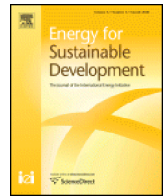




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Building a consumer market for ethanol-methanol cooking fuel in Lagos, Nigeria

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ABSTRACT

A recently completed randomized controlled study in Nigeria that transitioned pregnant women from traditional fuels to ethanol in their cook stoves demonstrated improved pregnancy outcomes in mothers and children. We subsequently conducted a pilot study of 30 households in Lagos, Nigeria, to determine the acceptability of blended ethanol/methanol as cooking fuel and willingness to pay for the CleanCook stove. A third of the pilot participants expressed a willingness to purchase the stove for the minimum price of 42 USD or more. Fuel sales data suggest sustained, but non-exclusive, use of the CleanCook stove. These results will influence the final design and implementation of a planned 2500 stove commercial pilot that is scheduled to start in Nigeria in August 2018.

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Introduction

While research on the global burden of disease research provides a mandate for transitioning populations away from polluting cooking fuels, location-specific evidence on feasibility of alternatives and resulting health benefits is often lacking, particularly for alcohol fuels. Like liquefied petroleum gas (LPG), household alcohol fuels burn cleanly (MacCarty, Still, & Ogle, 2010; Shen et al., 2018), reducing risk factors associated with household air pollution (HAP) and cardio-respiratory diseases (Rehfuess et al., 2014). In Nigeria, birth outcomes associated with switching to ethanol were recently investigated with a randomized controlled clinical trial (RCT) with support from the Global Alliance for Clean Cookstoves. Outcomes and methods from the RCT are as follows (Alexander, Northcross, Wilson, et al., 2017; Alexander, Northcross, Karrison et al., 2017; Dutta, Brito, et al., 2017; Dutta, Khramtsova, et al., 2017; Northcross et al., 2016; Olopade et al., 2017):

The rate of adoption and use of the ethanol stoves was high. 84% of the women in the ethanol group give away their kerosene stoves before the end of the study (Northcross et al., 2016). The ethanol stove intervention improved pregnancy outcomes and reduced the risk of developing hypertension during pregnancy (Alexander, Northcross, Wilson, et al., 2017; Alexander, Northcross, Karrison, et al., 2017); HAP exposure during pregnancy was associated with chronic hypoxia in the placenta (Dutta, Brito, et al., 2017; Dutta, Khramtsova, et al., 2017).

Gas flaring represents another risk to human health and environmental quality, especially for residents of the Niger Delta in Nigeria (Giwa, Adama, & Akinyemi, 2014; Osuoha & Fakutiju, 2017). Studies show that flaring is a significant contributor of black carbon (BC) to the atmosphere and is likely responsible for greater than 42% of all BC surface deposition in the Arctic, linking it to climate change (Conrad & Johnson, 2017; Johnson, 2017). Gas flares also emit nitrogen oxides (NO_x), fine particulate matter (PM_{2.5}), polycyclic aromatic hydrocarbons (PAH), and unburned methane (Fawole, Cai, & Mackenzie, 2016). The Niger Delta is ranked seventh in the world for flare volumes (The World Bank, 2018), and the issue of flaring has become a highly contentious and politicized one for residents of the Delta (Ajugwo, 2013). The Nigerian Government's ban on flaring has global support, and oil producers are under pressure to eliminate the practice, creating an opportunity for alternative uses such as the production of methanol for cooking fuel.

The Nigerian Government is currently developing a national energy strategy and, while it has not yet adopted a specific position on alcohol fuels, interest in this issue is growing (Kennedy, 2017; Nigerian National Petroleum Corporation, 2017). The displacement of kerosene and biomass fuel has a greater opportunity for success with policy support from the Nigerian government. For example, the recent removal of the household kerosene fuel subsidy could have a positive impact on the market for an ethanol-methanol alternative. Further, Nigerian ethanol production is expected to grow robustly over the next few years, with the addition of new producers (Kennedy, 2017; News Agency of Nigeria, 2017; Sapp, 2017). For example, an affiliate of UNIKEM Industries Ltd. (Africa's leading importer and local producer of ethanol) recently commissioned a distillery in Kogi State, Nigeria, designed to produce up to 240,000 l of ethanol daily from cassava, sugarcane, and

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

other feedstock. Nigeria also possesses Africa's largest natural gas deposits, and plans exist to build several methanol plants to leverage this capacity (Gas Processing, 2017).

While alcohol fuels have been used for household cooking in Sub-Saharan Africa (SSA) for many years on a small scale, there is very little reporting on outcomes in the literature (Pope, Bruce, Dherani, Jagoe, & Rehfuess, 2017). Now a more extensive commercial pilot study will explore the potential of an ethanol-methanol fuel and stove system as a mainstream clean cooking option in Lagos. This Short Communication provides a brief description of the commercialization plans, but focuses primarily on an aligned, in-progress assessment called, Pilot Evaluation of Diffusion and Usage of Ethanol Clean Cooking Technology (PEDUCCT). The summary of the commercial pilot study is based on review of documentation supplied by Project Gaia and from interviews of key informants. The description of the PEDUCCT assessment methodology was drawn directly from the study protocol. Some preliminary assessment results are included, but the commercial pilot itself and the full assessment analysis are not expected to conclude until 2019. This work was supported in part through the Clean Cooking Implementation Science Network (ISN) with funds from the United States National Institutes of Health Common Fund program for Global Health as well as by the African Development Bank.

Commercial pilot of ethanol-methanol fuel in Lagos

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. Beginning in the third quarter of 2018, an initial 2500 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 study 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 into the Nigerian market and facilitate commercial scale-up of stoves and alcohol fuel. To enable this commercialization, the consortium focused on developing a commercial 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.

The two-burner stove has a stainless-steel body and an expected lifespan of 8 to 10 years. The factory cost is about 24,000 Naira (N).¹ The CleanCook stove has a unique, fiber-filled adsorptive fuel canister that retains the ethanol-methanol mix inside the canister (see Fig. 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 evaporates 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 unique adsorptive fuel canister and combustion chimney with sliding regulator plate ensure 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 need for a high-pressure 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.

¹ At the time of the WTP exercise, the exchange rate of Naira to USD was around 360 Naira/USD.

The stove has been used extensively 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, Northcross, Karrison, et al., 2017). 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).

In the commercial pilot, an ethanol-methanol blend is being promoted. Methanol, a one carbon alcohol, adds both hydrogen and oxygen to ethanol, enabling it to burn more completely. Ethanol often contains distillation impurities in small amounts, in the form of 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, Peng, & Zhang, 2018). One hundred thirty billion liters of ethanol are produced annually around the world today. The addition of methanol could double the supply of household fuel.

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 5000 tons per day (6.35 million liters per day) methanol plant has been operating in Equatorial Guinea since 2001 (Atlantic Methanol Production Company, 2018).

Formative evaluation of the commercial pilot

In order to support the commercial scale-up of the CleanCook stove and ethanol-methanol fuel blend, the PEDUCCT assessment 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 has four primary field components, two of which were designed to occur prior to the launch of the commercial pilot study and two immediately following it (see Table 1). Laboratory testing of cookstoves is also being conducted in Nigeria to estimate emission factors/rates and fuel efficiency using local kerosene and the ethanol-methanol fuel blend.

PEDUCCT explores the hypothesis that the successful scale-up of ethanol-methanol cooking fuels would result in significant long-term reductions of climate-harming emissions in Nigeria. PEDUCCT has the following objectives:

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. Provide an estimate of the target markets’ willingness to pay for the CleanCook stove and fuel after an extended period of use;
5. 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); and
6. Estimate potential national-level impacts on climate with well-established modeling approaches.

The PEDUCCT data collection activities were launched in September 2017. The pre-market launch, experimental arm of the study has been completed, and the post market launch segment is expected to conclude at the end of 2018. The experimental arm of the study was conducted within areas with proximity to three Forte Oil gas stations located within the socio-economically representative neighborhoods where CleanCook stove commercial sales are expected: Mushin (low income), Shomolu (low to medium income) and Akoka (upper-middle income) (see Fig. 2). IRB approval was granted before the study and informed consent was obtained from all participants.

PEDUCCT evaluation methods

For the experimental sample, 30 households were randomly selected, with ten from each of the three recruitment areas, Mushin, Shomolu and Akoka in Lagos. Households were located within a two-kilometer radius of a Forte Oil filling station stocked with refilled fuel canisters for the CleanCook stoves, so that participants have access to fuel throughout the study period. The following criteria were used to select study participants:

- Use charcoal and/or kerosene as primary cooking fuel with minimal LPG;
- No planned relocation in the next 3–5 months;
- Not engaged in commercial cooking;
- Average family size of 2–7 people;
- No housemaid; and
- Decisions maker on cooking and fuels between the ages of 23 and 50.

The households in the experimental sample were given a free CleanCook stove for the study duration. They also received two fuel canisters filled with the blended ethanol-methanol at the study start, with

Table 1
Overview of PEDUCCT study design.

PEDUCCT approach and methods				
Phase	Group	Sample	Methods	Timeline
Pre-market launch	Experimental sample	30 households randomly selected from the catchment areas of the three Forte Oil gas stations	Household interviews, cooking observations in participants’ homes, and stove use monitors	September 2017 to February, 2018
	Willingness to pay	Same 30 experimental sample households plus a sub group of high LPG users		
Market launch				May, 2018
Post-market launch	Market survey	The impact of stove promotion activities will be measured in 200 randomly selected participants.	Rapid market intercept survey	June, 2018
	Early purchasers	Up to 35 early purchasers will be recruited from the point of sale for the CleanCook stoves for the first 3 months of the study	Household interviews, cooking observations in participants’ homes, and stove use monitors	Mid-2018

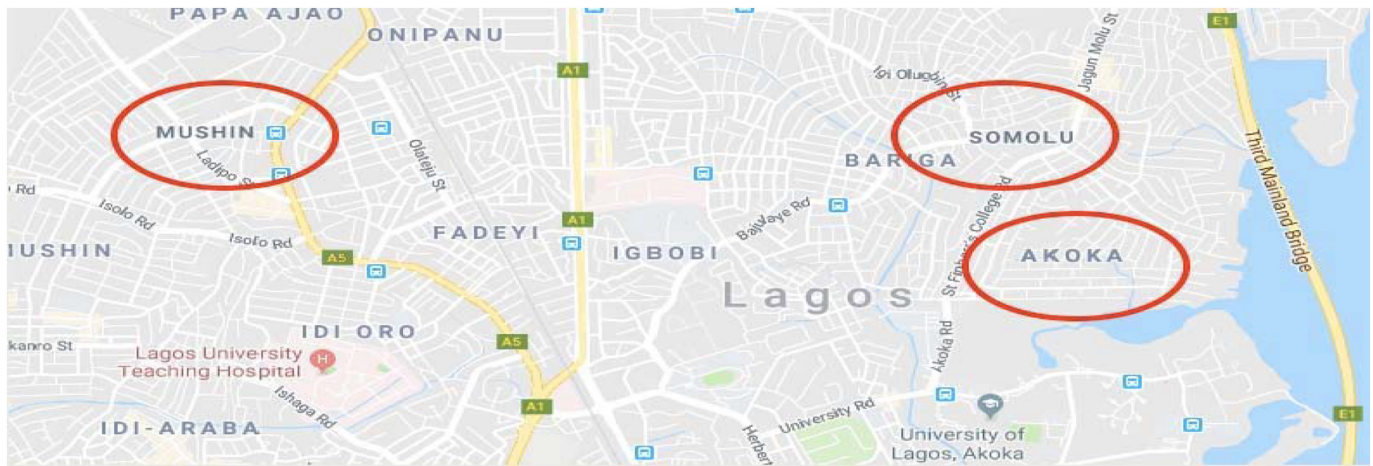


Fig. 2. Map of Lagos, Nigeria, showing areas for the commercial pilot (Google, 2018).

the expectation that they were responsible for depositing empty canisters and purchasing refilled ones at the local Forte Oil filling station. At the end of the study, participants had the option to purchase the stove for a discounted price, after they participated in a willingness to pay negotiation, described below. All households were also given a small gift at the end of the study to thank them for their participation, regardless of whether they decided to purchase the CleanCook stove or not.

Data were collected over 5–6 months in the 30 experimental households. Stove use monitoring commenced at baseline and continued for the full monitoring period. Simultaneously, a baseline survey and three follow-up surveys were conducted, with additional intermittent visits to download the stove use sensor data. Data on the frequency of canister purchases were also collected from the filling stations.

For the second study arm, up to 35 early purchasers will be recruited from the point of sale for the CleanCook stoves during the first 3 months of the study. Customers showing interest in the CleanCook stove at any of the participating Forte Oil stations will be invited to participate in the in-home assessment of early adopters. In return for their participation, these early purchasers will be offered the stove at the lowest price, provided they delay the delivery of their new stove for 7–10 days to allow for baseline monitoring. If this is not possible, baseline stove use patterns will be collected using recall. Post-intervention stove use

monitoring and household surveys will be conducted during a minimum of two follow-up visits.

In both the experimental arm and the prospective early-purchaser sample, household surveys focus on participants' acceptance of, and preferences regarding, the CleanCook stove, the canisterized fuel system, and the ethanol-methanol blended fuel, to assess potential opportunities and barriers to scaling up. Questions also provide context for, and understanding of, the household stove use patterns, including any 'adoption niche' (Ruiz-Mercado, Masera, Zamora, & Smith, 2011) that has occurred. The assessment aims to elucidate drivers and barriers to proper and consistent stove and fuel use. The analysis of the survey data from the experimental households is currently ongoing.

In the experimental sample, a combination of methods and indicators were implemented to assess the extent to which households adopt and correctly use the CleanCook stove, and how they integrate it into their kitchens over time. The approach provides a robust 3D evaluation by validating self-reported stove use with objective sensor-based monitoring. Our assessment includes stove use measurements for five months post-acquisition, which provides a good indication of acceptance beyond the initial 'honeymoon' period, although this does not guarantee long-term sustained adoption. Stove use monitoring employed iButtons (model DS1922T, Maxim, USA), which measured temperature as a proxy for use events. iButtons were placed on the

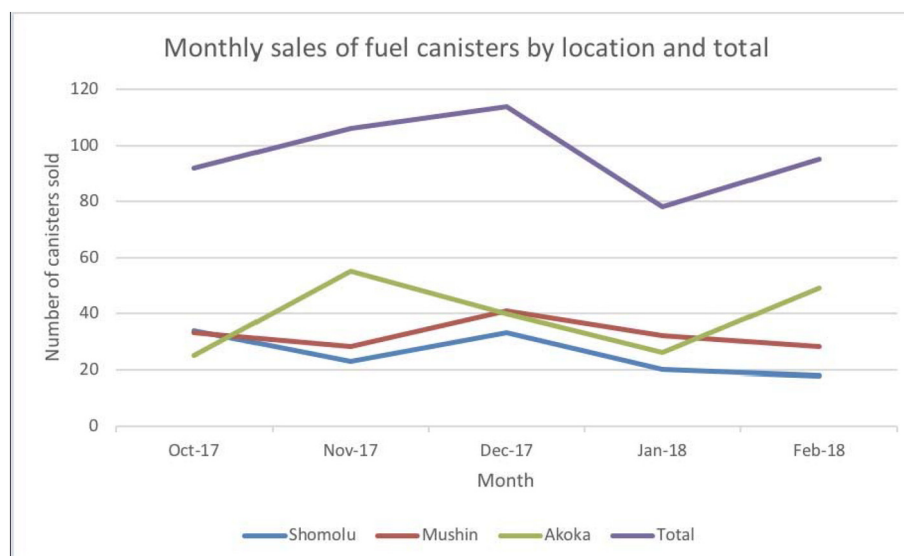


Fig. 3. Monthly sales of fuel canisters by location and total.

Table 2
Overview of PEDUCCT study results.

		Outcome
<i>Accepted opening price of N19,000</i>		
N	35	1 accepted the opening price of 19,000. 34 wanted to continue to the negotiations.
<i>First offer</i>		
N	34	5 offered a price the same as or more than the minimum bid. 12 offered below and then decided to stop bargaining. 17 offered below and then continued.
Mean (SD)	8956 (3694)	
<i>Second offer</i>		
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)	9853 (3445)	
<i>Third offer</i>		
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)	
<i>Cumulative</i>		
N	12	A total of 12 households purchased the CleanCook stove during the WTP exercise.
Mean (SD)	N15,916 (1240)	

CleanCook stove and all stoves/cooking devices that had been used in the home within the month prior to the baseline visit. When aggregated, these data provide an objective assessment of cooking patterns, including the nature of any stove stacking, which will also be used to probe the usage drivers and characteristics in the household surveys. Data analysis from the experimental households is currently ongoing.

At the end of the in-home assessment for the experimental study group, and prior to the launch of any CleanCook stove marketing activities, the PEDUCCT team conducted a WTP negotiation, adapted from methods developed and successfully piloted by United States Agency for International Development's (USAID) WASHplus program (WASHplus, 2016). CleanCook stove users were given the opportunity to purchase the study stoves in a bargaining exercise that mimicked as much as possible the sales and financing techniques to be used in the commercial pilot. Due to the logistical challenges created by allowing

payment in instalments and because the 'lump sum' approach provides a more conservative estimate, instalments were not offered as part of the WTP exercise. Preliminary results are described below.

Preliminary evaluation results

As of May 2018, preliminary results on the willingness to pay negotiation and the canister refilling rates are available. 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 Fig. 3.

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.

A total of 37 households were available to take part in the WTP exercise, during which 32.4% (n = 12) 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. The surveyor then explained that the stove was 'worth' N24,000 (the approximate factory price), but by participating in the study, they could purchase it for a discounted N19,000. Participants were given a week to assemble the payment and/or discuss with other family members and renege if needed. One participant agreed to purchase the stove at this opening price of N19,000.

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 N15,000 was established but as per the WTP protocol, this was not disclosed to the participants. If they offered over N15,000, their bid was accepted. If their bid was less than N15,000, 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

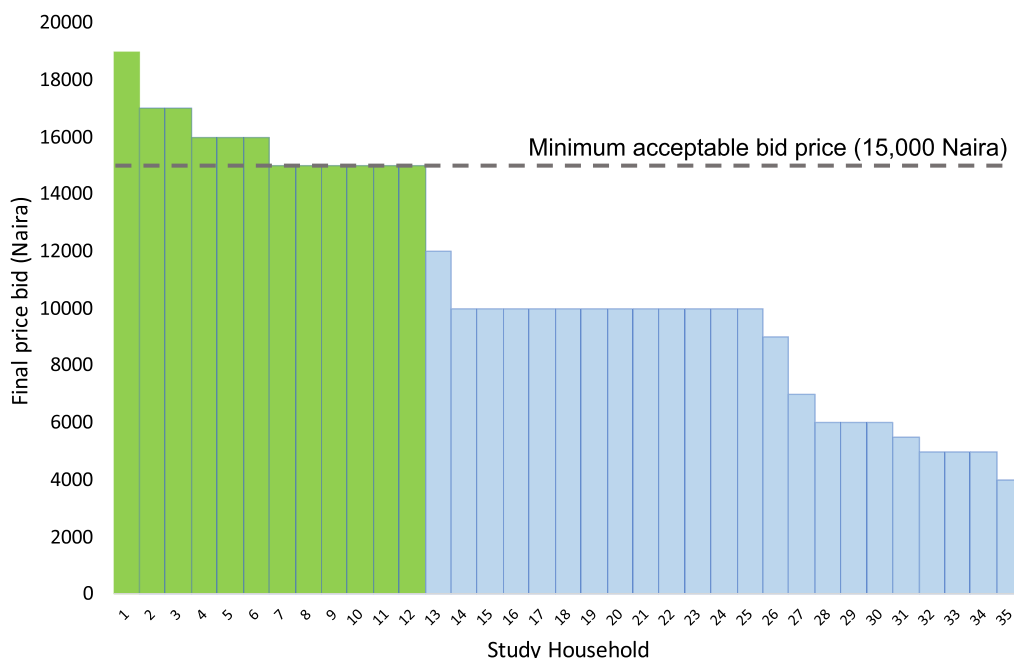


Fig. 4. Distribution of final bids for CleanCook stove, regardless of round.

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 2 below.

Table 2 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 N15,916 (SD 1240 n = 12). The distribution of final bids is presented in Fig. 4.

Once the WTP exercise had been completed in all homes, those participants with successful bids were informed that they would only need to pay N14,500, regardless of the price they had negotiated. 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. More in depth analysis is currently ongoing to explore the effect key factors may have had on the WTP results, such as baseline stove use, CleanCook stove perceptions, and the presence or absence of people during the exercise.

Conclusions and recommendations

Preliminary results from the PEDUCCT study show approximately one-third of the study's participants were willing to purchase the stove at or above the minimum price of N15,000, which is approximately USD \$42. Further they have demonstrated the acceptability of the blended ethanol-methanol fuel and the willingness of the participants to purchase it from gas stations that are within 2 km of their homes. Households purchased an average of 2.3 canisters per month, which is approximately 25% of the estimate monthly need for a typical Lagos household. The canister sales data suggests sustained, but not exclusive, use of the CleanCook stove, and further detailed analysis of the stove use monitoring data and household surveys will allow more complete investigation of adoption patterns.

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