.1	408.9	576.4	602.2	588.6	529.24	85.22044	16.10
Low Power PM	mg/min/L	224.05	160.01	146.66	110.8	152.6	158.824	41.0757	25.86
High Power Indoor Emissions CO	g/min	0.05	0.03	0.04	0.056	0.036	0.0424	0.0105	24.83
High Power Indoor Emissions PM	Mg/min	102.7	76.9	75.2	68.8	62.8	77.28	15.2662	19.75

IWA Tiers	Tier	Tier	Tier	Tier	Tier	Average
High Power Thermal Efficiency	3	3	3	3	3	3
Low Power Specific Consumption	0	0	0	0	0	0
High Power CO	4	4	4	4	4	4
Low Power CO	4	4	4	4	4	4
High Power PM	2	2	2	2	2	2
Low Power PM	0	0	0	0	0	0
High Power Indoor Emissions CO	2	3	3	2	3	3
High Power Indoor Emissions PM	0	0	0	0	0	0

Standard Performance Measures		Test 1	Test 2	Test 3	Test 4	Test 5	Average	Standard Deviation	Coefficient of Variation (COV), %
Fuel to Cook 5L (850/1500)	g	1029.2	670.7	818.4	616.6	896.1	806.2	167.5323	20.78
CO to Cook 5L (20)	g	17.4	10.4	15.6	12.85	13.6	13.97	2.671984	19.13
PM to Cook 5L (1500)	mg	8102.4	12900.7	13129.1	8118.4	8067.8	10063.68	2695.355	26.78
Energy to Cook 5L (15,000/25,000)	kJ	19624	25740	28410	18908	34500	25436.4	6470.845	25.44
Time to Boil	min	15.3	20.7	14.8	16.7	22.2	17.94	3.321596	18.52
CO2 to Cook 5L	g	5733	3369.2	3860.3	4529.4	5466.8	4591.74	1012.633	22.05

Summary

The Original Wheel Kerosene stove was received at NSEL on May 29th 2018 for testing in accordance with the International Organization for Standardization (ISO) International Working Agreement (IWA) using the Water Boiling Test (WBT). Testing was carried out using a flat bottom pot. It was carried out five (5) times to ensure statistical accuracy. The high power thermal efficiency of the stove averaged **41.78%.** Most of the metrics were within the recommended 25% CoV.

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Director, NSEL

Pilot Evaluation of the Diffusion and Use of Clean Cooking Technologies in Lagos, Nigeria (PEDUCCT)

Results Brief Annex 4

Notes on Laboratory Testing Results

Berkeley Air Monitoring Group

July 2018

Notes on Laboratory Testing Results

The performance of the kerosene and CleanCook ethanol/methanol stoves was tested for this project by the National Center for Energy Research and Development (NCERD), University of Nigeria, Nsukka. While testing might have been done at several different testing centers, including those with more advanced equipment in United States, NCERD was chosen because regional testing centers have easier access to the fuels and stoves being used in their areas as well as expertise operating locally-available technologies. Further, accessible and affordable testing centers are a vital component of health markets for improved cooking technologies and fuels and important partners in climate change mitigation.

Conversely, many of these regional testing facilities, including that at NCERD, do not have access to advanced equipment and resources, which are especially important when measuring low-emitting stove-fuel combinations such as ethanol, LPG, biogas, and others. For example, the scales used to measure the mass deposited on filters during testing likely do not have the precision needed to resolve the low mass depositions typical of clean-burning fuels. Additionally, the sensors used to measure carbon dioxide and carbon monoxide require periodic calibration, yet acquiring calibration gas is often prohibitively expensive or logistically difficult in developing countries.

These limitations suggest that the results reported here for the emissions of particulate matter and carbon monoxide likely have relatively large uncertainties compared to the quantities reported. Due to this uncertainty at lower concentrations, and because some of the climate forcing pollutants were not measured directly as part of the laboratory study, we incorporated data from other relevant sources into our analysis, as noted in the Results Brief Annex (see Annex 1, section 3.2).

While we cannot fully characterize the accuracy of the carbon monoxide and particulate matter presented in the performance testing reports, the additional uncertainty for these measurements means they should be interpreted within the context of the measurement limitations. Certainly, previous testing has indicated lower particulate matter emissions for ethanol stoves, though again, whether those differences are due to instrumentation limitations, variability in technician operation of the stove, differences or contamination of the fuel, or other factors is not possible to determine here. In general, however, we suggest that any review of cleaner burning stove/fuel combinations account for results from as many sources as possible, including those with testing facilities capable of resolving lower quantities of particulate matter and carbon monoxide.

We also recommend the continued support and development of regional testing centers. The regional testing centers are an important part of a healthy ecosystem for the development, testing, and marketing of cleaner cooking technologies.