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WILLINGNESS TO PAY AND CONSUMER ACCEPTANCE ASSESSMENT FOR CLEAN COOKING IN UGANDA

REBEL GROUP CONSORTIUM

FINAL REPORT

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Thank you to all of the households in Kampala and Wakiso distict who accepted us into their homes.

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Abbreviations

Abbreviation	Meaning
CI	Confidence intervals
HAP	Household air pollution
HH	Household
kg	Kilograms
KPT	Kitchen Performance Test
LPG	Liquefied petroleum gas
m	Meter
mg	Milligram
SA	Standard adult
SD	Standard deviation
SEC	Socioeconomic status
SUMS	Stove use monitoring system
WTA	Willingness to Accept
WTP	Willingness to Pay

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Executive Summary

Methods

The report presents the findings of a four-month in-depth study of consumer acceptance, willingness to pay and impacts of improved biomass cooktoves in the Kampala and Wakiso districts of Uganda carried out during May-August 2015. Seven stove models were tested during the study: 5 charcoal- and 2 wood-burning among a population of 379 households (272 whose primary fuel is charcoal and 107 whose primary fuel is wood and that were allocated the 2 wood-burning models) distributed in 17 parishes.

Stove use

Acceptance of clean cookstoves was measured through displacement of baseline stove use. All stoves show statistically significant displacement of baseline-stove use despite small sample sizes. Differences in displacement between stove models were not statistically significant, however larger sample sizes may provide a different picture. In general, charcoal intervention stoves were more likely to be used exclusively, but traditional stove use remains high: only 21% of households reported using the intervention stove exclusively. However, more than 80% of charcoal-using households reported **adopting the intervention stove** as their primary stove. The story was different for wood-burning stoves where less than 30% of households reported using intervention stoves as their primary stoves.

Fuel consumption

Energy savings were assessed with using 3-day kitchen performance tests (KPTs) where fuel measurements were made prior to intervention stove dissemination (baseline) and 5 weeks after the stoves were disseminated (post-intervention). Results show modest savings in fuel use after dissemination of the charcoal stove, with the highest savings seen in the Burn Jikokoa group, which saw a 22% reduction in charcoal consumption per household per day.

	Charcoal Use			Total Energy Use		
	kg/HH/day	kg/SA/day	kg/person meal	MJ/HH/ day	MJ/SA/ day	MJ/person meal
Envirofit Econochar 1.0	**15%**	4%	3%	**16%**	5%	4%
Burn Jikokoa	**22%**	**22%**	11%	**19%**	**19%**	8%
Ugastove	**20%**	9%	-3%	**21%**	10%	-2%
Prakti Leo Char:	**16%**	13%	5%	**16%**	13%	5%
Briketi EcoStove	9%	6%	-4%	**10%**	7%	-3%

The savings were similar with both wood-burning stoves. Due to the occurrence of fuel swapping in some of these homes, the total energy is a more representative figure of the changes in fuel consumption. The savings in total energy use per household per day for the ACE1 and Biolite HomeStove was 27% and 21% respectively.

	Wood Use			Total Energy Use		
	kg/HH/day	kg/SA/day	kg/person meal	MJ/HH/ day	MJ/SA/ day	MJ/person meal
ACE 1	**32%**	**28%**	19%	**27%**	**23%**	13%
Biolite HomeStove	**30%**	**26%**	**19%**	**21%**	**18%**	10%

Willingness to Pay

At the end of the post-intervention KPT, the project investigated willingness to pay (WTP) and willingness to accept (WTA) for the intervention stoves. WTP was first assessed using Becker-DeGroot-Marschak (BDM) experiments with an option to reinstate bids if the outcomes of the experiment indicated that the participant could not purchase the stoves. This option remained unknown to the participants until after completing the BDM experiments to prevent biasing the experiments. This second bid allowed assessing the actual demand for improved cookstoves. Demand is predicted by income levels, prices, the stove model, and stove usage behavior in light of price uncertainty during a trial period. Overall, Jikokoa and ACE[1] present the highest WTP and the Briketi and Ugastove the lowest, but these two local models also cost less. The demand models accurately predict 80% of the time whether the participant will buy or not the stove under the experiment conditions.

The WTA assessment revealed that participants would not accept to sell the stoves for prices significantly above the WTP, cost of stoves and demand. We hypothesize that the discrepancy between demand and WTA is due to liquidity constraints. Participants do not have the cash at hand to pay for the full value they ascribe to the stoves; hence, WTP is mediated by cash-constraints and is lower than WTA.

Study limitations

We measured differences in fuel consumption at *the household level* and not at the stove level to obtain more reliable measure of the impact of a single intervention stove in the entire household. In the study design, we were also bound by the definitions of our target populations. Charcoal stoves were distributed among primary charcoal users, but those who already owned an improved cookstove were included in the sample as well and given a more advanced model. Wood stoves were distributed among a population of wood users that often collected fuelwood. These advanced wood models may require steeper behavioral changes among this population.

In terms of measuring actual stove use, the sample size for the stove use monitoring systems (SUMS) was relatively small (less than 20 per stove model) which inhibited making statistically robust conclusions about displacement of baseline stoves.

For the WTP assessment, we were bound by experimental conditions that do not necessarily reflect real stove commercialization scenarios. For instance, the study duration did not permit to increase the number of installment payments, although increasing these may have resulted in higher WTP estimates.

Overall conclusions

[1] The ACE and Biolite populations are different from the populations where charcoal stoves were disseminated. In the former, the primary fuel is wood and are located in peripheral areas of the study area .

The different intervention stove models presented important differences in fuel savings and willingness to pay. Although the SUMS-derived baseline stove displacement is not conclusive between the different stove models, every single model displaced – to an extent—baseline stove use. No stove saved more than 32% of cooking fuel energy at the household level, evidencing fuel stacking behaviors and actual field performance of stoves.

The WTP estimates are based on actual demand for stoves under the experiment conditions. The Becker-deGroot-Marschak method failed to capture accurate demand estimates and WTA estimates do not reflect the population's purchase capacity. Hence, the actual purchase stoves using randomized prices was used to more accurately measure demand. Median WTP for stoves are sold under three equal monthly installments and when participants are presented an installment price (versus a full price to then divide in installments) is UGX 63,000 (US 19.39), but important differences exist between stove models.

1 Introduction.

1.1 Study Background and Objectives

This report addresses the need to increase market penetration of clean stoves with the end goal of reducing household air pollution and the associated disease burden as well as to reduce non-renewable biomass fuel consumption. . The first step in this goal is identifying suitable cleaner cooking technologies for the Ugandan market. A second step is ensuring that the cleaner cooking technologies are adopted to materialize reductions in indoor air pollution and biomass fuel consumption. A third step is to find suitable models and marketing strategies to introduce these technologies into households. A final step is ensuring that these technologies are adopted in the long term or are replaced by cleaner technologies. This study deals with elements of steps 1, 2, and 3 through its core objective that is "To carry out a Willingness to Pay (WTP) and Consumer Acceptance (CA) assessment over a 4-month period using 7 short-listed stoves that meet minimum efficiency and emissions benchmarks and additional criteria in order to understand:

a. The value proposition stove models present to households, including the price consumers are prepared to pay as indication of stove desirability.
b. The impact of the short listed stoves on household fuel economy.
c. Performance of shortlisted stoves compared to the baseline cooking patterns and within stove comparisons over time.
d. The level of durability of the shortlisted stoves after being in Uganda urban homes for 2-3 months.
e. Determinants and pattern of short listed stove adoption and use.
f. Consumer perceptions of the shortlisted stoves.

1.2 Intervention stoves

Seven stove types were selected by the World Bank team to be included in the assessment. Five charcoal burning stoves and two wood burning stoves,[2] giving a total study sample of 110 wood burning and 275 charcoal burning intervention stoves. An additional 10 stoves were procured from each manufacturer to cover the risk of stove failure. Please see Table 1 and Table 2 for an overview of the final selection.

[2] ACE cookstoves can also burn briquettes.

Table 1: Selected project stoves: charcoal-burning stoves

Charcoal Burning Stoves	
Ugastove Produced by Uganda Stove Manufacturers Country of origin: Uganda Cost per unit* [USD]: 6.66 	**ECCL, Econochar 1.0, Charcoal Clean Cook Stove**[3] Produced by Envirofit Econochar 1.0 Country of origin: USA Cost per unit* [USD]: 23 
Prakti Leo Char[4] Produced by Prakti Leo Char Country of origin: India Cost per unit* [USD]: 23.6 	**Burn Jikokoa** Produced by Burn Country of origin: Kenya Cost per unit* [USD]: 27.81 

[3] Note: the manufacturer has indicated to the World Bank that a new model of Econochar stove (version 4.0) was developed during the time of the study. The manufacturer has stated that the new model has a 50% larger combustion chamber (resulting in longer burn times) and 30% more fire-power.

[4] The manufacturer communicated to the World Bank that a new model (Prakti Leo Char-Fuji) may be better suited to the market based on claims of more durable material construction (the new model is made 100% of stainless steel), lower fuel use, and lower price.

Briketi EcoStove* EcoStove Produced by Green BioEnergy Country of origin: Uganda Cost per unit [USD]: 7  	

Table 2: Selected project stoves: wood burning stoves

Wood Burning Stoves	
ACE 1 Solar Powered Biomass stove Produced by Africa Clean Energy Country of origin: Lesotho Cost per unit* [USD]: 85 	**HSAA HomeStove**[5] Produced by Biolite HomeStove Country of origin: USA Cost per unit* [USD]: 50 

* Costs are exclusive of shipping, taxes and duties
** Consists of cost of cookstove (USD 65), solar panel (USD 10), wall charger (USD 4) and LED lamp (USD 6).

1.2.1 Cost per unit

The cost per unit shown above is the price for which Rebel purchased the respective stoves. In relation to the local stoves – Ugastove and the Briketi EcoStove, the cost per unit equals the price for which the stove can be purchased in the Ugandan market, taking into account changes in Uganda Shilling / USD exchange rates.

[5] Note: The manufacturer has indicated to the World Bank that they plan to launch a new version of the HomeStove early next year, which they claim will considerably enhance usability. In the words of the manufacturer, it will have a larger mouth, reduced char buildup, easier initial lighting and require less tending, alongside enhancements to USB electricity output and emissions reductions.

In relation to the international stoves, this equals the wholesale price at the time of purchase for the study, as the international manufacturers had not yet started retailing their stoves in Uganda. International manufacturers importing stoves to Uganda will need to absorb (i) shipping costs and (ii) taxes and duties. The following taxes and duties need to be considered:

a) VAT 18% of the cost of stoves
b) Withholding tax 6%
c) Domestic VAT 15%
d) Import duty 25%.
Import duty will not be paid if the stoves are originating within East Africa.

Given the differences in manufacturing origin (either within or outside East Africa), the shipping mode (air freight) and small quantities ordered, the prices presented above might not portray what the actual retail prices would be in Uganda. Most manufacturers indicated that in order to keep costs under control, they might set up a local manufacturing facility to reduce costs if the Uganda market proofs commercially attractive. For these reasons, the cost per unit for international manufacturers may not represent actual retail prices.

2 Methods

2.1 Overview of Study Design

The study design is a quasi-experimental method that compares key intervention stove outcomes before and after introducing the new technology. There is no control group; rather, changes in values are compared within households over time. Differences in key outcomes were compared between the time when the household used traditional/baseline cooking systems to 5 weeks after intervention stove dissemination.

This study design allowed for the stoves to be left in the household for a period of 5 weeks before conducting the follow up kitchen performance test (KPT), exit survey/WTP or WTA. A period of 5 weeks allows for the user to become accustomed to the stove and for the gradual integration into the cooking patterns as they become more confident in its use.

This part of the study was conducted between May and July 2015. Study households were visited 3 times during this time: during the first week (for a baseline or pre-intervention assessment), at 2 weeks (for a mid-term follow up), and at 5 weeks (to conduct willingness to pay (WTP) / willingness to accept (WTA) assessment and collect post-intervention data).

A durability study to assess "the level of durability of the shortlisted stoves after being in Uganda urban homes for 2-3 months" was completed during August 2015, 11-15 weeks after the intervention-stove dissemination. The durability study followed a simple cross-sectional study design to collect survey data and conduct observations of the intervention stoves as well as kitchen and cooking practices in study households.

2.2 Sample size

Statistical reliability levels are defined for one hypothesis and one desired outcome:

- Hypothesis: kitchens with intervention stove of model 'a' saves fuel with respect to kitchens without the intervention stove The desired statistical reliability levels for this hypothesis are a 95% confidence and a power of 80%.

- Desired outcome: the willingness to pay for intervention cookstoves has a precision of 10% for a 90% confidence level, after controlling for the cookstove model.

Based on the above reliability requirements, the estimated sample size per intervention-stove type was 50. Fuel savings implied by average thermal efficiencies from water boiling tests of traditional compared to intervention charcoal stoves is 25% (1-(0.24/0.32) and for traditional to intervention wood burning stoves is 58% (1-(0.18/0.43).[6] To ensure the sample size is adequate to detect the smallest expected difference in fuel consumption before and after stove intervention, the most conservative expected charcoal stove fuel savings of 25% was used to determine sample size. Based on past studies, coefficients of variation (COV) from charcoal KPTs range from 48 to 60%. Taking into consideration the inclusion of different social strata, a conservative estimate of 63% was applied. With a statistical power of 80% and precision level of 0.05 based on a before and after study design a sample size of 50 households is needed. It is prudent to add in an extra 10% for missing or unusable data and loss to follow up between rounds of data collection and the final **sample size was 55 households per stove type** giving a **final sample size of 385 households.**

2.3 Household Selection.

Households were selected using a multi-stage sampling approach. During the first stage, parishes in the Kampala/Wakiso districts were selected adjusting the probability of selection based on the size of the population using charcoal or wood (depending on the stove models to be disseminated). 17 parishes were selected in this manner. During the second stage, households within the parishes were selected using a systematic approach where households were spaced more or less equidistantly at around 150 meters apart from each other to hamper communication. A neighboring household was selected in cases where the target household could not be sampled. All parishes had about the same number of households.

2.3.1 Durability study households

50%[7] of the households retaining intervention stoves after the WTP/WTA exercise were selected for inclusion in the durability study. The team conducted a rapid assessment of the homes showing most use according the available SUMs data.[8] All households showing no stove use on the SUMS data were excluded. The remaining homes were randomly selected within the respective intervention stove type group to provide a sample size of 25-30 households per stove type.

[6] Stove Performance Inventory Report GACC [http://www.cleancookstoves.org/resources_files/stove-performance-inventory-pdf.pdf]

[7] n=180 plus a 10% extra for people not being available so final selection 198 households

[8] Based on the fraction of time temperature data loggers attached to stoves recorded temperatures above 40 C.

2.4 Training of field staff

The field team consisted of 16 field workers all with prior field experience in cookstove projects within Uganda involving KPTs, surveys and SUMS monitoring. The field team attended a three-day training workshop during the week of April 27th 2015 at the CIRCODU offices in Kampala. The three-day workshop included in classroom training and role-play as well as an in-field pilot.

Actions were also implemented to ensure the survey teams were trained in the correct use of all the intervention stoves so they could instruct end users in proper stove use. The level of input from the stove manufacturers varied.

- All companies were asked to send the most recent written user manuals if it was not supplied with the stoves. All team members were given copies of the manuals to study.
- All members were asked to practice lighting each stove type at the CIRCODU office prior to dissemination. It was reiterated that all personnel should be comfortable with operating each stove model before dissemination commenced.
- Representatives from Biolite, Envirofit, Africa Clean Energy (ACE) and Green BioEnergy visited the CIRCODU offices either during the training week or the during the baseline study timeframe to demonstrate the use of their stoves.
- Burn Lab presented the use and maintenance of the Burn Jikokoa stove via telephone from Kenya.
- Efforts to communicate with a representative from Prakti by Skype failed due to poor internet connection.
- The team did not meet with a representative from Ugastove but all field team members had significant experience using the stove.

It should be noted that the stove manufactures were at no point invited into the study communities and were not provided contact details of study households.

2.5 Participant demographics, behaviour and perceptions

Information on participant demographics, cooking practices and preferences, and perceptions of the intervention stoves was collected through survey of all participating households during the baseline KPT prior to stove installation and again at follow up prior to the WTP exercise. The survey aimed to collect data to contextualize and understand:

- The demographics and socio economic status of the study sample and how these might influence key outcomes.
- Determinants of consumer acceptance of the intervention stoves.
- Stove use patterns before and after stove intervention- including reported level of uptake and use of the intervention stove and displacement of the baseline cooking practices.
- Fuel use patterns before and after stove intervention.
- The impact of fuel consumption changes on household expenditures (and, hence, possibly on poverty alleviation).
- The time burden associated with cooking, cleaning and fuel procurement (and hence, how this might possibly impact involvement in educational and money generating activities).
- How WTP is influenced by demographic, socio-economic, behavioral, product use and attitudes variables.
- The level of awareness of improved cook stoves currently sold in the market and stated barriers to ownership.

2.6 Stove Usage Monitoring (SUMS)

The extent and nature of intervention-stove uptake and adoption was also measured using the Stove Use Monitoring System (SUMS), which employs temperature-logging sensors placed on stoves to collect data on how often the stoves were lit [see Figure 1]. Placement trials of the sensors (iButton model DS1922L, Maxim, USA) were conducted at the CIRCODU offices to ensure a good signal with minimal risk of iButton failure due to overheating. The sensors were fixed to the main traditional and intervention stoves in 125 households. These were randomly chosen within parish and intervention stove group. Ambient sensors were also placed in a total of 10 homes to differentiate ambient temperature fluctuations from those caused by cooking events.

Figure 1: SUMS sensor in protective wooden holder on traditional charcoal stove

The sensors were set to record the stove temperature every 10 minutes for the duration of the study. If the stove was purchased at the end of the 5-week trial, permission was asked to leave the sensor in situ until the household was revisited 6-9 weeks later for the durability study.

The team developed an algorithm in R[9] to identify cooking events from the SUMS raw data based on the methods presented by Ruiz-Mercado et al (2008).[10] The algorithm identified "fueling events" (those events where temperatures increased above a predefined rate) and grouped fueling events that occurred less than 60 minutes apart into single "cooking events." Analysis of ambient temperature SUMS revealed the potential to identify some ambient temperature changes as cooking events, and therefore, the definition of a cooking event also included the following:

- Those cooking events lasting less than 10 minutes would not be considered cooking events (e.g. because they may have been caused by sudden temperature changes,

9 R Core Team (2013). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/.

10 Ruiz-Mercado, Ilse, Nick L. Lam, Eduardo Canuz, Gilberto Davila, and Kirk R. Smith. "Low-cost temperature loggers as stove use monitors (SUMs)." Boiling Point 55 (2008): 16-18.

measurement errors in the dataloggers or sudden presence of a source of heat near the stove).

- Fueling events where the maximum recorded temperature was below 34 C were not considered cooking events, under the assumption that temperature peaks below this threshold would be mostly caused by external sources, as cooking events would likely result in higher temperatures.
- Fueling events that were not followed by a steep decrease in temperature were not considered cooking events either, as it is expected that stove cooling after a cooking event would occur at a grater pace than if the heating event was created by an external source of heat or by changes in ambient temperatures.

These rules greatly reduced the rate of false-positives (ambient temperature changes misclassified as cooking events). Each "true" cooking event was then recorded in a database with the proper household, stove model, time, and dates identifier to compute statistics that are presented in the Results section below.

2.7 Fuel Efficiency Assessment

Fuel consumption was measured using the standard KPT protocol (version 3.011[12]). All fuels to be used in the household stoves were weighed at the beginning and end of each of the three consecutive 24-hour monitoring periods. Fuels were weighed with ElectroSamson Hand Held Digital scales of 10kg and 25kg capacities (Salter Brecknell Weighing Products, Fairmont, MN 56031) with a resolution of +/- 0.01 kg.

To account for wood moisture in the final analysis, wood moisture readings were measured daily in each household using a dual pin moisture meter (either a Delmhorst Instrument Co J-2000 Wood Moisture Meter manufacturer or a Extech MO201 Pocket Moisture Meters) at three points on three randomly selected pieces of wood in the household's fuel inventory.

A questionnaire was administered each day to record information about stove and fuel usage, the number and type of meals prepared, and the number of people cooked for. The households were asked to maintain their typical cooking patterns for the duration of the survey.

2.8 Fuel Economy

Household fuel economy was assessed using three approaches to allow for verification and cross checking: KPT's to assess the impact on total cooking fuel consumption after installation of the intervention stove, self-reported fuel expenditures both before and after stove installation, and a survey of local market prices for all cooking fuels purchased by the study households.

2.9 Willingness to pay and willingness to accept

The method initially used to obtain WTP was the Becker-deGroot-Marschak (BDM) experiment.[13] The method was selected because it is theoretically incentive compatible and

[12] **www.pciaonline.org/testing** , Bailis 2007

[13] Becker GM, DeGroot MH, Marschak J (July 1964). "Measuring utility by a single-response sequential method". Behav Sci 9 (3): 226–32.

proved the best adapted to the conditions of the study. In this experiment, the final price of the stove is hidden to the participant and the enumerator and is located in a paper that the participant has to pull at random from a set of other papers containing different prices. Participants are asked to elicit their maximum willingness to pay for the intervention stove before drawing the paper with the price. If their maximum WTP is lower than the price in the paper, the participant cannot get the intervention stove; hence, the participant is incentivized not to bid a low price. If the participants' WTP is equal or higher than the price in the paper, they can buy the stove at the price they mentioned and hence the participant is incentivized not to bid too high; thereby giving a more accurate estimate WTP.

In practice, the BDM method does not reveal accurate WTP estimates because it is hard for individuals to assess their precise WTP. Under WTP uncertainty, the risk-averse opt to give conservative estimates.[14] Because of this bias, participants were given a chance to reinstate their WTP to equal the price on the random-draw piece of paper. The option to reinstate WTP was known to the users only after outlining the initial WTP. This second experiment is equivalent to presenting the participants with the real price and can yield more accurate demand estimates *under the experiment conditions*. Conducting the BDM method beforehand is nonetheless useful because it provides a preamble to randomize prices while reducing participant bargaining behaviors.

The overall sample was split into two groups: those that would respond to the question "*can you tell me what you would be willing to pay to keep the stove?*" and "*can you tell me what you would be willing to pay for each installment to keep the stove?*" These procedures were introduced to understand the marketing effects of promoting the price as an installment or a lump-sum price.

At the beginning of the experiment, participants were given the choice of paying in a single lump sum payment or paying in installments. Those wishing to pay in a single lump sum entered automatically into the first question category (see paragraph above). The choice of installments or single payment sought to understand differences in the willingness to engage in debt as well as to reduce WTP biases arising form less-than-preferred payment methods.

Those paying in installments would have to pay for the stove in 3 monthly payments and were given the choice of paying the first installment at the end of the experiment or a week later to allow households some time to collect the money. Those opting for a single lump sum payment were also offered the opportunity to pay a week later.

The sample of participants whose WTP was lower than the random price were offered the possibility to own the stove so they could enter into a WTA experiment. The transfer of intervention stove ownership was managed carefully to formalize the user's possession of the stove; to reduce the likelihood that participants communicate to others the expectation of free stoves; and to reduce inadvertent enumerator-induced biases during the WTP experiments. Participants whose WTP was lower than the random price could enter a draw to win the intervention stove. Around 80-90% of the draws ended in positive outcomes for the participants.

[14] Kaas, K.P., Ruprecht, H. (January 2006). "Are the Vikrey Auction and the BDM Mechanism Really Incentive Compatible? Empirical Results and Optimal Bidding Strategies in Cases of Uncertain Willingness-to-pay" (PDF). Schmalenbach Business Review 58: 37–55.

To assess the biases of having conducted a WTP experiment before WTA, the team selected a sub-sample of the population (30 households) who only experienced the WTA experiments. Findings (subject to some uncertainty) indicate the WTP experiments did not bias WTA conclusions.

Once the transfer of ownership was formalized, the participants were offered non-negotiable amounts of money to get the intervention stove back from the participants (actual WTA experiment). The floor value of the non-negotiable amounts of money was initially established based on retail prices of similar stoves in the market. Varying amounts above these values were offered to participants at random. Households sampled later in time were offered higher amounts, in most cases higher than their WTP [80% of cases] as the results indicated that very few households were interested in the WTA amounts being offered.

2.10 Quality Control

All survey and WTP/WTA data was entered in to an excel spreadsheet with validation checks incorporated. The project manager then checked the entered data for quality, and any seemingly inconsistent or incorrect entries were verified against the paper forms by the field team.

All scales used were factory-calibrated when new. On an annual basis, the scales are taken to Uganda National Bureau of Standards for calibration. The records of calibration are available on request. Throughout the duration of the study calibration checks were conducted weekly on every scale using standard weights (2kg, 3kg, 5kg, 10kg, 20kg). The results were analyzed to determine the degree of deviation from the standard weights using ordinary least squares regression. All scales passed the calibration checks.

Moisture meters were checked daily for battery life and general functionality following the manufacturer's guidelines.

Each surveyor used the same scales and moisture meters throughout the monitoring period to remove any effect of variability between equipment.

3 Results

3.1 Final Study Sample

The original target sample size was 385 households (HH) allowing for 10% loss to follow up in each stove group of 55. This sample size was to be complied for charcoal and wood fuel purchasers using a traditional cookstove.

However, once field recruitment commenced it became apparent that:

- A large proportion of wood users in the study area collect and do not purchase firewood.
- Ugastove (and other equivalent stoves) had significant market penetration in the study location. Observation in the study sites suggested that if households had the capital, they would most likely purchase an Ugastove (or similar models). It was in fact these homes that were most suited to purchase imported advanced cookstoves such as some of those disseminated by the project. Many of the households that exclusively owned traditional charcoal stoves seemed to be very poor and appeared unlikely to have the purchasing capacity to acquire more expensive cookstoves.
- According to information from the Biolite representative, many of their current customers (those which had previously purchased this stove and were not involved in the current study) had used charcoal on a traditional stove before buying the Biolite HomeStove. This raised the question whether the study population should also include charcoal users willing to switch cooking fuels.

As a result, the profiles of the study households at recruitment were modified. The final profiles were as follows.

- Households purchasing charcoal as their cooking fuel and cooking on either a traditional charcoal stove OR a Ugastove (or an equivalent stove[15]) for most or all of their household cooking.
- Households purchasing charcoal and cooking on either a traditional charcoal stove OR a Ugastove (or an equivalent stove) for most or all of their household cooking and were willing to swap cooking fuel to wood and/ or briquettes (for intervention wood stoves only).
- Households purchasing and/or collecting wood for cooking fuel for use on a traditional wood burning fire. After recruitment of wood using homes (either those which collect or purchase wood fuel) proved to be extremely difficult it was decided to relax the inclusion criteria for this group to include homes that were cooking commercially on a small-scale.[16]

The households using an Ugastove (or an equivalent stove) were randomly allocated one of the more advanced cookstove models (Envirofit Econochar 1.0, Burn Jikokoa, Prakti Leo Char and ACE1 or Biolite HomeStove if willing to fuel swap). Households exclusively using traditional

[15] This included stoves such as the Sessa, Okelo Kuc, AES, EUF, Briketi EcoStove

[16] If the household sold on average less than 10-15 snacks per day directly from their home they were included in the study. However if they sold meals or food more than a snack, at a large quality (15+ per day) or from a street stand away from the house. i.e. they are a larger scale commercial cook or street vendor then they were excluded.

charcoal stoves were randomly allocated any of the charcoal burning models. A separate appendix document presents copies of the household screening forms, which list the criteria to match these profiles.

The recruitment process yielded a final baseline study sample of 379 HH located in total of 17 parishes within the districts of Kampala and Wakiso (see separate appendix for names of all parishes included). The mid-term visit was carried out in a total of 350 homes 2-3 weeks after the initial stove dissemination. The follow up visit 4-5 weeks after stove dissemination was completed in 357 homes, representing an overall 5.8% rate of loss to follow up.

3.2 Stove allocation

Table 3 shows the final numbers of disseminated intervention stoves by stove type. During the first 3 weeks of monitoring the charcoal burning stoves were disseminated in 11 parishes. The Biolite HomeStove stoves were then disseminated in 6 parishes and the ACE1 in 3[17] during the last week of monitoring.

Table 3: Intervention stove dissemination by stove group.

Stove Type	Final Number Disseminated
Envirofit Econochar 1.0	59
Burn Jikokoa	55
Ugastove	52
Prakti Leo Char	56
Briketi EcoStove	51
ACE1	52
Biolite HomeStove	54

A total of 7 households were willing to swap from charcoal to one of the wood burning stoves (4 ACE1 and 3 Biolite HomeStoves.

One bag of briquettes supplied by the local producer, Formula Energy, was provided to each household that received an ACE1 stove at the time of stove dissemination. Each home was given contact details for Formula Energy if they wished to purchase more briquettes; they were also told they could use wood on the stove if they preferred. This was key for homes that collected their cooking fuel and did not want/ were unable to start to pay for briquettes.

3.3 Demographic profile of participants

Many demographic factors unrelated to the intervention stoves could potentially influence the key outcomes of this study, therefore random allocation of the intervention stoves within certain population groups aimed to create groups as similar as possible with regard to key

[17] The number of parishes over which the ACE1 stove was disseminated was reduced in an attempt to facilitate the sale of briquettes to the study homes.

characteristics. As the selection criteria were very different for the homes using wood as their main baseline cooking fuel and those using charcoal, the two groups were compared separately. Analysis of similarities and differences was carried out for participants available at follow up (n=357).

Table 4 and Table 5 show a range of socio-demographic characteristics of each charcoal intervention stove and wood burning stove group, respectively. It can be seen that the charcoal intervention stove groups are very comparable in respect of the key characteristics listed - even though there are some differences, none is statistically significant.

Table 4: Socio- demographic characteristics by intervention stove group: Charcoal-burning stoves

Characteristic	Envirofit Econochar 1.0	Burn Jikokoa	Ugastove	Prakti Leo Char	Briketi EcoStove	P-value
n	55	50	47	53	50	
Age of main cook (yrs): Mean (SD)	33.0 (11.3)	31.9 (11.8)	33.2 (13.2)	34.5 (12.0)	34.5 (12.1)	P=0.737[1]
% With primary income earner completing secondary education	64.1%	45.7%	51.7%	52.6%	54.3%	P=0.616[2]
Number of HH members with paid work: Mean (SD)	1.6 (1.3)	1.5 (1.5)	1.4 (0.7)	1.5 (1.0)	1.5 (1.0)	P=0.879[1]
% Owning their home	41.8%	36.0%	23.4%	26.4%	32.0%	P=0.273[2]
Crowding index[18]: Mean (SD)	2.9 (1.3)	3.3 (1.8)	3.0 (1.3)	3.1 (1.5)	3.1 (1.7)	P=0.696[1]
PPI[19] : Mean (SD)	0.33 (0.18)	0.35 (0.17)	0.36 (0.17)	0.34 (0.20)	0.37 (0.17)	P=0.784[1]
% With electricity connection main source of lighting	83.6%	90.0%	87.2%	81.1%	76.0%	P=0.370[2]

1. ANOVA for testing differences between intervention groups
2. Chi-squared test for testing differences between intervention groups.

Even though the stoves were disseminated using random allocation, a similar analysis for the wood burning stove groups, showed somewhat more important differences between the study groups. The ACE1 stove homes showed a evidence of having a higher socio-economic profile than the Biolite HomeStove stove group, with a higher proportion of primary income earners reached secondary or higher education (P=<0.01), owning their home (P=0.05) and having electrical connection as their main source of lighting (P=<0.01). As measured by the Progress

18 Household crowding has been shown to be negatively correlated with socioeconomic development particularly in urban settings (Melki, 2004). A household crowding index (HCI), defined as the total number of residents per household, divided by the total number of rooms excluding bathrooms and kitchens, was calculated.

19 This indicator was computed using the methods created by Progress out of Poverty Index® (PPI) and used data from the both baseline and durability surveys. It reflects the probability that a household fell below two times the Ugandan poverty line. Additional data was collected during the durability study because a new PPI was released after the baseline survey was conducted (the new indicator was created based on the Uganda National Household Survey (UNHS) 2012/2013). For households that did not participate in the durability study, PPIs were computed using the previously available indicator based on the UNHS of 2009/2010.

Out of Poverty Index (PPI®) the ACE1 group also had a lower probability of falling below two times the Ugandan poverty line.

The implications of these key differences were controlled for during the final demand analysis.

Table 5: Socio-demographic characteristics by intervention stove group: Wood burning stoves.

Characteristic	ACE	Biolite HomeStove	P value
n	50	52	
Age of main cook (yrs): Mean (SD)	49.5 (16.2)	46.3 (16.7)	P=0.345[1]
% With primary income earner completing secondary education	56.5%	20.5%	P=<0.01[2]
Number of HH members with paid work: Mean (SD)	1.6 (1.1)	1.5 (0.6)	P=0.605
% Owning their home	94.0%	80.8%	P=0.05[2]
Crowding index: Mean (SD)	2.0 (1.1)	2.2 (1.2)	P=0.396[1]
PPI : Mean (SD)	0.40 (0.20)	0.48 (0.16)	p=0.03[1]
% With electricity connection main source of lighting	70.0%	42.3%	P=<0.01[2]

1. Student's T-test for independent samples.
2. Chi-squared test for testing differences between intervention groups.

3.4 Stove Use

3.4.1 Baseline stoves

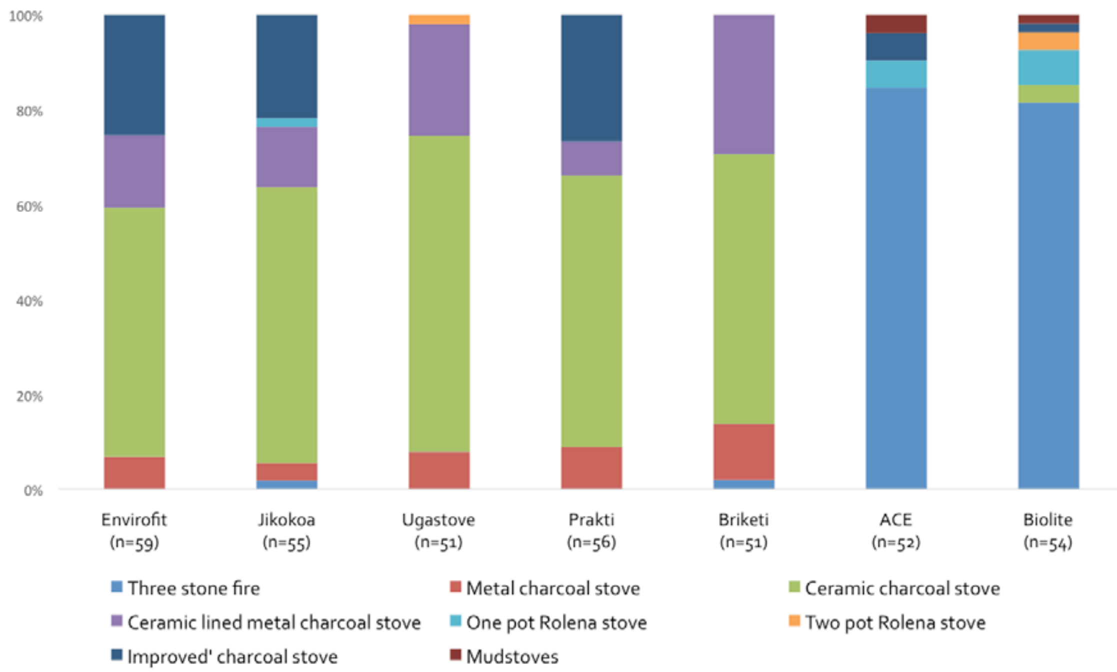
3.4.1.1 Reported use

As determined by the selection criteria all homes had either a charcoal or wood burning primary stove at baseline. The list of traditional stoves used at baseline included three stone fires, Rolena stoves (both one and two pot), ceramic lined metal charcoal stoves, metal charcoal stoves and local 'improved' charcoal stoves. Kerosene stoves and electric kettles were also used, but more as the secondary or tertiary stove option. See Figure 2 for images showing a selection of the baseline stove types.

Figure 2: Selection of baseline stoves found in participant homes: Clockwise from top left metal charcoal stove, ceramic charcoal stove, three stone fire, two pot Rolena stove.

The reported primary baseline stoves by intervention group are shown in Figure 3. The most frequently used baseline stove in the charcoal stove groups was the ceramic charcoal stove and the three stone fire in the ACE1 and Biolite HomeStove groups.

Figure 3 Reported primary baseline stove by intervention-stove group



The practice of stove stacking[20] was commonplace at baseline with over half of the homes (range 58-80%) in each of the intervention-stove groups reporting to use more than one stove during an average week to meet their cooking[21] needs. On average 1.8 (SD 0.6) different stoves were used in a week. There was no significant difference observed between the numbers of stoves used between intervention-stove groups (p=0.406 ANOVA). Figure 5 shows images of stove stacking occurring in study homes at baseline.

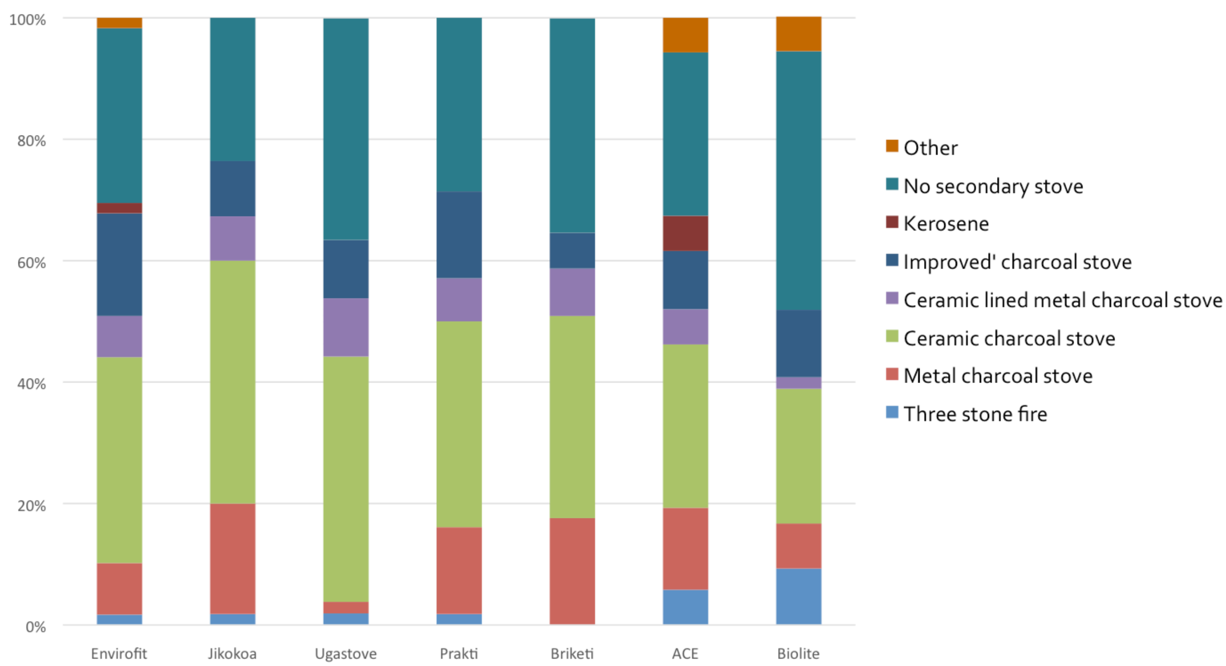
Figure 4: Stove stacking with baseline stoves

[20] Stove stacking is the practice of using more than one stove or fire to carry out the cooking and other stove related tasks i.e. heating bathing water, preparing feed for animals. It can be simultaneous use or at separate times.

[21] The report refers to 'cooking needs' for simplicity but the authors recognize that many tasks beyond cooking are regularly carried out on these households stoves.

Figure 7 shows the secondary stove use pattern at baseline. The Biolite HomeStove group had the highest rate of single stove use at baseline with 42% reporting that they had no secondary stove, the frequency of single stove use ranged from 20%- 35% in the other groups [p= 0.230 chi squared test]

Figure 5: Secondary stove use at baseline



Tertiary stove use was also reported in a small proportion of homes (ranging 6%-12% in the charcoal stove groups and 6% in the ACE1 and Biolite HomeStove groups). The most frequently used tertiary stove type was the kerosene stove (n=12, 39% of all tertiary stoves used).

3.4.1.1 Reported use of an 'improved charcoal' stove at baseline

As discussed in Section 3.1, the group's receiving an Envirofit Econochar 1.0, Burn Jikokoa or Prakti Leo Char stove included homes with an improved charcoal stove as a baseline stove. Consideration of this factor when allocating stoves led to the groups having similar proportions with an improved charcoal stove at baseline (Envirofit Econochar 1.0: 35%, Burn Jikokoa: 30%, Prakti Leo Char: 32%. p= 0.883 chi-squared test).

3.4.2 Follow up stove use: Mid-Term visit

It is important to note that the household members did not know exactly the timing of the mid term visit and so were unable to prepare for the visits. This approach potentially increased the number of homes that were not available for the visit but allowed the team to see a more accurate picture of the cooking patterns post stove dissemination.

Apart from the group with the Biolite HomeStove stove, the majority of homes had the intervention stove in the cooking area on arrival at the study home [see Table 7].

Table 6 Presence of the intervention stove in cooking area on arrival at the home: Mid term visit.

	Total number households available for mid-term visit	% with intervention stove in cooking area on arrival at home
Envirofit Econochar 1.0	53	94%
Burn Jikokoa	50	98%
Ugastove	50	98%
Prakti Leo Char	52	85%
Briketi EcoStove	47	89%
ACE1	48	81%
Biolite HomeStove	50	62%

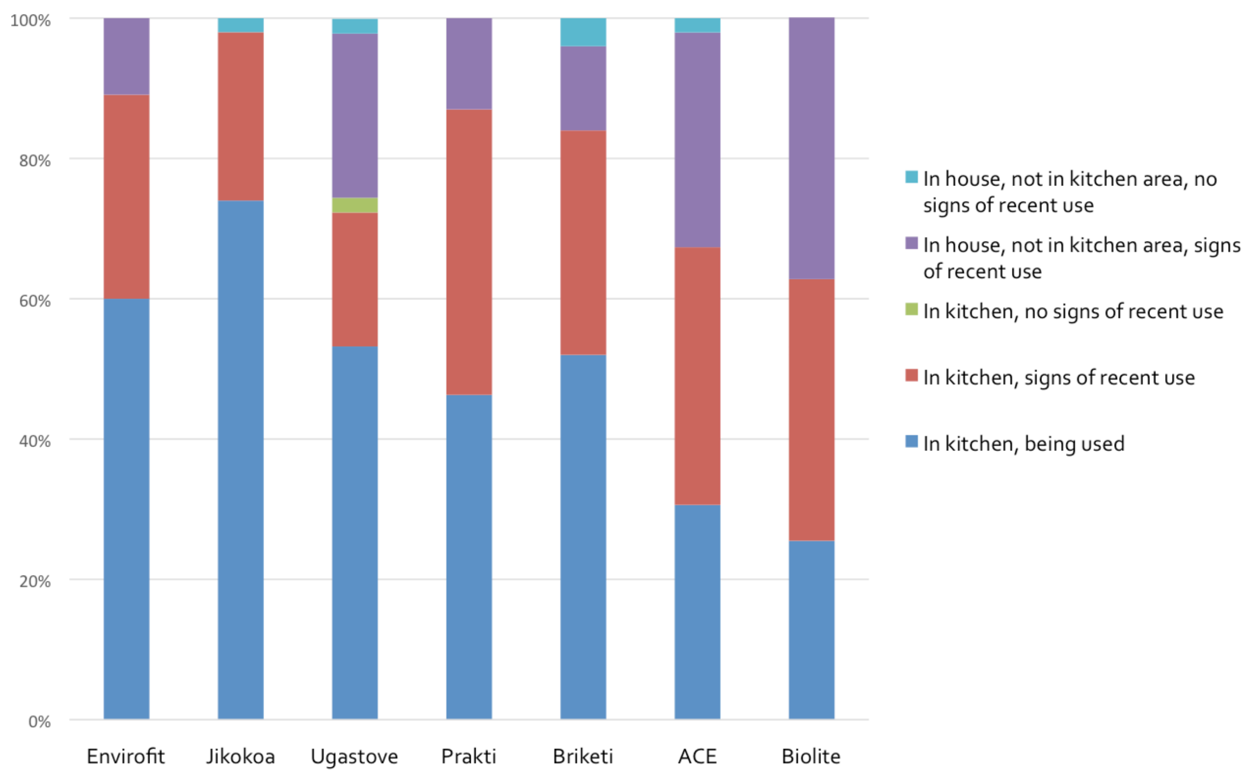
A summary of the status of the stoves at the mid term visit in outlined below.

- Only one stove was no longer at the study household as it had been taken to the participant's place of work.
- The remaining intervention stoves, which were not in the cooking area on arrival, were inside the house. All, apart from two of these (1-Ugastove and 1- Briketi EcoStove), showed signs of recent use such as collection of ash or discoloration.
- Several participants reported concerns that the intervention stove would be stolen and so moved it into the house away from the cooking area and brought it out only to cook. This was the reoccurring reported reason for not having the Biolite HomeStove in the cooking area on arrival to the home.
- 3 ACE1 stoves were temporality out of use due to the dirt/ grit obstructing the fan. The field team cleared the obstruction and the stoves were returned to working order.
- Where the intervention stove was in the cooking area on arrival at the home, most households also had another stove suggesting the presence of stove stacking.

3.4.3 Follow up stove use: 5 week follow up visit

Figure 8 shows the status of the intervention stove on arrival at the study homes 5 weeks after stove dissemination. All stoves were still present in the house. The ACE1 and Biolite HomeStove stoves were least likely to be in the kitchen area; further questioning revealed that rather than an indication of low use, in several cases this was due to a fear of the stove being stolen and so after cooking the stove was removed from the outdoor kitchen area to inside the home. Very few stoves showed no signs of recent use.

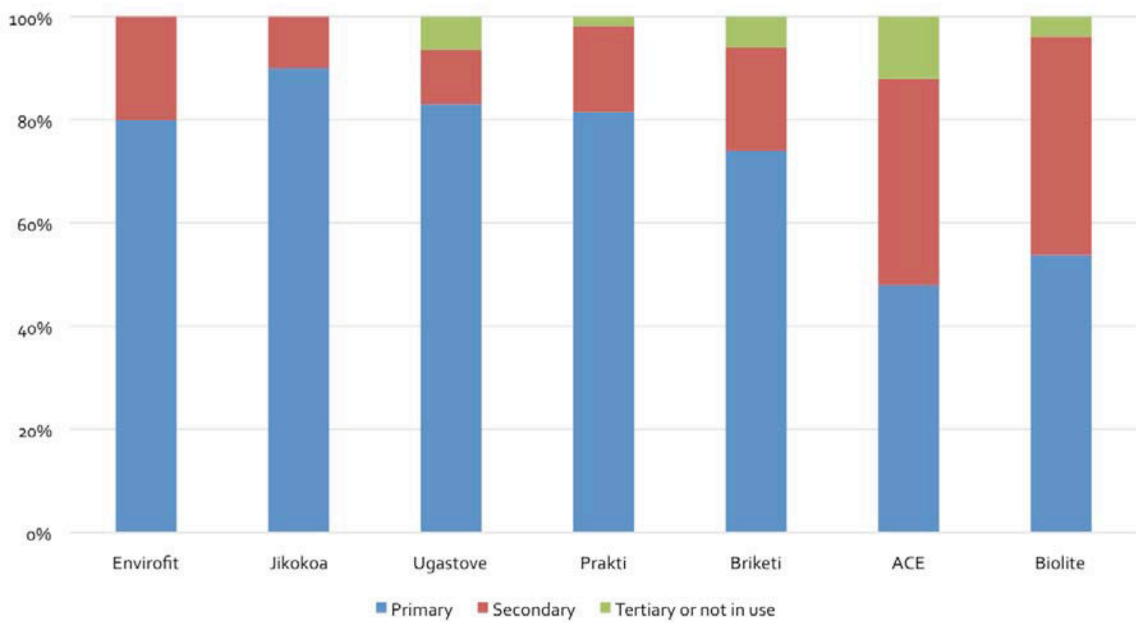
Figure 6: Status of intervention stove on arrival at the home: 5 week follow up visit



3.4.3.1 Reported stove use: 5 week follow up

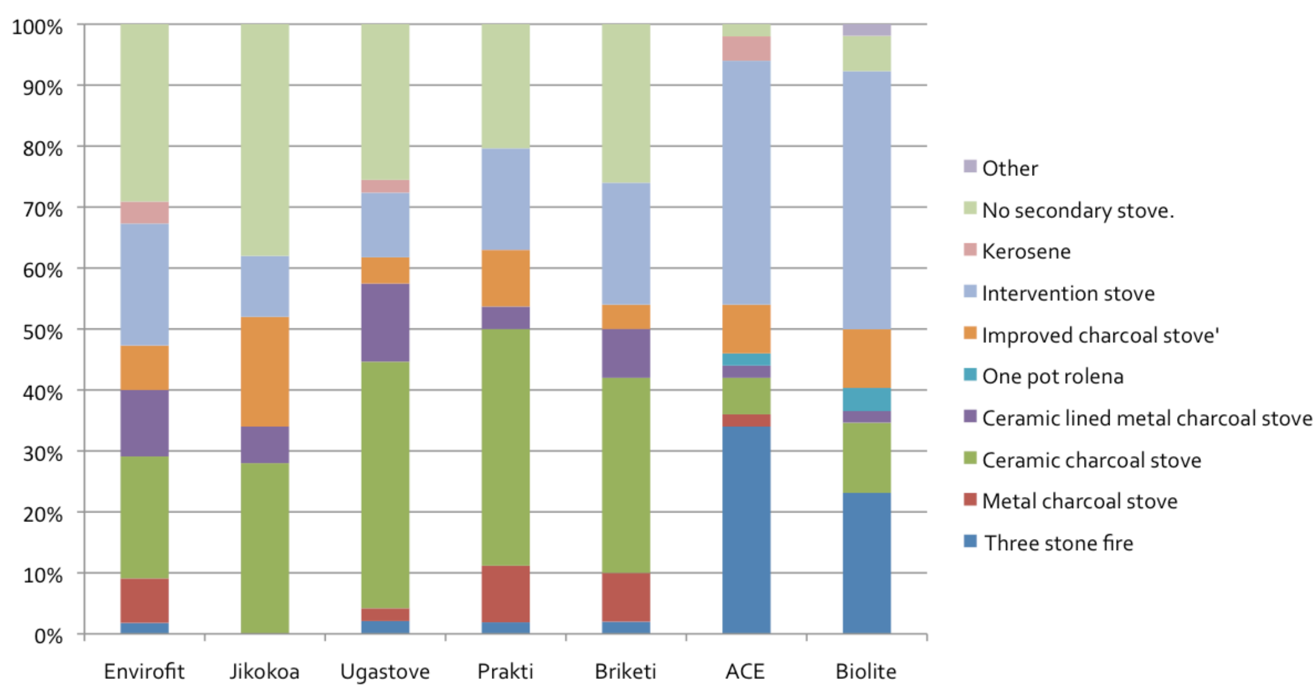
5 weeks after the intervention stove was installed, the participants were asked what stove type they "currently used most of the time" and then "what would you say is your secondary stove". The reported status of the intervention stove in response to these questions is reflected in Figure 9. The frequency of households reporting to use the intervention stove as the 'stove they use most of the time' (categorized as the primary stove for the figure) was significantly higher in the charcoal burning stoves compared to the ACE1 and Biolite HomeStove stoves, which were more likely to be the secondary stove used in the home [p-value <0.01 chi squared test]. The rates of tertiary or no use were minimal but highest in the ACE1 stove (12%). The intervention stove most likely to be used as the primary stove was the Burn Jikokoa (90%).

Figure 7: Reported status of intervention stove, primary, secondary or tertiary stove: 5 week follow up visit



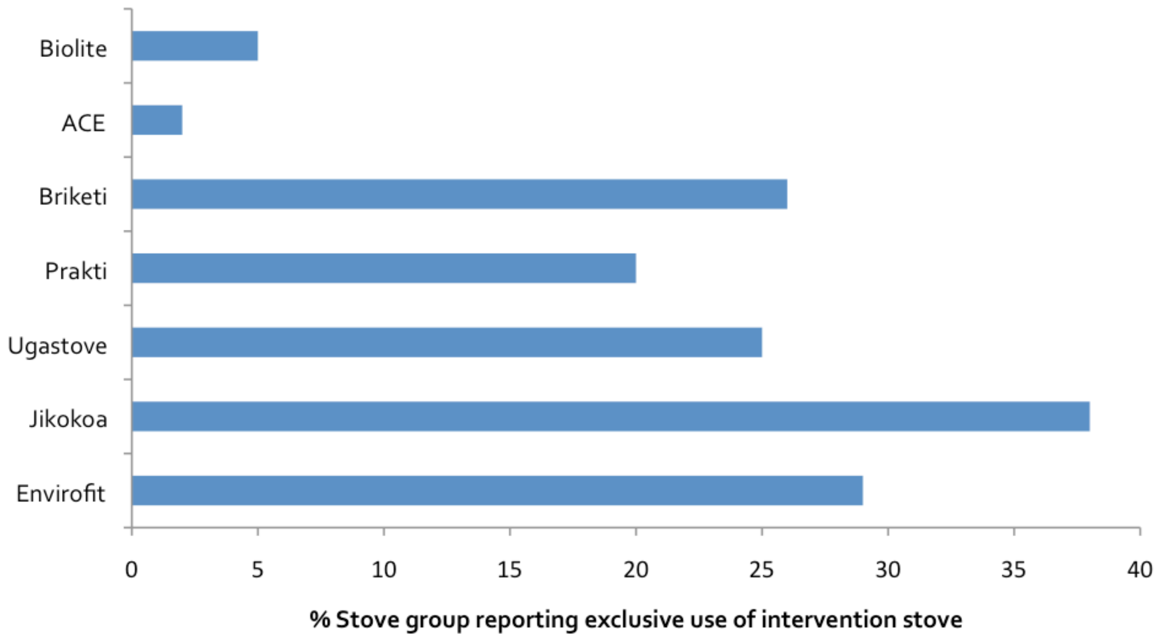
Although the intervention stove was reported to be the primary stove in the majority of charcoal using households, they often co-existed with baseline stoves. Figure 11 shows that the reported secondary stove use was high in all stove groups. The ceramic charcoal stove was the device most frequently used as the secondary stove in the charcoal intervention stove groups. The ACE and Biolite HomeStove homes were most likely to use the intervention stoves as the secondary device.

Figure 8 Secondary stove use pattern: 5 week follow up visit.



Reflecting the high rate of secondary stove use, exclusive use of the intervention stove was self-reported in only 21% of all study households. The rate of exclusive use was however much higher in the households with a charcoal burning intervention stoves compared to the ACE1 and Biolite HomeStove homes, with the highest rate reported in the Burn Jikokoa group (38%) (Figure 13).

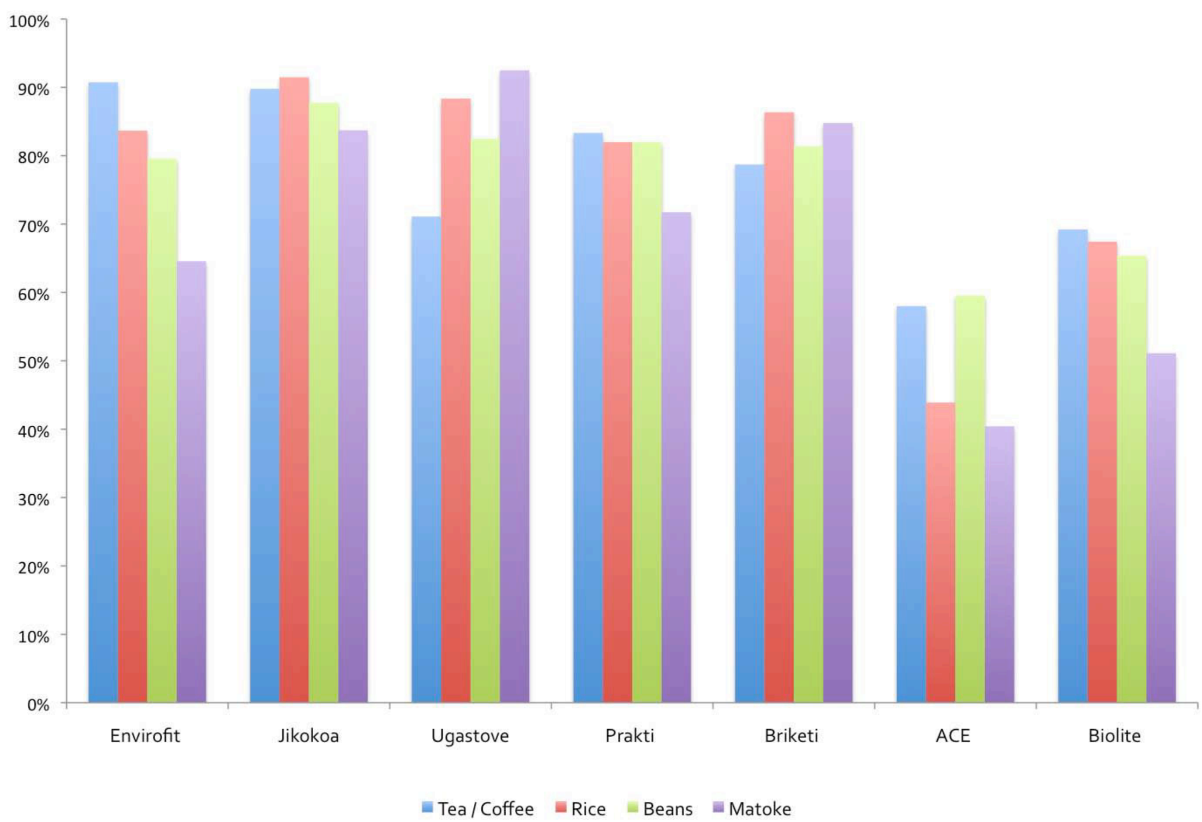
Figure 9: Proportion of households reporting exclusive use of the intervention stove 5 weeks after dissemination (% of stove group)



A comparison of the number of stoves used in an average week at baseline and then at 5 weeks post intervention showed a slight increase in the total number used (mean 1.9 SD 0.59) with a significant difference between intervention-stove groups (p=<0.001 ANOVA). The ACE1 and Biolite HomeStove stove homes reported to use the highest number of different stoves during an average week (ACE mean 2.3 SD 0.50 Biolite HomeStove mean 2.1 SD 0.5).

To explore the patterns of intervention stove use across different cooking tasks the cooks were asked which stove they usually used to prepare a range of items which require differing levels of fire power, cooking techniques and time demands. Figure 15 shows the integration of the intervention charcoal stoves was slightly more extensive than the wood burning stoves for all cooking tasks. The task least likely to be carried out on all intervention stoves except the Ugsatove and Briketi stoves was cooking matoke which requires slow steaming over a long period.

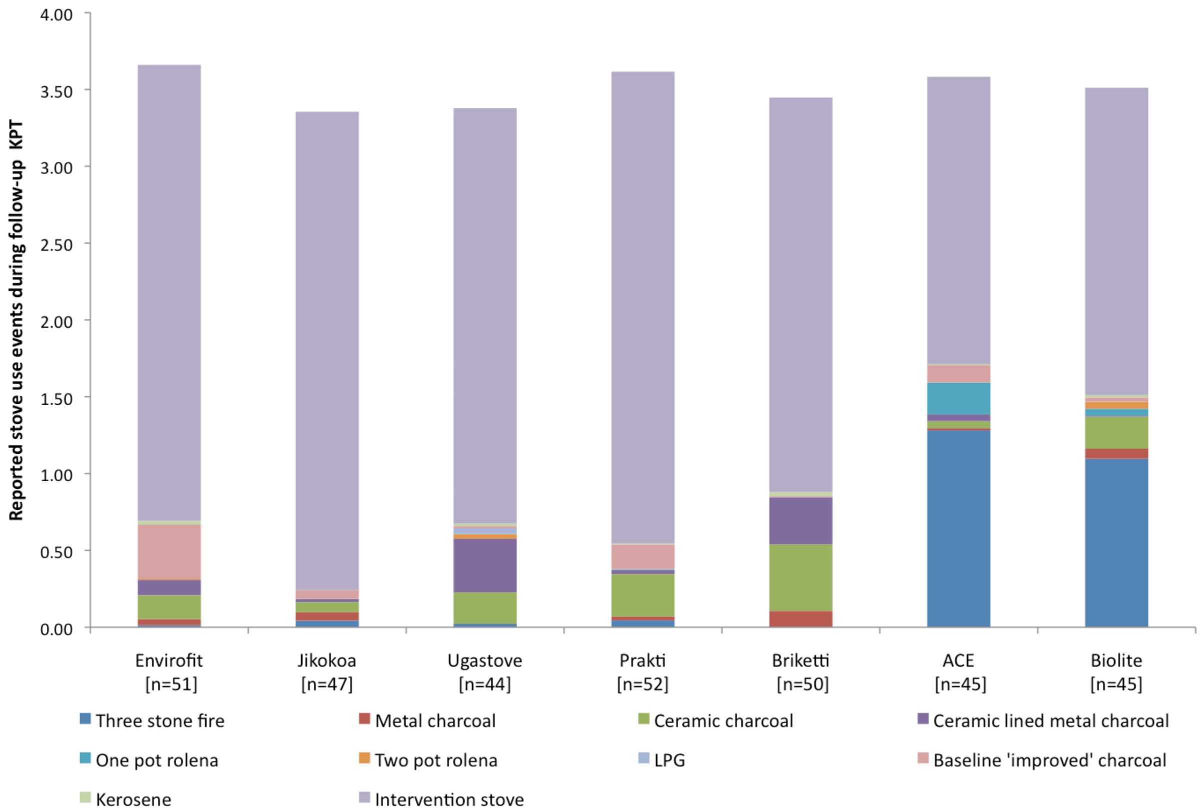
Figure 10: Proportion of homes carrying out cooking tasks on intervention stoves [self reported]



3.4.4 Reported stove use during the follow up KPT

Figure 16 shows the **self-reported stove use** based on KPT survey questions over the three-day follow up assessment. ANOVA test showed no difference between the average number of reported stove use events between intervention stove groups during the follow up KPT ($p=0.670$ on log-transformed data) with all groups having an average between 3.4 to 3.7 stove events per day. Based on this self reported data the Burn Jikokoa was used for most (93%) of the stove events carried out during the 3 day KPT, with the ACE1 and Biolite HomeStove's contributing to approximately 55% of the overall stove events during the KPT assessment period.

Figure 11: Self reported stove events during follow up KPT



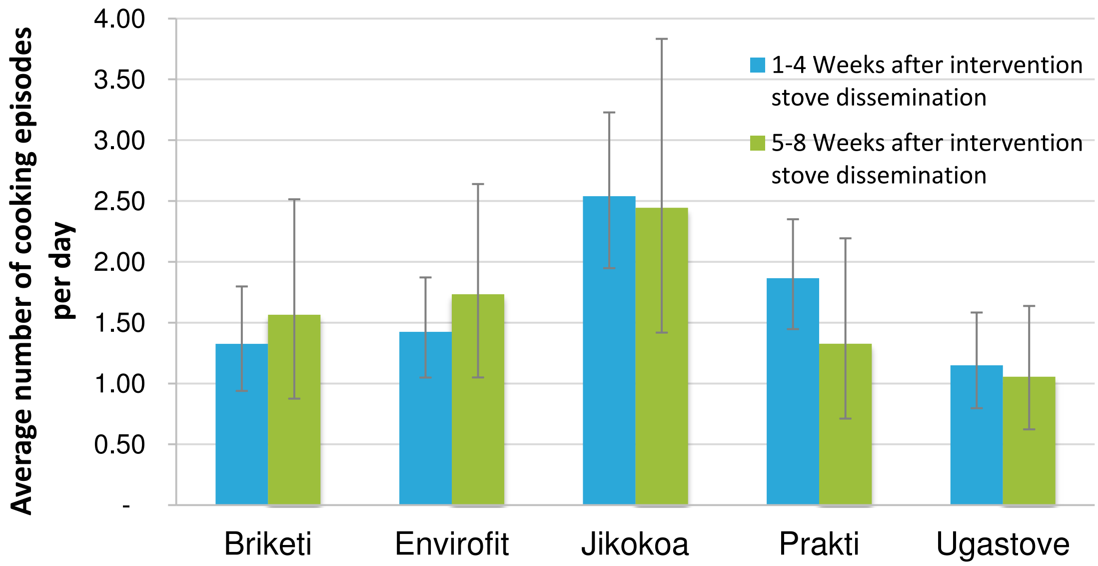
3.4.5 Measured use

3.4.5.1 Charcoal burning intervention stove group

Charcoal intervention stove use

The Burn Jikokoa group presented the highest number of cooking episodes carried out on an intervention stove per day during the first 4 weeks after stove distribution (median = 2.54) followed by the Prakti (median =1.87). The difference between the Burn Jikokoa and all other cookstove models except Prakti Leo Char is statistically significant at the 90% confidence level during these 4 weeks. However, the differences between the Briketi, Ugastove, Envirofit and Prakti stoves are not statistically significant. It is worth noting that SUMS were placed in less than 20 samples of each stove model, so the small sample sizes make it difficult to make precise comparisons. Figure 12 presents average intervention stove usage during the first 4 weeks and from weeks 5-8 after stove dissemination.

Figure 12: Average intervention stove use 1-4 weeks and 5-8 weeks post dissemination: Charcoal intervention group.



Note: KPTs were conducted during week 5. Some studies[22] have reported the possibility of the presence of Hawthorne effect (cooking behaviors being affected by the awareness of being observed) during KPTs. We analyzed individual SUMs records, but could not find evidence, based on our small sample, of this effect during the time of KPTs.

Because sample sizes reduced for the 5-8 week period after stove installation, the differences across stove models are not significant. Trends in stove usage over time are also difficult to ascertain based on the small sample sizes. However, some stove-adoption models, like that presented by Ruiz-Mercado et al (2011),[23] outline a dynamic pattern of improved cookstove adoption over time. Under Ruiz-Mercado et al's model, adoption begins by an initial acceptance, followed a learning time for the population to incorporate the device into the existing cooking practices (where adoption increases), and a stable level of sustained use with temporal fluctuations due to seasonality, availability of cash, special events, etc which is lower than the maximum attained at the end of the learning time.

In practice, during our study the population behavior around the stove use might have been affected by 1) initial and personalized training (which may have helped reduce the learning phase) and 2) by the uncertainty of owning the stove after the 1 month trial period. In fact, 37% of the participants reported having a stove use pattern affected by the uncertainty of the stove price (participants were told that stoves were going to be sold at the end of the trial period, but

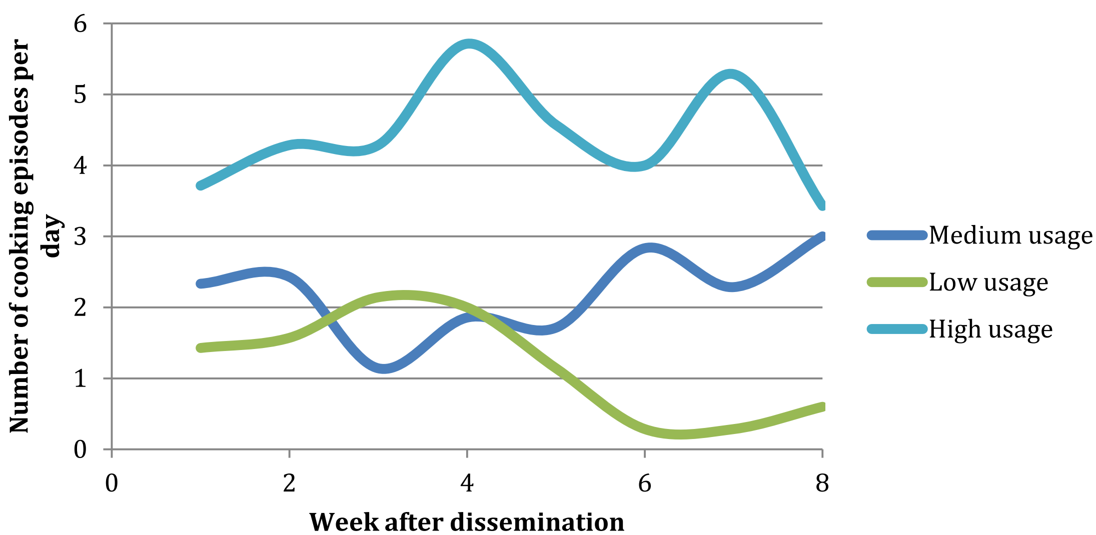
[22] See Rosenbaum, Julia, Elisa Derby, and Karabi Dutta. "Understanding consumer preference and willingness to pay for improved cookstoves in Bangladesh." Journal of health communication 20, no. sup1 (2015): 20-27 and Beltramo, Theresa, and David I. Levine. "The Effect of Solar Ovens on Fuel Use, Emissions, and Health: Results from a Randomized."

[23] Ruiz-Mercado, Ilse, Omar Masera, Hilda Zamora, and Kirk R. Smith. "Adoption and sustained use of improved cookstoves." Energy Policy 39, no. 12 (2011): 7557-7566.

the price was not revealed beforehand). 10 % of the sample reported using it more (e.g. to get a good sense of the stove performance or to take advantage of the opportunity of cooking in the stove while they had it) and 27% reported using it less (mostly for fear of breaking it apart and being held liable for the stove damage).

The analysis of individual trends in intervention stove usage revealed high variability over time, but general patterns of adoption. Figure 13 presents 3 examples of individual intervention stove use patterns over a period of 8 weeks.

Figure 13: Intervention stove use patterns over a period of 8 weeks: Charcoal stove groups



The high-use stove is potentially meeting most of the household cooking needs and the pattern of adoption over time, although variable, presents a consistent high-usage trend. In contrast, the low-usage stove was used with moderate intensity during the trial period, but its use fell soon after to meet potentially just a few cooking needs. The medium-usage stove shows increased adoption over time possibly due to a learning period where the household progressively adapts its cooking needs to the device.

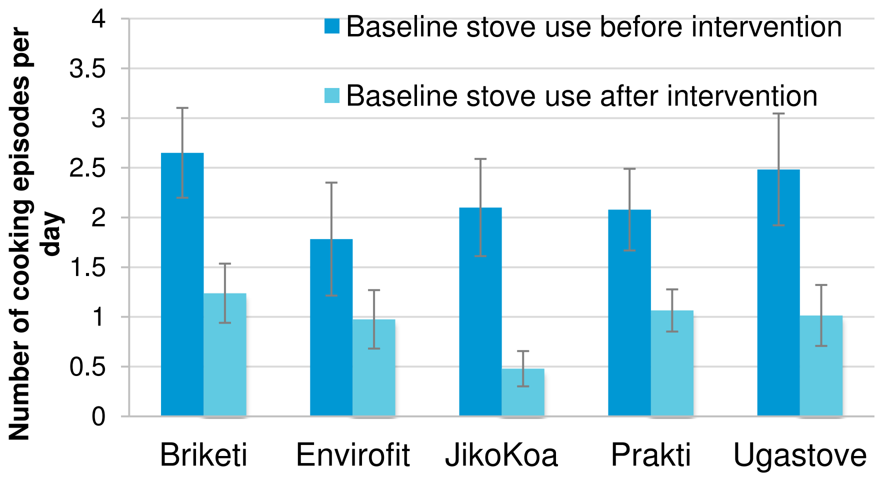
Baseline stove use

Data recorded using SUMS showed the average number of cooking episodes per day performed on baseline stoves fell from a mean of 2.11 events/day at baseline to a mean of 0.91 events/day after introducing the intervention stoves, or a 57% reduction for the general population (p-value of difference across entire population <0.001).[24] The differences in baseline stove use at baseline between the different models were not statistically significant, but the Burn Jikokoa stove presented a statistically significant difference with respect to other stoves in baseline stove use post-intervention (this model recorded the lowest baseline stove use after introducing the intervention stove). Figure 14 presents the number of cooking episodes before

[24] Baseline stove use was assessed during the baseline KPT. The trends of after intervention stove introduction were assessed for the first 2 weeks after introducing the intervention stove using. All measurements were assessed using SUMS.

the intervention stove was introduced (darker blue bars) and after the intervention stove was introduced (light blue).[25]

Figure 14: Number of cooking episodes before and after intervention stove dissemination.



<u>Displacement of baseline stove use</u>

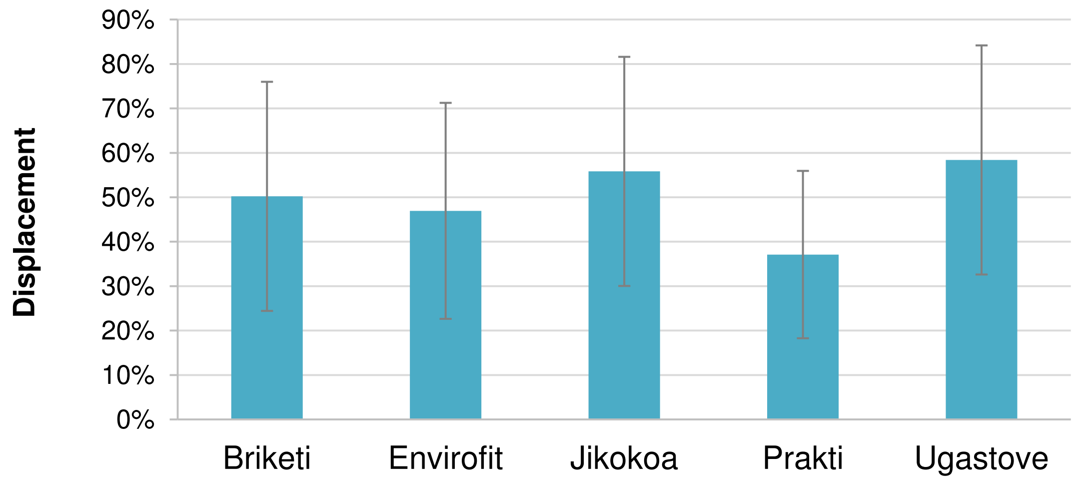
We explored whether the number of cooking episodes found for each intervention stove model were due to differences in the number of cooking episodes at baseline. For instance, households with a given intervention stove model that cooked more at baseline would present a higher number of cooking episodes carried over the intervention stove because the household cooks more in the first place.

To test whether the reductions in baseline stove use were different between stove models, we computed the percent reduction in cooking episodes from baseline to post-intervention.[26] This analysis is independent of the number of cooking episodes at baseline and therefore intervention stove groups that reported fewer cooking episodes at baseline are not penalized. Among charcoal stoves, Ugastove displaced the largest amount of traditional stove cooking episodes (58%) and the other charcoal intervention stoves displaced between 56% (Jikokoa) and 36% (Prakti). Figure 15 presents the average level of displacement and the error bars represent the 90% confidence interval of each stove model's data.

[25] This value takes the average of the number in cooking episodes for the first 9 weeks after the intervention stove dissemination.

[26] The displacement is calculated by computing the % reduction in the number of cooking episodes in traditional stoves from the baseline to when the intervention stoves were present in households. The reductions were computed at the household level and averaged across each stove model's data.

Figure 15: Average % of baseline stove displacement by intervention stove group: charcoal stoves

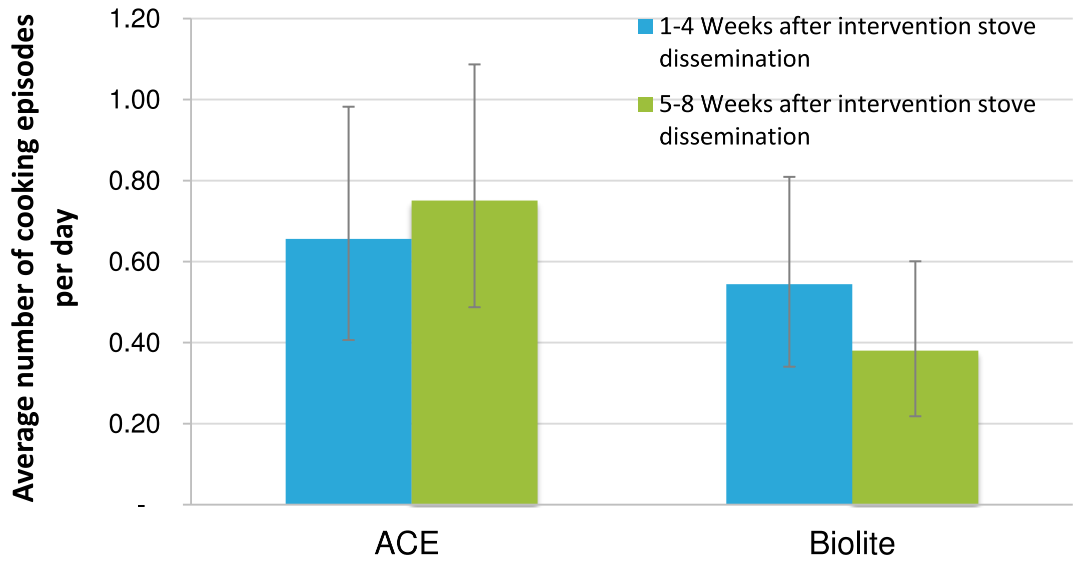


All intervention stoves show statistically significant displacement of baseline stoves. However, the differences between stove models are not statistically significant based on the small sample. Larger sample sizes may reveal differences across the different stove models. Note that the amount of cooking that the household performs may change from baseline to post-intervention. For instance, households may increase dietary intake if fuel savings are allocated to preparing more food. For interpretation purposes, it is also worth noting that baseline stove use before introduction of intervention stoves was assessed only during 3 days and that seasonal changes occurred during the intervention assessment period that could have affected the number of cooking episodes. Therefore, we suggest interpreting the amount of displacement as an indicative, rather than a conclusive measure.

3.4.5.2 Wood burning intervention stove group

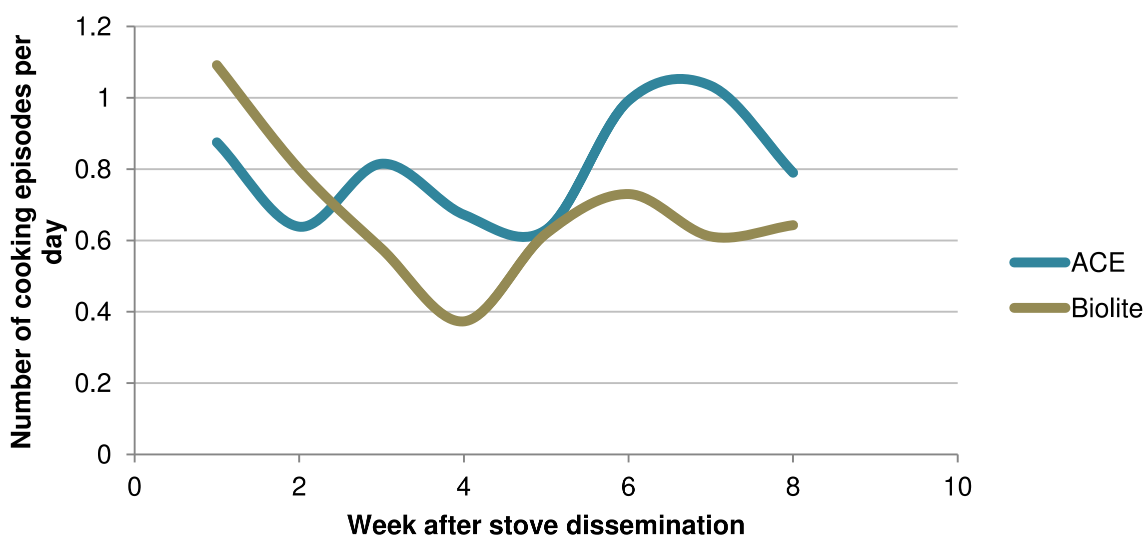
Baseline stove use among the ACE1 and Biolite HomeStove groups cannot be assessed reliably because many of the stoves were possibly moved away from iButtons (which were located near and not on the three stone fires in many cases) or were changed for other baseline stoves (the reasons could be seasonal changes in the period between baseline and follow-up KPTs made people select different cooking locations, the introduction of intervention stoves displaced the cooking location of the traditional stoves, or other). However, we were able to obtain more reliable estimates of the number of cooking episodes performed on the intervention stoves. The trends are presented in Figure 16 below:

Figure 16:Average intervention stove use 1-4 weeks and 5-8 weeks post dissemination: Wood intervention group.



Overall, the differences in usage between ACE and Biolite are not statistically significant either in the first 4 weeks after stove dissemination or after. Figure 17 presents a week-by-week comparison of the trends in stove use for the two stove models.

Figure 17 Intervention stove use patterns over a period of 8 weeks: Charcoal stove groups



Clear trends are difficult to ascertain because of the small sample sizes in the population (17-20 samples per stove model). However, as in the case of charcoal stoves, the number of cooking episodes on the stoves is unstable over time.

3.5 Fuel Use

After removal of households with inconsistent or missing information, data for 333 households were available for the before and after KPT analysis (between 44-52 homes per stove group).

Table 8- Table 14 presents the fuel consumption measured during the three day KPT for the 7 stove groups. Data is presented as kilograms (kg) of charcoal and/or wood and total energy use (MJ), which takes into account **all fuels used on all the cookstoves in the home**. Each is presented on a 'per HH /per day basis', as well as on a 'per standard adult equivalent[27] (SA) per day' basis which controls for the calorific requirements of different age/sex groups of the people cooked for and by 'per person meals cooked' which is calculated using the reported number of people cooked for during the KPT monitoring. The SA and 'person meals cooked' metrics controls for different household sizes and number of people cooked for and provides more comparable values than the household level estimates.

Charcoal Burning Intervention Stoves

There was no significant difference between charcoal consumption per standard adult/per day or total energy consumption per standard adult per day between the charcoal burning intervention stove groups at baseline (p=0.788 charcoal SA/day and p=0.718 total energy consumption SA/per day. ANOVA on log-transformed data).

Table 7 provides a summary of the over all % savings for each charcoal burning intervention stove as measured during the 3 day KPT's at baseline and 5 week follow up visit. Analysis showed the highest reduction in charcoal use kg/per SA/per day was in the group with the Burn Jikokoa, which showed a statistically significant 22% reduction (p=<0.01). The group with the Prakti Leo Char stove had the next largest savings with a 13% reduction in kg charcoal /SA/day although this result was only borderline statistically significant (p=0.08).

Table 7: % savings for all charcoal burning stoves

	Charcoal Use			Total Energy Use		
	kg/HH/day	kg/SA/day	kg/person meal	MJ/HH/ day	MJ/SA/ day	MJ/person meal
Envirofit Econochar 1.0	**15%**	4%	3%	**16%**	5%	4%
Burn Jikokoa	**22%**	**22%**	11%	**19%**	**19%**	8%
Ugastove	**20%**	9%	-3%	**21%**	10%	-2%
Prakti Leo Char:	**16%**	13%	5%	**16%**	13%	5%
Briketi EcoStove	9%	6%	-4%	**10%**	7%	-3%

Note: Values significant at the 0.05 level are in bold.

As is expected when the majority of the study population is mono cooking fuel households, the total energy consumption followed a similar pattern as the charcoal. The Burn Jikokoa homes saw a 19% statistically significant reduction in MJ/SA/day (p=0.03) and the Prakti Leo Char

[27] "Standard adult" equivalence factors defined in terms of sex and age (from Guidelines for Woodfuel Surveys, for F.A.O. by Keith Openshaw cited in (Joseph, 1990)). Gender and age fraction of standard adult: child 0-14 years = 0.5; female over 14 years = 0.8; male 15-59 years = 1; and male over 59 years = 0.8.

stove showed the next highest savings with a 13% reduction that was boarder line statistically significant (p=0.08).

Table 8: Summary of fuel use measured by 3 day KPT: Envirofit Econochar 1.0 Stove

Envirofit Econochar 1.0 n=51	Charcoal Use			Total Energy Use		
	kg/HH/day	kg/SA/day	kg/person meal	MJ/HH/ day	MJ/SA/ day	MJ/person meal
Baseline						
Median	1.68	0.43	0.10	51.40	13.23	3.13
Lower 90% CI	1.07	0.39	0.10	14.55	3.65	1.01
Upper 90% CI	1.92	0.50	0.11	58.72	15.20	3.48
Follow Up						
Median	1.44	0.42	0.10	43.41	12.56	3.01
Lower 90% CI	0.98	0.37	0.10	12.19	4.20	0.98
Upper 90% CI	1.64	0.46	0.11	49.68	13.88	3.34
% Difference	**15%**	4%	3%	16%	5%	4%
Upper 95% CI of savings (%)	24%	14%	13%	19%	15%	14%
Lower 95% CI of savings (%)	4%	-8%	-8%	12%	-6%	-7%
p value	0.04	0.552	0.652	<0.001	0.440	0.524

Note: Values shown are back transformed data. All analysis conducted on log-transformed data. The CI are therefore no longer symmetrical

Table 9: Summary of fuel use measured by 3 day KPT: Burn Jikokoa

Burn Jikokoa n=47	Charcoal Use			Total Energy Use		
	kg/HH/day	kg/SA/day	kg/person meal	MJ/HH/ day	MJ/SA/ day	MJ/person meal
Baseline						
Median	1.80	0.46	0.11	54.86	13.23	3.13
Lower 90% CI	1.09	0.41	0.10	16.08	4.43	0.95
Upper 90% CI	2.06	0.52	0.12	63.53	15.77	3.67
Follow Up						
Median	1.41	0.36	0.09	43.40	12.55	3.01
Lower 90% CI	0.95	0.33	0.09	12.53	3.44	0.78
Upper 90% CI	1.61	0.41	0.11	50.87	12.87	3.46
% Difference	22%	22%	11%	19%	19%	8%
Upper 95% CI of savings (%)	32%	32%	24%	23%	31%	22%
Lower 95% CI of savings (%)	10%	10%	-4%	15%	6%	-9%
p value	<0.01	<0.01	0.218	<0.01	0.03	0.533

Note: Values shown are back transformed data. All analysis conducted on log-transformed data. The CI are therefore no longer symmetrical

Table 10: Summary of fuel use measured by 3 day KPT: Ugastove

Ugastove n=44	Charcoal Use			Total Energy Use		
	kg/HH/day	kg/SA/day	kg/person meal	MJ/HH/ day	MJ/SA/ day	MJ/person meal
Baseline						
Median	1.70	0.49	0.12	51.60	14.82	3.60
Lower 90% CI	1.03	0.42	0.11	14.15	4.06	1.04
Upper 90% CI	1.97	0.47	0.14	59.96	17.22	4.13
Follow Up						
Median	1.36	0.44	0.12	40.75	13.33	3.65
Lower 90% CI	0.92	0.39	0.12	12.70	4.32	1.02
Upper 90% CI	1.53	0.50	0.14	46.04	14.93	4.23
% Difference	20%	9%	-3%	21%	10%	-2%
Upper 95% CI of savings (%)	28%	19%	11%	26%	20%	12%
Lower 95% CI of savings (%)	11%	-3%	-19%	16%	-1%	-18%
p value	<0.001	0.199	0.752	<0.001	0.136	0.855

Note: Values shown are back transformed data. All analysis conducted on log-transformed data. The CI are therefore no longer symmetrical

Table 11: Summary of fuel use measured by 3 day KPT: Prakti Leo Char

Prakti Leo Char n=52	Charcoal Use			Total Energy Use		
	kg/HH/day	kg/SA/day	kg/person meal	MJ/HH/ day	MJ/SA/ day	MJ/person meal
Baseline						
Median	1.75	0.48	0.11	54.51	14.90	3.34
Lower 90% CI	1.10	0.42	0.10	16.22	4.47	0.94
Upper 90% CI	1.99	0.55	0.12	61.55	16.80	3.81
Follow Up						
Median	1.47	0.42	0.10	45.84	12.98	3.17
Lower 90% CI	1.00	0.37	0.10	14.54	4.02	0.92
Upper 90% CI	1.63	0.47	0.12	51.13	14.55	3.61
% Difference	16%	13%	5%	16%	13%	5%
Upper 95% CI of savings (%)	26%	24%	18%	19%	23%	18%
Lower 95% CI of savings (%)	4%	1%	-10%	12%	1%	-10%
p value	0.03	0.08	0.56	<0.001	0.08	0.56

Note: Values shown are back transformed data. All analysis conducted on log-transformed data. The CI are therefore no longer symmetrical

Table 12: Summary of fuel use measured by 3 day KPT: Briketi EcoStove

Briketi EcoStove n=50	Charcoal Use				Total Energy Use		
	kg/HH/day	kg/SA/day	kg/person meal		MJ/HH/ day	MJ/SA/ day	MJ/person meal
Baseline							
Median	1.56	0.44	0.10		47.67	13.38	3.20
Lower 90% CI	1.02	0.39	0.10		13.48	4.03	0.93
Upper 90% CI	1.79	0.49	0.12		54.54	15.10	3.64
Follow Up							
Median	1.42	0.41	0.11		43.05	12.40	3.30
Lower 90% CI	0.66	0.15	0.05		14.74	3.96	1.00
Upper 90% CI	1.57	0.46	0.12		47.43	13.85	3.73
% Difference	9%	6%	-4%		10%	7%	-3%
Upper 95% CI of savings (%)	18%	16%	7%		12%	17%	8%
Lower 95% CI of savings (%)	-1%	-4%	-17%		7%	-3%	-16
p value	0.133	0.294	0.558		<0.001	0.237	0.638

Note: Values shown are back transformed data. All analysis conducted on log-transformed data. The CI are therefore no longer symmetrical.

Wood Burning Stoves

Data from before and after intervention was available from only 5 households that had swapped from charcoal as their primary cooking fuel to wood and/or briquettes. The numbers are too small to analyze this group with confidence separately and so they have been included in their respective intervention stove groups. Due to this and, in the case of the ACE1 stove homes, the fact that some homes also switched from wood to a combination of wood and briquettes, the changes in total energy consumption is a more reliable estimate of impact in these homes than looking at fuels on an individual basis.

There was no significant difference between total energy consumption per standard adult per day between the ACE1 and Biolite HomeStove groups at baseline (p=0.229 total energy consumption SA/per day, Independent samples t-test).

Even though their reported exclusive use was limited, data from homes with both ACE and Biolite HomeStove stoves showed statistically significant reductions in total energy consumption (kg/SA/day) between baseline and follow up monitoring. The ACE showed a slightly higher reduction at 22% (p=0.01): the Biolite HomeStove group 18% (p=0.04).

Wood Burning stoves

Table 13: Summary of fuel use measured by 3 day KPT: ACE Stove

ACE 1 n=45	Charcoal Use			Wood Use			Total Energy Use		
	kg/HH/day	kg/SA/day	kg/person meal	kg/HH/day	kg/SA/day	kg/person meal	MJ/HH/day	MJ/SA/day	MJ/person meal
Baseline									
Median	0.78	0.16	0.03	4.54	0.97	0.22	94.37	20.47	4.70
Lower 90% CI	0.51	0.14	0.03	3.68	0.79	0.18	25.71	5.75	1.30
Upper 90% CI	1.07	0.22	0.05	5.59	1.19	0.27	109.64	23.62	5.44
Follow Up									
Median	0.61	0.13	0.03	2.97	0.66	0.17	68.82	15.86	4.10
Lower 90% CI	0.37	0.12	0.03	0.70	0.17	0.04	17.83	4.32	1.06
Upper 90% CI	1.02	0.24	0.06	12.66	2.58	0.64	80.92	18.43	4.82
% Difference	42.46	33.76	-1.13	31.72	27.83	19.29	27.07	22.51	12.83
Upper 95% CI of savings (%)	69.42	65.80	39.42	48.28	45.46	38.56	38.85	36.15	29.15
Lower 95% CI of savings (%)	-8.26	-28.30	-68.82	9.87	4.48	-6.03	13.02	5.95	-7.26
P value	0.081	0.198	0.962	0.008	0.024	0.120	0.001	0.011	0.189

Note: Values shown are back transformed data. All analysis conducted on log-transformed data. The CI are therefore no longer symmetrical

Table 14: Summary of fuel use measured by 3 day KPT: Biolite HomeStove Stove

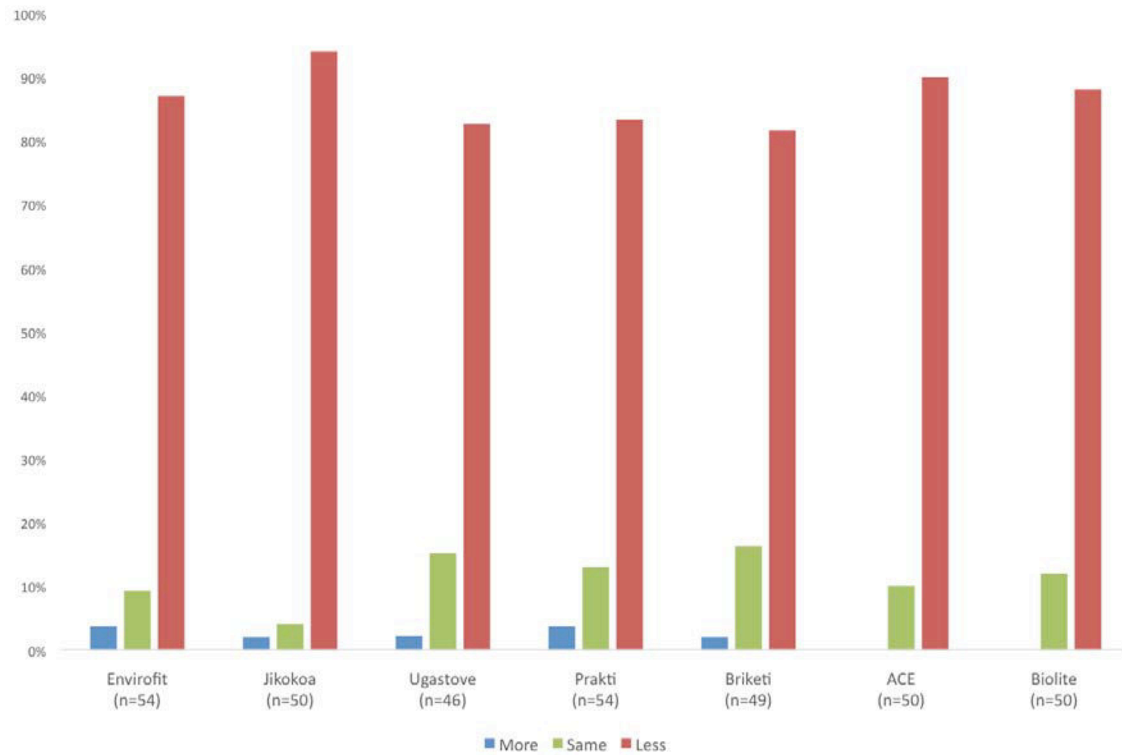
Biolite HomeStove n=45	Charcoal Use			Wood Use			Total Energy Use		
	kg/HH/day	kg/SA/day	kg/person meal	kg/HH/day	kg/SA/day	kg/person meal	MJ/HH/day	MJ/SA/day	MJ/person meal
Baseline									
Median	0.83	0.18	0.04	5.28	1.27	0.28	102.49	24.63	5.47
Lower 90% CI	0.48	0.16	0.04	4.66	1.11	0.24	33.02	7.56	1.56
Upper 90% CI	1.20	0.28	0.06	5.98	1.46	0.33	90.30	22.92	5.58
Follow Up									
Median	0.70	0.17	0.04	3.79	0.95	0.23	80.69	20.16	4.90
Lower 90% CI	0.43	0.15	0.04	3.27	0.80	0.20	26.16	6.07	1.46
Upper 90% CI	1.05	0.24	0.06	4.39	1.11	0.27	114.85	27.87	6.29
% Difference	50%	43%	34%	30%	26%	19%	21%	18%	10%
Upper 95% CI of savings (%)	74%	70%	68%	40%	38%	33%	26%	30%	24%
Lower 95% CI of savings (%)	4%	-11%	-36%	18%	13%	2%	16%	4%	-6%
P value	0.085	0.157	0.652	<0.001	0.005	0.067	0.006	0.036	0.282

Note: Values shown are back transformed data. All analysis conducted on log-transformed data. The CI are therefore no longer symmetrical

3.4.3.Perceived changes in fuel consumption

The respondents were asked about their perception on changes in fuel consumption since receiving the intervention stove 5 weeks previously (Figure 18). The majority of homes (>80%) in all stove groups reported that since getting the stove they were using less fuel. Between 5-17% reported no change and 2-5% reported using more fuel. Notably no homes in the ACE1 and Biolite HomeStove groups reported to be using more fuel.

Figure 18:Perceived changes in fuel consumption post intervention stove installation



3.6 Fuel Economy

Household fuel economy was assessed using two approaches to allow for verification and cross checking: In addition to the KPT data presented in Section 3.5, self-reported fuel expenditures both before and after stove installation were cross checked using data from a survey of local market prices for all cooking fuels purchased by the study households.

Market survey

Table 15 shows the average weight of charcoal by price paid according to study parish. 1000 and 2000 UGX worth of charcoal were the volumes most frequently purchased by the study households during the KPTs. This amount is often bought on a daily basis from mobile or nearby street vendors. Purchase of large sacks of charcoal occurs in the minority of households

Table 15: Average cost of units of charcoal by study parish.

	Price paid for charcoal (UGX)									
	1000		**1500**		**2000**		**3000**		**4000**	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Banda	1.70	0.27	1.72	0.03	3.14	0.59	4.58	0.95	6.29	1.20
Bukasa	1.75	0.26	-	-	3.01	0.37	-	-	-	-
Busega	1.61	0.23	-	-	-	-	-	-	5.39	0.87
Kansanga	1.45	0.18	2.49	0.22	2.73	0.39	-	-	-	-
Kasengejje	1.45	0.38	-	-	-	-	-	-	4.40	0.81
Katwe	1.73	0.43	-	-	-	-	4.65	0.86	5.97	1.21
Kisugu	1.64	0.24	-	-	2.92	0.55	-	-	-	-
Kitende	1.81	0.30	3.04	0.18	-	-	-	-	-	-
Maganjo	1.75	0.25	3.25	0.50	-	-	-	-	-	-
Makerere 1	1.51	0.33	2.36	0.57	3.15	0.38	-	-	-	-
Makerere 2	1.54	0.24	2.09	0.27	-	-	-	-	5.26	0.54
Masajja	1.74	0.38	2.20	0.46	3.02	0.71	4.24	1.05	5.73	0.96
Mbuya	2.00	0.17	2.00	-	2.75	0.54	4.06	0.72	5.42	1.02
Nangabo	1.34	0.32	2.08	0.38	3.04	0.47	-	-	-	-
Nsambya	1.74	0.21	2.48	0.44	3.31	0.43	4.92	0.63	6.68	0.80
All areas	**1.62**	**0.30**	**2.43**	**0.56**	**2.99**	**0.52**	**4.49**	**0.87**	**5.71**	**1.08**

3.6.1 Changes in fuel expenditure based on market survey and KPT data.

Charcoal prices from 15 parishes in Kampala were analyzed. The mean charcoal price per kg was UGX 671/Kg [95% confidence interval = UGX 706.88 and UGX 636.61; precision at 95% confidence = 5.2%].

Although economies of scale could be expected, these were very small. For every kg increase in the quantity purchased, the price per kg only decreased by approximately 1.5%. It should be noted that our sample included charcoal presentations in quantities ranging from 0.7 kg to 8.0 kg. Larger presentations are available and these could be cheaper on a per unit basis than what we found (Table 17).

Table 16: Estimated household level savings in expenditure on charcoal based on KPT and market survey data.

	Briketi	Envirofit Econochar 1.0	Burn Jikokoa	Prakti Leo Char	Ugastove
n	50	51	47	52	44
Charcoal saving HH/kg/day	0.14	0.25	0.39	0.28	0.34
Amount saved (UGX/HH/day)	93.82	164.63	264.26	188.76	229.03
Weekly saving (UGX)	656.77	1152.41	1849.81	1321.33	1603.18

3.6.2 Reported changes in expenditure on fuel.

Charcoal

As per the selection criteria all households selected to use the charcoal burning intervention stoves used charcoal as their main cooking fuel at baseline. An ANOVA test showed no statistically significant differences in baseline fuel expenditure between intervention-stove groups (p-value: 0.919 statistical analysis carried out in log-transformed data). The differences in average reported weekly expenditure (UGX[28]) for the main cooking fuel between baseline and follow up are presented in Table 18 and show the largest reported difference in expenditure on charcoal between baseline and follow up data was in the Burn Jikokoa group (35.6% p=<0.001) followed by the Ugastove group (26.6% p=0.002) which follows the pattern of fuel saving seen in the KPT data. However it was sometimes difficult to obtain clear information on reported expenditure from the participants particularly if the person being interviewed was the maid rather than family member. The values should therefore be treated with caution and seen as indicators of expenditure rather than definitive values.

Table 17:Difference in reported weekly expenditure on charcoal before and after intervention stove installation.

	Envirofit Econochar 1.0	Burn Jikokoa	Ugastove	Prakti Leo Char	Briketi EcoStove
Baseline					
n	55	46	46	52	45
Mean (UGX)	7304.66	7521.42	6725.12	7202.78	6629.79
Lower 95% CI	6161.81	6223.28	5824.44	6124.32	5635.60
Upper 95% CI	8659.48	9090.35	7765.07	8471.15	7799.38
Follow Up					
Mean (UGX)	5865.43	4845.07	4935.15	5638.97	5619.53
Lower 95% CI	5096.42	3969.96	4251.49	4655.63	4892.25
Upper 95% CI	6750.48	5913.09	5728.73	6830.01	6454.93
% Difference	19.7%	35.6%	26.6%	21.7%	15.2%
UGX savings per week	1439	2676	1790	1564	1010
P value	0.02	<0.001	0.002	0.05	0.05

Note: Values shown are back transformed data. All analysis conducted on log-transformed data. The CI are therefore no longer symmetrical.

Wood

Although 42% (n=21) ACE1 and 48% (n=25) Biolite HomeStove groups purchased all or most (over ¾) of the primary cooking fuel at baseline, the calculation of savings on weekly expenditure on cooking fuels was complicated by the fact that some homes within these two stove groups were swapping from charcoal to wood and/or briquettes or from wood to briquettes in the case of ACE1 users. Therefore changes in fuel expenditure is not presented for these two stove groups.

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28 At time of writing 1 USD= 3670 UGX

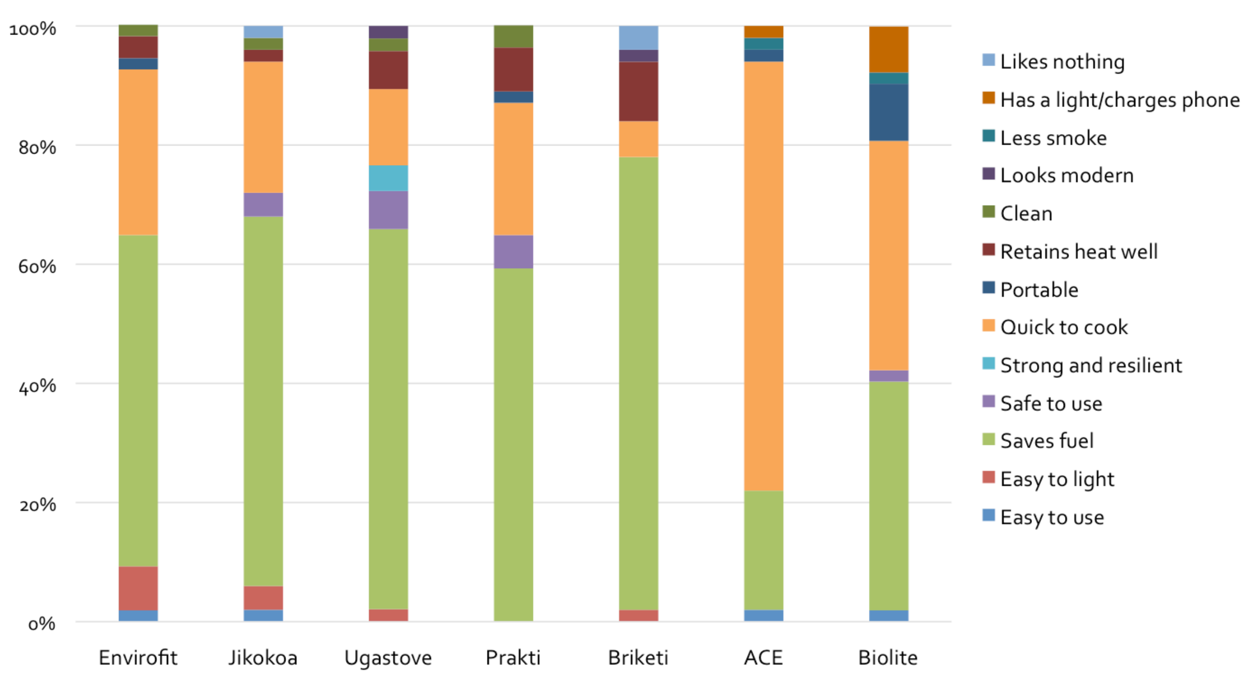
3.7 Reported Stove Perceptions

3.7.1 Perceptions of intervention stoves: 5 week follow up.

Figure 19 and Figure 20 shows the aspect most liked and disliked about the intervention stove 5 week after dissemination according to stove type. This was an unprompted response to the question "What is the main aspect you like (dislike) about the X?" after first confirming that there were in fact aspects they liked or disliked.

The perception that the stove saves fuel was the aspect most liked about all of the charcoal intervention stoves. The speed of cooking was the most frequently liked aspect of the ACE1[29] and Biolite HomeStove stoves; with fuel savings coming a close second (Figure 19.)

Figure 19 Reported aspect most liked about intervention stove, by stove type.

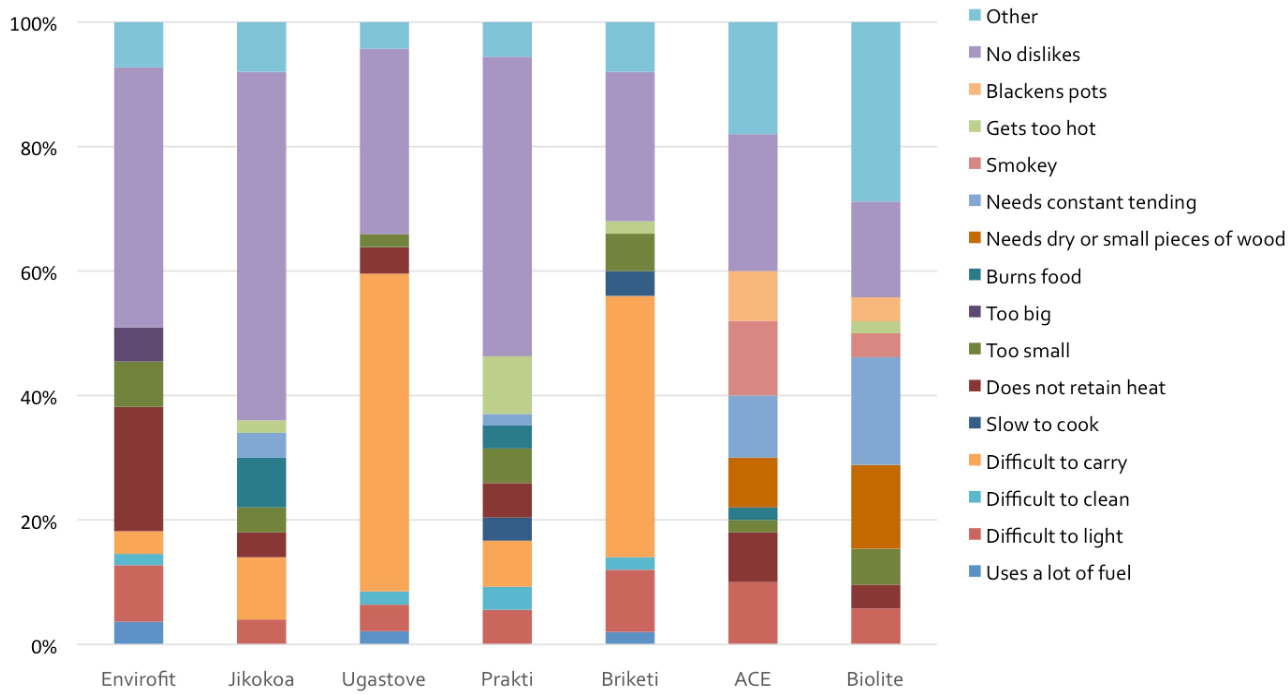


Approximately half of the participants with the Burn Jikokoa (56%), Prakti Leo Char (48%) and Envirofit Econochar 1.0 (42%) stoves reported that there was nothing they disliked about the stove. For those participants that did report something they did not like about their respective intervention stove, responses were very varied. The most frequently reported dislike was in

[29] During the 5 weeks between dissemination and follow up the field team offices received several calls from neighbors/ friends of ACE1 stove participants wanting to purchase the stove.

related to the Ugastove and Briketi EcoStove groups where the stove was reported to be very heavy and difficult to carry (Figure 20).

Figure 20 Reported aspect most disliked about intervention stove, by stove type



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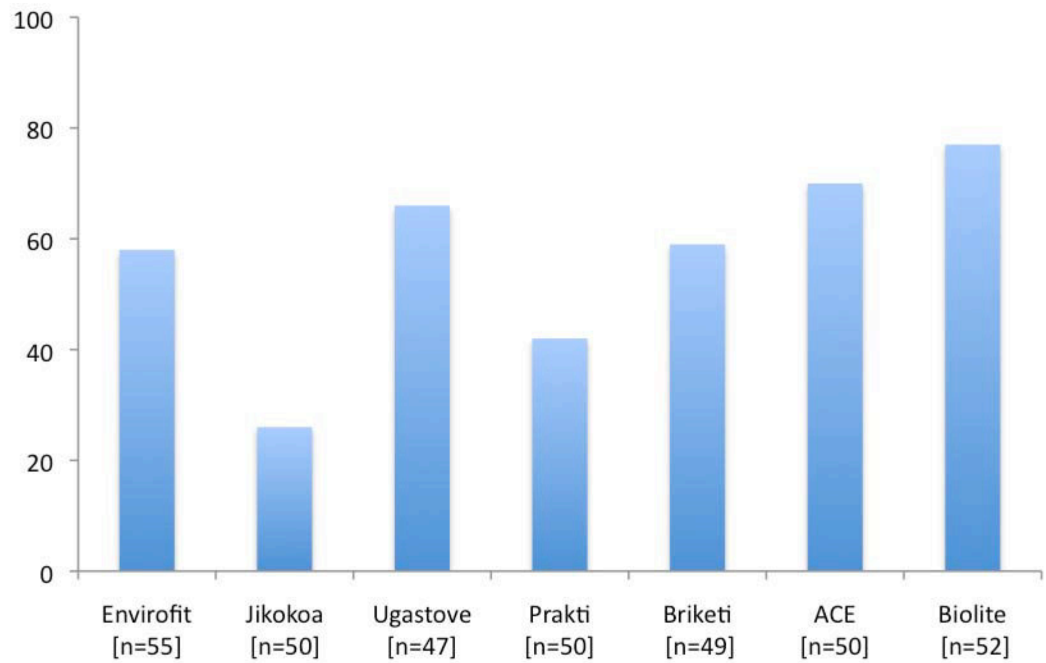
3.7.2 Perceptions of baseline stoves and drivers for continued use

The participants were asked if their previous primary cookstove had any advantages compared to the intervention stove. Figure 21 shows the proportions reporting that the baseline stove has advantages compared to the intervention stove. The participants in the wood burning stove groups were more likely to report that their previous stove had advantages over the intervention stoves (ACE1 70% n=35 Biolite HomeStove 77% n=40). The Ugastove group reported perceived advantages in their baseline stove most frequently amongst the charcoal stoves (66% n=31), with Burn Jikokoa users the least likely to report that their previous stove had advantages (26% n=13).

Figure 21: Proportion (%) of stove group reporting that the baseline stove had advantages compared to the intervention stove



The characteristics of the baseline stoves that the participants believed provided an advantage over the intervention stoves were understandably somewhat dependent on the baseline stove they were being compared to. The most frequent advantage reported by the participants in the Envirofit Econochar 1.0 and Burn Jikokoa groups was the baseline stoves ability to retain heat, this was also an advantage given by the Prakti Leo Char group along with the ability to accommodate large pots. The majority of participants in both Ugsatove and Briketi groups reported that that baseline stove was lighter and more portable than the intervention stove.

The wood burning intervention groups had different responses. The most frequently reported advantage provided by the baseline stoves in the ACE1 group was that it accommodated large pots whereas in the Biolite HomeStove group it was the ability to cook with wet and large pieces of wood. Graphical representation of the responses from each group can be found in the separate appendix document.

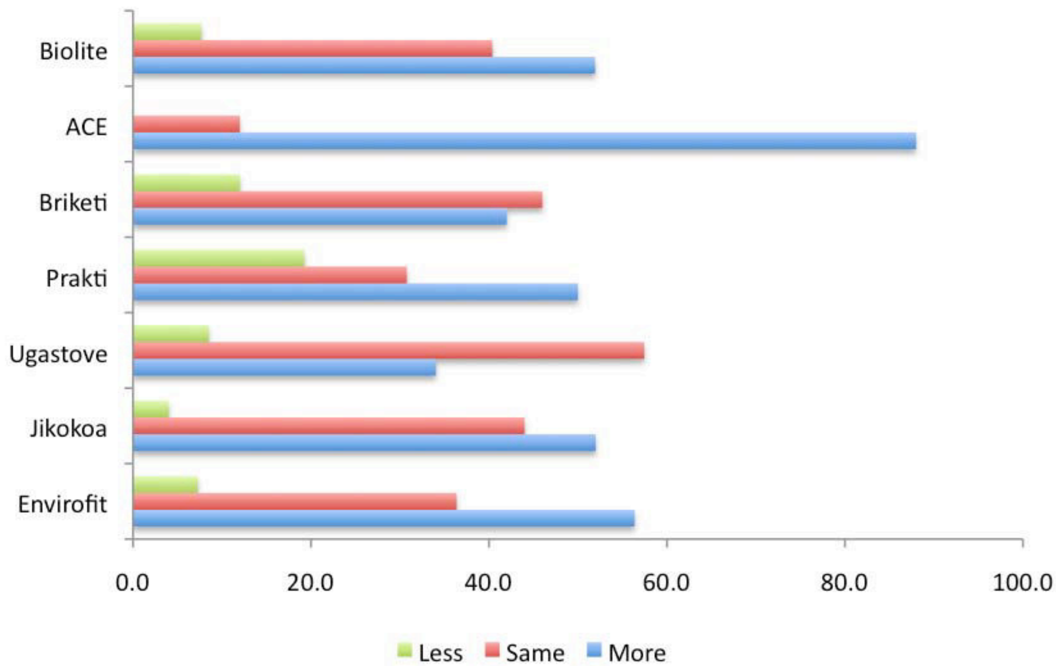
3.7.3 Perceived impacts on well being

The participants were asked if they thought that the intervention stove had any impact on their health. They were encouraged to consider positive as well as negative impacts. Very few households in each stove group reported that the stove had any impact on their health in any

way, either good or bad. The highest frequency was in the Envirofit Econochar 1.0 stove group where 11% (n=6) reported impacts on health- mostly associated with reduction in emissions and levels of heat from the stove, which reportedly reduced the risk of burns.

When asked about whether their level of 'physical comfort[30]' had changed since receiving the intervention stove, the majority of participants in all groups except the Briketi EcoStove and Ugastove groups reported an improvement. Nearly 90% of ACE homes reported a positive change. However just under 20% (n=10) of the Prakti Leo Char stove household reported that their level of comfort was less compared to before to receiving the stove (Figure 22).

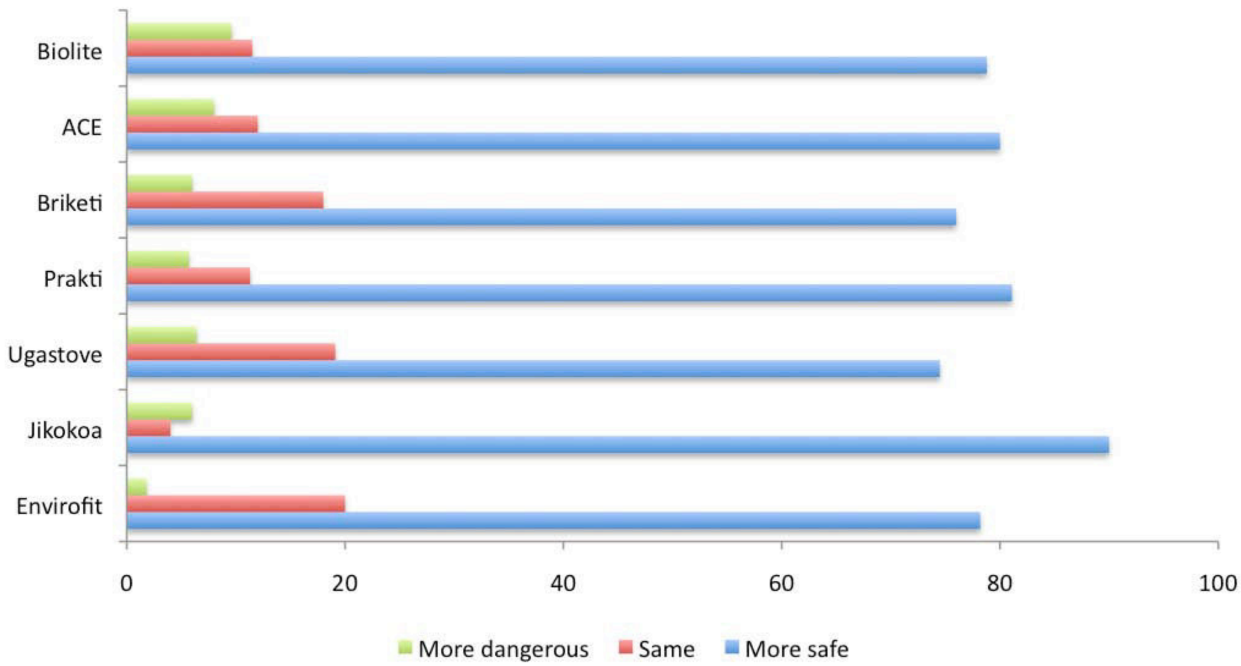
Figure 22: Relative change (%) in physical comfort since receiving intervention stove



The participants were asked about their perceptions of how safe the intervention stove was compared to their pre-intervention primary stove. The majority of participants in all stove groups perceived the intervention stove to be safer (Figure 23). When the intervention stove was perceived as being safer than the baseline stove it was usually due to it being more stable (34%) or due to the fact that the fire was more enclosed (21%). In the few cases where the intervention stove was seen to be more dangerous than the traditional stove it was usually attributed to the fact that the stove gets very hot, increasing risk of burns. 33% (n=17) of the participants with a Biolite HomeStove stove and 25% of those with a Prakti Leo Char stove reported suffering burns after receiving the intervention stove. Although most burns reported were light with only one burn incidence reported as severe and leaving a large scar, they occurred when using the intervention stove and so highlights the need for training and awareness to avoid such incidences when adjusting to a new technology.

[30] This was used as a generic 'catch all' term to provide the participants perceptions on changes in general physical well being since receiving the stove.

Figure 23: Perceived safety of intervention stove compared to pre-intervention primary cooking device



3.8 Stove Quality and Short Term Durability

3.8.1 Malfunctions and damage to stoves: Mid term visit

Eight ACE1 stoves were reported to be not working correctly **prior to the mid-term** visits via telephone calls to the local project manager. Based on the information provided by participants, the ACE1 representative provided advice on how to try to fix the stoves at the home. 4 stoves were successfully fixed using this advice. The remaining 4 had the following problems and could not be fixed in situ:

- One stove had a solar panel cable damaged and hence could not be charged.
- Two stoves did not charge at all
- One stove's fan only worked in strong sunshine. If clouds cover the sun the fan goes off immediately.

These were removed from the homes and replacements given. Please see separate appendix for a copy of the report provided by ACE after examining the stoves (numbers 1-4 on case sheet).

In addition to the participants calling the field team office, a further 3 ACE1 stoves were found to have non-functioning fans on arrival at the home for the mid-term visit. These were all fixed at the home by the field team following the advice given by the ACE1 representative.

The door of one Briketi EcoStove stove had come apart from the stove. The field team was able to fix this in to allow proper operation of the stove.

3.8.2 Malfunctions and damage to stoves: 5 Week follow up visit

On arrival at the homes 5 weeks after dissemination a total of 7 stoves were found to be damaged or experiencing issues.

The door of one Briketi EcoStove damaged at mid-term stove was still damaged. A cross bar on the wood holder of one Biolite HomeStove stove was broken.

A total of 6 ACE1 stoves were experiencing problems, although not all were affecting the cooking functionality of the stove.

- One ACE1 stove had its phone cable chewed by rats (this was not impacting on the cooking functionality of the stove).

- Three ACE1 stoves had problems with dirt/grit in their fan. These were taken to the ACE representative and restored to working order. (Cases 6-8 in the ACE1 repair/review report – please see separate annex

- The fan in one stove would not turn off, however it was still possible to use the stove. The review by ACE concluded that this was due to a faulty circuit board possibly caused by liquid ingress (Case 9 in the ACE1 repair/review report – please see separate annex)

- One household claimed to have problems with the battery in the ACE1 stove stating ‘ the battery couldn’t store enough energy. However, the report on this stove showed the issues were related to a faulty circuit board and not battery. The issue was most likely caused by liquid ingress (case 5 in the ACE repair/review report – please see separate annex)

Subsequent communication with the ACE1 representative has highlighted that their team have introduced an intermediate solution to the liquid ingress by plugging the hole with sealant, which seems to be working well. They state, “However, future production models will see the hole replaced by a little bump, completely eliminating the issue.”

After 5 weeks use many stoves looked extremely dirty as though they had not been cared for very well and were showing signs of rust and deterioration (see section 3.10 for further details on deterioration of stoves after 3 months use)

3.9 Willingness to pay and willingness to accept

Analysis indicates that the median WTP for the ICS (the point at which 50% of the population[31] would buy the ICS) is UGX 40,490 (USD 12.46) if sold in a single lump-sum payment during the experiment or UGX 63,000 (USD 19.39) if sold in three equal monthly installments under the experiment conditions. However, this value also depends on the stove model, income levels,[32]

[31] The population is defined as those with income levels in the 75th percentile among the sampled population and whose use of the stove was not affected or who used the stove more as a result of price uncertainty during the trial period. This population is likely to be early adopter of the improved cooking technologies in the study area.

[32] Proxied by the Progress out of Poverty Index (PPI) ®. This index can be translated into probability values that households fall below a given poverty line. In this case, we translated PPIs into the probability of falling below two

and factors related to risk and uncertainty-aversion behaviors.[33] We tested the influence of energy and fuel savings on demand and willingness to pay, but found no statistically significant influence of this factor across the sample.[34] This indicates that although some stoves are more appreciated and better paid for, the degree of fuel savings is not a determinant of demand. SUMS-derived stove usage did not have an effect on stove demand either.

The study found a significant difference in WTP under the installment and full-price WTP. Estimates indicate that the installment BDM WTP is 35% higher than the full-price WTP.[35] Note that the payment conditions were exactly the same (3 monthly installments with the same facilities to pay), so cognitive factors, such as thinking that the stove is cheaper when the lower installment price is available in the participant's mind, are at play in the decision to pay more or less depending on whether the participants are elicited an installment or a full price. Moreover, these differences are retained in the actual demand for the stoves when participants come across the actual price of the stove and hence have full information to make a decision (versus when only outlining what they think their WTP is without being confronted with an actual price) and therefore can play a role in the marketing of the products.

See Figure 24 below for estimates of median willingness to pay for the different improved cookstove models. Demand curves for each stove model are presented in separate appendix document.

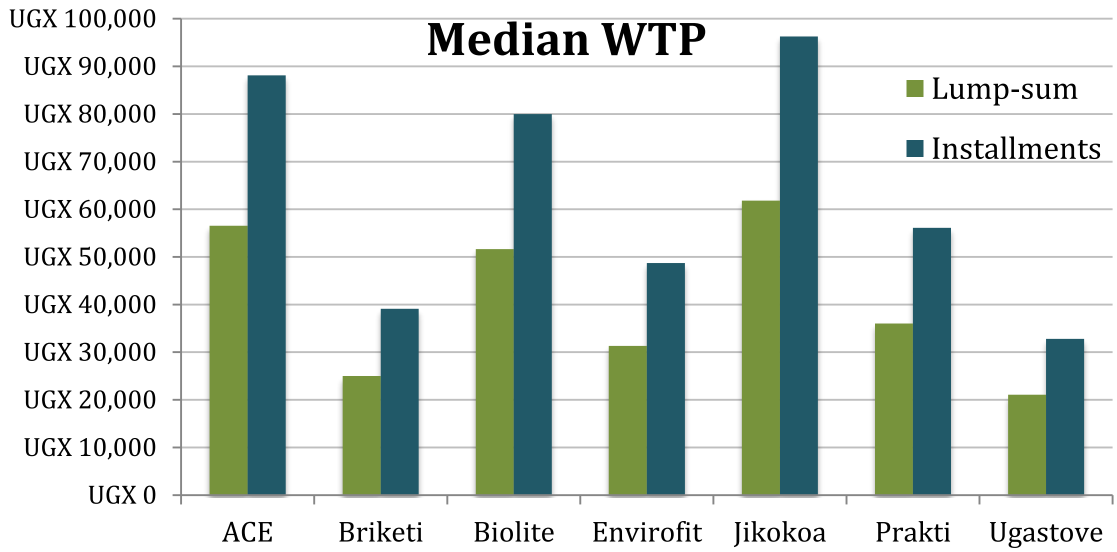
times the income levels that would classify a household as poor according to Uganda National Household Survey 2012/2013.

33 Such as how uncertainty in the intervention stove price affected the use of the stove. Users were asked "How did the fact of not knowing the price of the stove affect the way you used the stove?" Those that responded: "It did not affect in any manner" or "I used it more to test it well and know if I want to buy it" had a higher willingness to pay. These households may have been less uncertain about their true willingness to pay and hence were able to make higher bids at the moment of the experiments. Other risk and uncertainty aversion factors were also assessed, but did not have a statistically significant influence on WTP.

34 P-value is 0.39 for energy savings, 0.17 for charcoal savings (only charcoal stoves), and 0.47 for wood savings (only wood stoves).

35 The estimate goes up to 56% if people that paid in lump-sum are compared against those that were asked the per-installment WTP using actual demand estimates (versus BDM demand estimates) at the median.

Figure 24: Median willingness to pay for the different improved cookstove models (UGX)



Overall, the Ugastove and Briketi EcoStove models present the lowest WTP. These ICS models are sold in the study area at competitive prices, which may partially explain the outcomes. Likewise, the Biolite HomeStove and Burn Jikokoa[36] stoves were sold in the study area but at much higher prices, which is likely to have predisposed participants to pay more for them, although the prior knowledge of stove prices[37] does not seem to affect the willingness to pay estimates. In the case of the ACE stove, we asked the participants "Did the thought of not being able to find briquettes in the future affect your willingness-to-pay?" to which only 6% said that their WTP was affected (negatively in all cases).

Below a price of 15,000 UGX the stove intake was 100%. The maximum willingness to pay for any ICS in the experiment was UGX 201,000 for a Biolite HomeStove paid in installments. Please note that at the time of the experiment, the exchange rate of UGX to USD was around 3,250 UGX/USD.[38]

Baseline fuel expenditures were thought initially to positively affect WTP for stoves. Our initial hypotheses for this phenomenon included the following: 1) wealthier households spend more on fuel and have more spending power reflected in the WTP; and 2) these households put more emphasis in cooking than others and the fact of having a good stove matters more than for household cooking less. When analyzing the level of wealth against WTP, we found this factor to be a predictor of WTP and that it captured the effect on WTP that fuel expenditures would have otherwise had. Note: for wealth indicator we used was the probability that a household fell below two times the Ugandan poverty line. This indicator was computed using the methods

[36] Based on CIRCODU's field observations.

[37] Participants were asked: "Did you know the price of the stove at the time of the willingness-to-pay experiment?"

[38] The exchange rates ranged from 3,105,22 UGX/USD on June 8, 2015 when the experiments started to 3,364.58 UGX/USD in July 3 when the experiments ended. The source of exchange rates was the Bank of Uganda accessed through https://www.bou.or.ug/bou/rates_statistics/statistics.html on August 15, 2015.

created by Progress out of Poverty Index® (PPI) and used data from the baselines and durability surveys.[39]

WTA is significantly larger than WTP. Despite constant increases in prices offered during each of the 4 weeks of the experiment, only 9% of the participants were willing to accept money in exchange for a stove. There were no discernible patterns between stove model and WTA, but the users that accepted lower amounts of money were not satisfied with the stove and had immediate pressing needs to fulfill. All others accepted amounts greater than UGX 80,000, which is clearly significantly higher than most WTP values. The reasons for this difference are explored in the discussion section below.

3.10 Three-Month Durability Study

A total of 158 households were visited 11-15 weeks after they received the intervention stove. The households were aware that the team would return to their home and had consented for this visit to take place but they did not know exactly when it was occurring. They were therefore not able to 'prepare' or change their cooking space.

The numbers interviewed per stove group are shown below. The percentages are the proportions of the total number of households having retained (either via WTP or WTA) the stove type at the 5 week follow up study. Between 42% (Burn Jikokoa) and 61% (Prakti Leo Char) of each stove group was interviewed.

Envirofit Econochar 1.0	Burn Jikokoa	Ugastove	Prakti Leo Char	Briketi EcoStove	ACE	Biolite HomeStove
24 (49%)	21 (42%)	18 (44%)	28 (61%)	19 (45%)	27 (56%)	21 (46%)

One stove (Biolite HomeStove) was locked away and the team was not able to access it, another (ACE1) had been sent for repair.

3.10.1 Stove use patterns 3 months after dissemination

The status of the intervention stove on arrival at the home is shown in Table 19. The Ugastove group had the highest proportion of stoves that were alight (either with or without cooking happening) on arrival at the home (77%). Although there were very few stoves that did not show any signs of recent use the highest number was seen in the ACE1 stove group. In 1 case the owner had been away for two weeks and had just returned, 3 stoves were currently experiencing problems, and 1 person was unable to provide a reason for not using the stove.

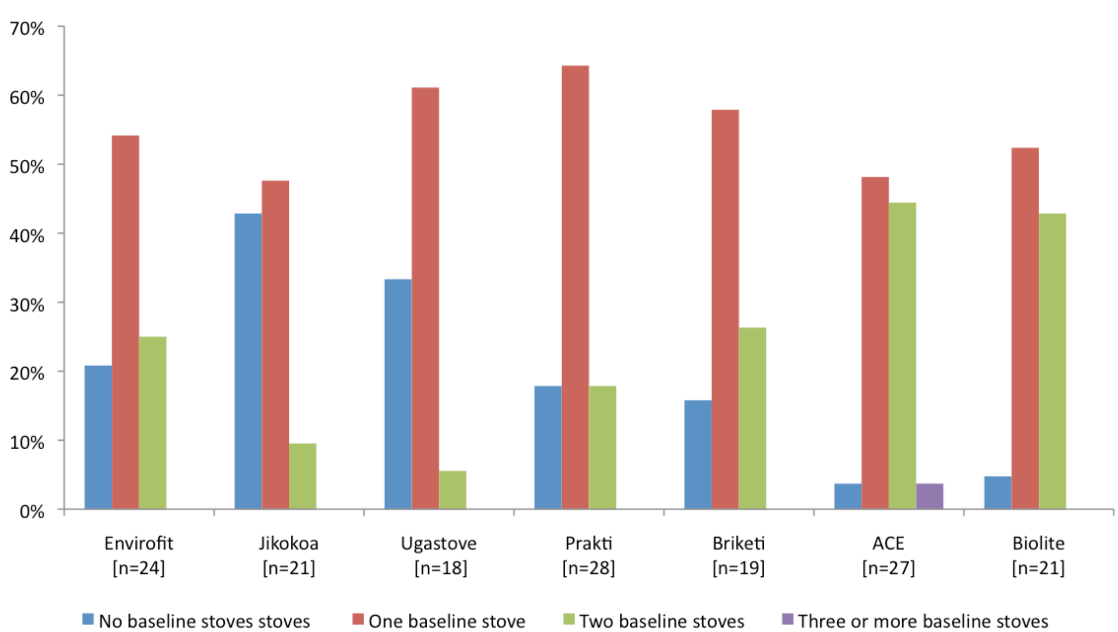
[39] Additional data was collected during the durability study because a new PPI was released after the baseline survey was conducted (the new indicator was created based on the Uganda National Household Survey (UNHS) 2012/2013). For households that did not participate in the durability study, PPIs were computed using the previously available indicator based on the UNHS of 2009/2010.

Table 18: Status of intervention stove on arrival at the home: Durability study n (%)

	Alight and being used for cooking	Alight but no cooking happening	Not alight but hot to touch	Not alight, cold to touch but signs of recent use	Not alight, cold to touch, NO signs of recent use.	Other
Envirofit Econochar 1.0	11 (46)	0 (0)	3 (13)	9 (38)	1 (4)	0 (0)
Burn Jikokoa	12 (57)	0 (0)	3 (14)	6 (29)	0 (0)	0 (0)
Ugastove	12 (67)	2 (11)	0 (0)	4 (22)	0 (0)	0 (0)
Prakti Leo Char	13 (46)	2 (7)	2 (7)	10 (36)	1 (4)	0 (0)
Briketi EcoStove	9 (47)	0 (0)	2 (11)	6 (32)	2 (11)	0 (0)
ACE1	3 (11)	0 (0)	0 (0)	18 (67)	5 (19)	1 (4)
Biolite HomeStove	1 (5)	0 (0)	1 (5)	17 (81)	1 (5)	1 (5)

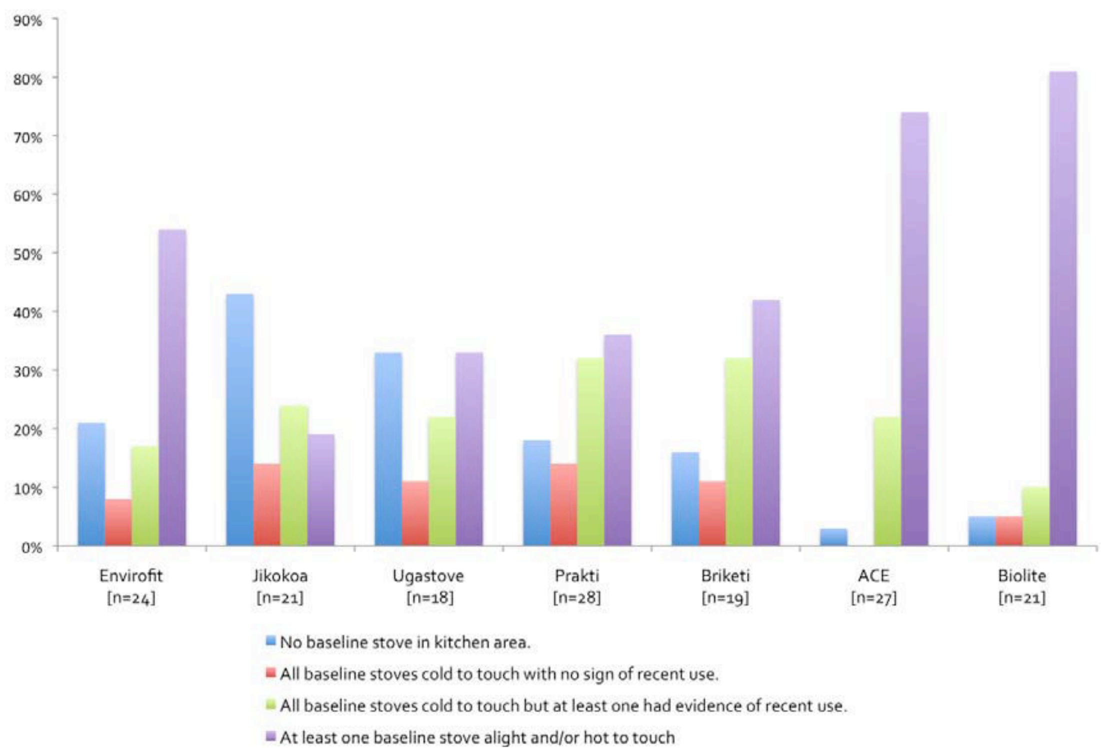
On arrival at the home there was evidence of stove stacking in the majority of households. As also seen 5 weeks post dissemination, it appeared that in many cases the intervention stove had been added into the cooking options and rather than significant baseline stove displacement, the cooking tasks had been redistributed of over more devices. Figure 25 shows the number of baseline stoves in the kitchen on arrival at the home. The wood burning stoves (ACE1 and Biolite HomeStove) showed the highest number of retained baseline cooking devices in the kitchen area.

Figure 25: Number of baseline stove evident in kitchen on arrival at the home: Durability study.



The status of the baseline stoves was also observed (see Figure 26). The Burn Jikokoa group showed the highest number of households (43%) that had apparently displaced the traditional cook stove, suggested by no evidence of a baseline stove in the kitchen on arrival at the home. Both ACE1 and Biolite HomeStove stoves had the highest proportion of **baseline stoves** that were alight / or hot to touch in the kitchen (74% and 81% respectively).

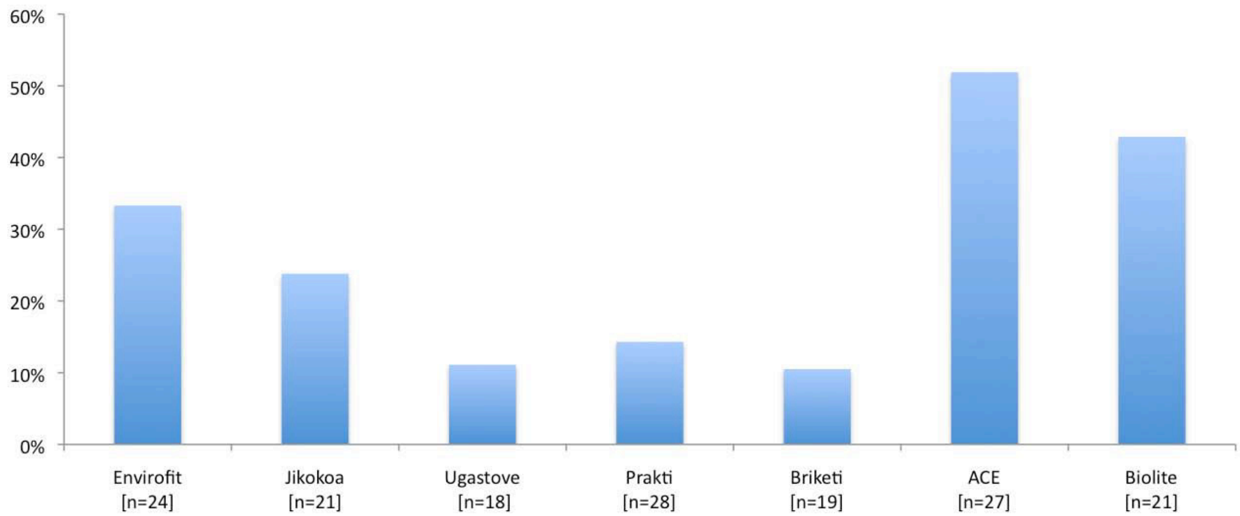
Figure 26: Presence of baseline stoves in kitchen: Durability study [% of stove group]



Across all homes, 57% (n=90) reported carrying out simultaneous stove use since receiving the stove. This suggests a need for more than one burner equivalent to carry out the household cooking tasks. There was however no difference found between the proportions using stoves simultaneously in each stove group (p=0.705 chi-square test). Of the households reporting simultaneous stove use 36% (n=32) report to do this on a daily basis.

Overall, 28% (n=44) of participants reported that there were tasks they were unable to complete on their intervention stove. Figure 27 shows the proportions by intervention-stove group. The wood burning stoves (ACE1 and Biolite HomeStove) showed the highest number of participants reporting an inability to carry out certain cooking tasks on the intervention stoves. The Ugastove and Briketi EcoStove stove groups showed the lowest frequency. This perhaps reflects the behavior changes required for the more advanced stoves whereas the Ugastove and Briketi EcoStove are more similar design to the baseline stoves and are familiar products within the study communities.

Figure 27: % reporting to be unable to carry out some cooking tasks on intervention stove

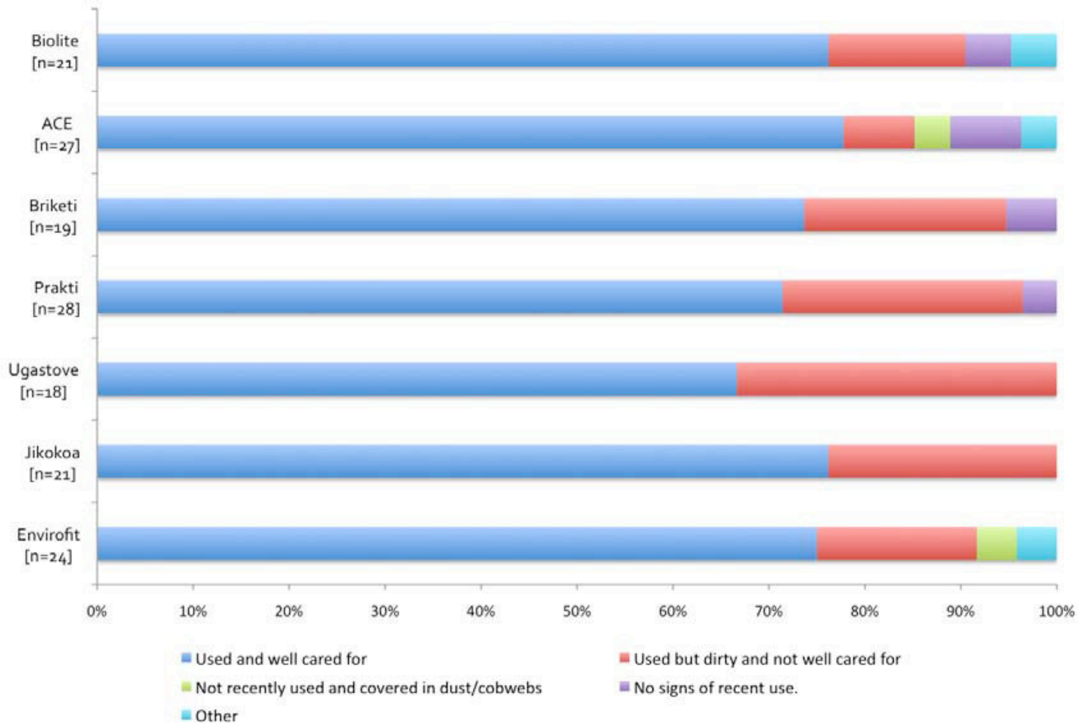


The tasks most frequently reported by the participants as ones they were unable to carry out on the intervention stoves were steaming matoke (n= 13 30%) and mingling posho (n=11 25%) with 11% of participants reporting that they were unable to prepare for large numbers of people on the stove. Echoing responses given 5 weeks after stove dissemination, the most frequently reported reasons for being unable to cook certain foods in all stove groups was because the stove was too small and did not accommodate the required sized pans (n=20 46%).

3.10.2 Durability and quality of intervention stoves

Figure 28 shows the appearance of the intervention stove on arrival at the study homes. The majority of stoves in all groups were used and well cared for.

Figure 28: Appearance of intervention stove on arrival at the home



Four stoves had parts missing. Two Envirofit Econochar 1.0 stoves had the 'ashtray' missing and two ACE1 stoves had the phone charger missing.

Of the 156 stove available for observation 63.5% were showing signs of 'wear and tear' or damage. Most of this was either minor discoloration/ abrasions or minor to major rusting particularly on the top / pot holder area of the stove. Although this impacted on the aesthetics of the stove and could potentially negatively affect the user perceptions and the perceived aspirational value of the product it did not appear to be affecting the performance of the stove. Table 20 below details the nature and level of 'wear and tear' and damage observed. Evidence of 'wear and tear' or damage was highest in the Envirofit Econochar 1.0 stove group, with 96% of all stove showing some evidence of corrosion or damage.

Table 19: Observed condition of intervention stoves: Durability study

	% of stoves with evidence of corrosion or damage		Level of corrosion or damage seen % of stoves showing issues.		
			Minor	Major	Critical
Envirofit Econochar 1.0 [n=24]	96 (23)		57 (13)	30 (7)	13 (3)
Burn Jikokoa [n=21]	71 (15)		80 (12)	20 (3)	0
Ugastove [n=18]	56 910)		90 (9)	10 (1)	0
Prakti Leo Char [n=28]	68 (19)		79 (15)	21 (4)	0
Briketi EcoStove [n=19]	74 (14)		93 (13)	7 (1)	0

	% of stoves with evidence of corrosion or damage	Level of corrosion or damage seen % of stoves showing issues.		
		Minor	Major	Critical
ACE1 [n=27]	48 (11)	64 (7)	0	36 (4)
Biolite HomeStove [n=21]	33 (7)	86 (6)	0	14 (1)
Minor	Discoloration, some rusting, minor abrasions			
Major	Significant rusting or rust evident in more than one area of the stove.			
Critical	Damage or breakages that could potentially impact on the stoves function.			

The nature of the 'critical' damage observed in the stoves is described in Table 21 below. The exact cause for the damage seen in these stoves was not explored in detail and so it cannot be said whether they are due to improper use or technical failure.

Table 20: Description of issues categorized as 'critical' observed in intervention stoves

Envirofit Econochar 1.0	Stove 1:The screws to the pot stand were either missing or had fallen out on two stoves making the stand loose. This makes cooking with big pots very difficult. [Figure 22a below] Stove 2: A screw from the handle on the ashtray had fallen out rendering it difficult to use. [Figure 22b]
ACE1	Stove 1 and 2: The fans were not functioning on arrival at the home. These stoves were restored to full working order by the field team. Stove 3. The pin that attaches the solar panel to the stove was broken [Figure 22c]. This stove was taken to the ACE1 representative. Stove 4: The charging section from the solar panel was broken. The stove could still be charged but with some difficulty [Figure 22d].
Biolite HomeStove	One stove was unable to charge the cell phone. Although it is recognized that this does not impact on the stoves cooking performance but it was included in this category as this malfunction was perceived as a major disadvantage of the stove to the participant.

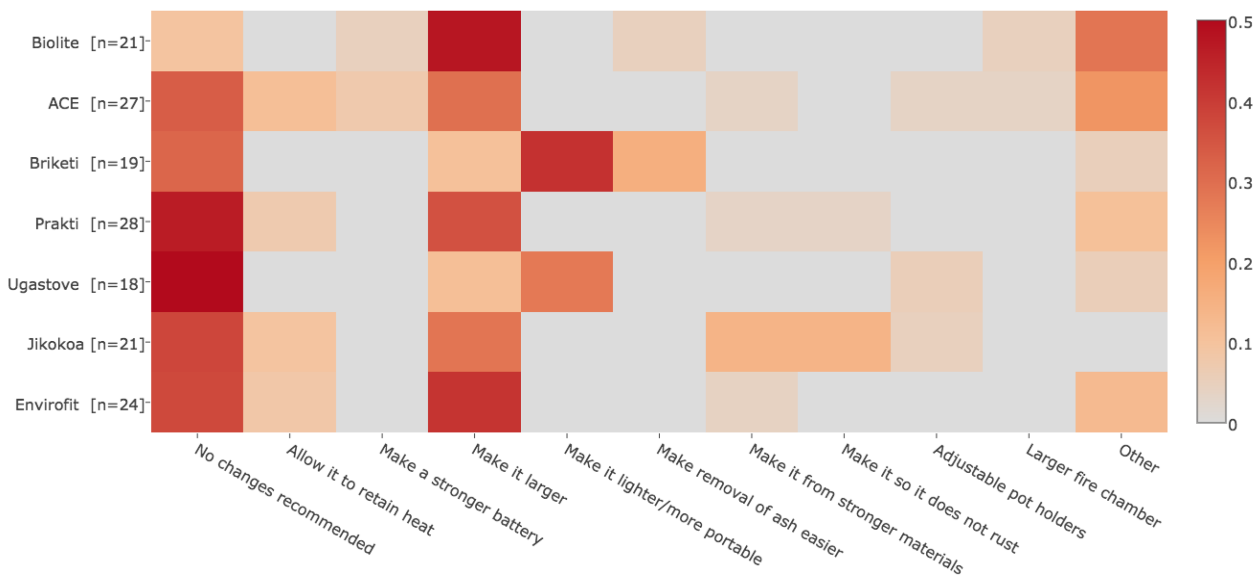
Thirteen durability study participants reported to have experienced damage or problems with their stove, which was now repaired. All were ACE1 stoves experiencing problems related to the fan and/ or charging cord.

Figure 29:Damage observed on intervention stoves: Clockwise from top left 22a, 22b, 22c, 22d

3.10.3 Suggested adaptations to the intervention stove

After having the stove in their house for 11-15 weeks the participants were asked if they would make changes to the intervention stove in order to make it easier or more pleasurable to use. Most participants reported that they would make no change to their stove. Of those that did offer suggestions for change the most frequently reported was to make the stove larger. The Ugstove and Briketi users also thought the stove would be improved by making it lighter / more portable (Figure 30).

Figure 30: Suggested adaptations to intervention stoves



4 Discussion

4.1 Study sample

Several important differences between the participants using wood and those using charcoal at baseline became apparent during the study. Analysis suggested that wood users were an older and apparently poorer population (as measured by the PPI index). However within the charcoal and wood user categories, the sampling strategy yielded study groups that were comparable with regard to socio-demographic characteristics, baseline stove use (number and types of stoves used per week), and total energy consumption. Although it is not possible to control for all confounding factors, similar groups strengthen the capacity to compare across intervention-stove groups when measuring changes in fuel consumption, stove use, and WTP.

To capture a population that would yield economic benefits from fuel-efficient stoves, purposive sampling aimed to select participants that purchased the majority of their stove fuel. This was easily achieved in the charcoal users all of which purchase fuel, of which approximately half did so on a daily basis; but proved harder among wood users. The proportion of wood purchasers in the study sample (~45%) is probably higher than that among primary wood users in the study area. It is worth noting that two of the more costly stoves in the study were distributed among this population, which raises the question of whether these are feasible targets for these particular stove models or if these should be targeted to charcoal populations, who spend more on fuel, assuming that these stoves reduce pollutant emissions as compared to charcoal stoves and households are willing to switch from charcoal to wood/briquette fuels. Because our sample of charcoal users who were given ACE 1 and Biolite HomeStove stoves is small (7 households), it is not possible to make inferences that could inform a program targeting charcoal users to switch into using these stoves.

Among the charcoal population, a large proportion (18.2%) already used Ugastoves (or similar models) indicating that previous programs have been successful at disseminating improved cookstoves in the study area. The high penetration of Ugastoves is likely to have an influence on the degree of fuel savings and stove use. However, the fact that some stove models presented much higher demand indicates that there is space for new participants to enter the market with stoves that meet user needs in terms of cooking adequacy and durability.

4.2 Stove Use

Although the intervention-stove performance, including fuel efficiency, is fundamental to the technology's potential to provide health, economic and environmental benefits, stove use and the proportion of overall cooking it contributes to, are key determinants of impact.

Stove use (baseline and intervention) was measured using both survey data and data recorded by stove use monitors (SUMS).

Stove use monitor data

The algorithm to detect cooking episodes combined minimum thresholds of temperature, heating and cooling slopes, as well as minimum duration of cooking episodes. This algorithm differentiates between ambient temperature fluctuations inside the kitchens from signals of cooking episodes. Although the algorithm parameters and cut-off points for cooking episodes

was optimized for robustness, it is likely that the data contains some level of false positives (ambient temperature fluctuations mislabeled as cooking episodes) and is therefore necessarily subject to some error.

The number of cooking episodes per day in intervention stoves is lower among wood stoves (0.79 per day) than among charcoal stoves (1.67 per day). We investigated if these differences would be due to the fact that wood stoves operate for longer during each cooking episode and found that the average length of cooking episodes in wood stoves was 86.0 minutes compared to 73.7 minutes in charcoal stoves (wood cooking episodes are 16% longer). However, this difference does not explain all of the large discrepancy in cooking episodes seen between the charcoal and wood populations. We visually investigated wood stove data to detect cooking episodes that do not have strong signals and would therefore not been identified as cooking episodes by the algorithm. However, we found that SUMS data generally presented cooking peaks with clear signals.

Because data on baseline stove use among the population that was given wood intervention stoves was not deemed credible (reasons explained in section 3.4.5), it is not possible to know if the level of displacement is higher among charcoal stoves or if the differences are due to different cooking patterns across the populations (e.g. because wood users often purchase food, have a different diet or engage in collaborative cooking more often).

Intervention stove use: charcoal stove

The practice of 'stove stacking', the use of more than one stove either simultaneously or sequentially, was present in the majority of all homes at baseline, indicating a need for more than one 'burner equivalent' to complete the tasks carried out on the stoves in these communities. This suggests that exclusive use of any intervention stove would be unlikely in these homes, unless two intervention stoves or two-burner stoves are disseminated. Despite these findings, the 10 homes in the Burn Jikokoa group reporting to use only one stove at baseline increased to 19 homes 5 weeks after receiving the intervention stove. Field notes show that as the baseline stoves broke they were not replaced and cooking continued on the Burn Jikokoa alone. This also occurred in 2 of the Envirofit Econochar 1 homes indicating that adaptation to 'one burner equivalent', although rare, is possible.

Objective measurements from SUMS, self reported data and semi-structured observations of kitchen areas revealed consistent evidence that the charcoal intervention stoves had been integrated in to the kitchen patterns in the study households, albeit with varying intensity between the different groups.

Five weeks after receiving the intervention stove, an unannounced visit to the home revealed the intervention stove to be alight or showed signs of recent use in the kitchens of over 80% of all charcoal stove groups and as high as 95% in the Jikokoa group. Although most participants reported the intervention stove as their primary stove, many also combined it with other baseline stoves. The practice of stove stacking is prevalent in most households and irrespective of the stove model (79% of households reported using other stoves).[40] Around one third of cooking is still conducted on baseline stoves, highlighting some deficiencies of ICS in fulfilling Ugandan cooking needs.

[40] Note significantly larger sample sizes may reveal a different story

Studies have shown surveys often over report compliance with cook stoves and other public-health interventions (Thomas E. 2013[41]). Thomas et al found that SUMS data show 40% fewer cook stove events per week than survey data and direct observation. Despite these findings, we found a consistent trend in reported and SUMS-derived intervention stove usage with certain stoves (e.g. Jikokoa and Ugastove) taking over many of the traditional cooking episodes (in these cases displacement rates were 56 and 58% respectively). Our study, nonetheless, shows that full displacement of baseline cookstoves is difficult to achieve, as even the most appreciated stoves showed significant stove stacking. It is to be seen if the household budgets can allow for more than one improved cookstove leading to higher displacement rates than if just one stove were put in the household mix.

Intervention stove use: wood stoves

The wood using groups showed a decreased reliance on a single stove after receiving the ACE1 or Biolite HomeStove. This was most pronounced in the Bioilite group, where the proportion of homes using just one stove fell to 5% from 22% after receiving the intervention stove.

The amount of baseline stove displacement is very difficult to measure accurately using the SUMS due to the challenges involved in recoding data with ibuttons from three stone fires; however, self reports indicate a limited integration into the cooking patterns.

The rate of secondary stove use is higher among wood users, possibly because the dissimilarities between open fires and improved wood stoves are greater and open fires still adapt better to certain meals.

When the stoves were taken to the homes, the cooks (and any other interested party in the home) received training and instruction on the stove including how to light and use it. When provided, these instructions followed those outlined by the representatives from the stove manufactures. When available, the participants were also talked though the instructions provided in the stove box. This instruction would likely be more in depth than if buying from a store. However, some of the more advanced stoves require a substantial behavioral shift, particularly if moving from a rudimentary stove such as a three stone fire. Perhaps a more prolonged training and sensitization would have increased use of these stoves.

Use after 3 months

Assessing stove use after 3 months allows for the initial learning period to end and a more stable stove use reflective of longer terms patterns to be established. Continued integration into the kitchen patterns was apparent in the majority of the charcoal burning intervention homes visited 3 months after dissemination. Kitchen observation revealed the intervention stove continued to contribute to the household cooking in up to 75% of the homes in some groups.

The wood burning stoves continued to be integrated at a lower rate with baseline stoves seeming to contribute to much of the cooking. However full abandonment of the intervention stoves was not apparent and kitchen observations were skewed by the desire to move the stove

[41] Evan A. Thomas , Christina K. Barstow ,Ghislaine Rosa , Fiona Majorin , and Thomas Clasen. Use of Remotely Reporting Electronic Sensors for Assessing Use of Water Filters and Cookstoves in Rwanda. Environmental Science & Technology 2013 47 (23)

from the kitchen area due to fear of theft. The wood burning stoves clear have roles within the kitchens of these homes, education and sensitization can work to increase and widen the scope of the current adoption niche.

4.3 Changes in Fuel Consumption post-intervention

The study measured changes in fuel and total energy use at a household and per person level 5 weeks after dissemination of the intervention stoves. The cooks were asked to maintain their usual cooking patters during the 3-day KPT assessment, although the 'hawthorne effect'[42] should always be a consideration when entering the participant's homes. Although all of the stoves tested had lab-based proven levels of fuel efficiency, real world scenarios are affected by user behavior, stove stacking, varying quality of fuel and baseline scenarios, to name a few. Suppressed demand (i.e. savings are allocated to purchasing more food and hence cooking increases) could also explain lower fuel savings in the field. Hence, field data cannot be expected to demonstrate the same level of fuel savings measured in the lab.

The majority of participants in all stove groups perceived fuel savings after using the intervention stoves. These reported fuel savings are generally higher than the measured fuel and energy savings; although the percent-wise differences are generally not statistically significant.

Participants could have been exposed to marketing of local improved stove such as the Ugastove, which highlights the fuel saving capacity of the stove, they were not directly subject to any promotional material of the intervention stove before receiving it. The field team was very careful not to refer to any of the intervention stoves as 'improved' when recruiting the homes but rather using the term 'new', although some product information included with the stoves could have claims fuel consumption reductions that the participant might have read. Hence, some priming effects may explain the higher-than-the-measured reported fuel savings.

It is worth noting that fuel savings do not influence demand for stoves, but may provide a rational justification for their purchase once the desire for the stove is established.

Charcoal stoves

Although somewhat modest, most study groups showed a reduction in charcoal and total energy consumption at the household level after the introduction of the intervention stove. The reduction in charcoal ranged from 9% (not statistically significant from zero savings) to 22% per HH per day. The highest charcoal savings were obtained for the Burn Jikokoa stove, which also reports the highest exclusive usage (38%) and lowest continued use of traditional stoves.

The Briketi EcoStove showed the lowest fuel savings (9%). The small sample sizes of the study mean that this estimate has important uncertainty. This uncertainty is reflected, for instance, in the fact that the Briketi EcoStove savings are not statistically significant from Ugastove's at the 95% confidence level.

[42] The Hawthorne effect (also referred to as the observer effect) is a type of reactivity in which individuals modify or improve an aspect of their behavior in response to their awareness of being observed. https://en.wikipedia.org/wiki/Hawthorne_effect

In all stove groups the savings in charcoal and total energy use were significantly less than efficiency figures published by the manufactures for their product. As discussed above it is not expected to find the same savings from field studies as those suggested by laboratory testing based on water boiling tests (WBT). A literature search found data on only one other urban charcoal KPT, a cross sectional study carried out in Benin in 2013.[4] The results showed a 29% reduction for a stove showing 41% savings derived from WBTs conducted at the local laboratory. However, the results we report are lower than might be have been expected given the reported efficiency of the stoves.

We reviewed the literature to understand if the baseline charcoal consumption values of this study were comparable to others. This study's average baseline values (kg/HH/day 2.0 (SD1.3) and kg/SA/day 0.53 (SD0.3)) are slightly higher than what others report, but available data is limited for Kampala. A 2007 study from GIZ estimated 1.22 kg/HH/day charcoal consumption in Kampala[43] and a separate study estimated consumption to be 0.3kg per capita per day.[44] More recent data from a 2013 cross sectional urban charcoal KPT conducted in Benin showed a baseline consumption 0.38kg/SA per day.[45]

Many participants in our study (approximately half) purchased and immediately after used small amounts of charcoal on a daily basis, which can introduce errors in the daily charcoal consumption estimates as the fuel is used before it can be measured. Although this was accounted for in the data collection process and analysis, it can be a source of measurement error. However, the effect of this would be the same for each round of measurements (baseline and follow-up) as well as for each stove group so it is unlikely to have a significant impact on the overall percent-wise fuel savings outcomes.

The continued use of baseline stoves alongside the intervention stove seen in most study households and across all stove groups is likely to have diluted the potential fuel savings. Although the number of households using only one charcoal stove increased in the Burn Jikokoa group and to a lesser extent in the Envirofit Econochar 1.0 group, the overall number of stoves increased between baseline and follow up, suggesting a redistribution of cooking practices over more devices rather than any significant displacement.

Due to the established presence of Ugastove and equivalent charcoal stoves in the study communities, the baseline scenario for some of the homes with Envirofit Econochar 1.0, Burn Jikokoa, or Prakti Leo Char stove included already one of these improved charcoal stoves. Although the groups had similar proportions of these stoves (hence, the impact it not likely to differ between these three groups), it is likely that their presence reduced the fuels savings that might have been realized had the baseline included only traditional charcoal stoves.

One further possible explanation for the limited fuel savings shown by our results is the practice of buying and immediately using the charcoal. This behavior was seen in approximately half of

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[43] Economic evaluation of the improved household cooking stove dissemination programme in Uganda GIZ 2007 Downloaded from http://www.un.org/esa/sustdev/csd/csd15/lc/GTZ_Uganda.pdf

[44] Briquette Businesses in Uganda , GVEP 2012 Downloaded from http://www.gvepinternational.org/sites/default/files/briquette_businesses_in_uganda.pdf

[45] Garland, C et al Impacts of household energy programs on fuel consumption in Benin, Uganda, and India. Energy for Sustainable Development 2014 DOI: 10.1016/j.esd.2014.05.005

the study sample. Field team observations revealed a habitual behavior of using an entire bag of charcoal each day regardless of the potential to save fuel in intervention stoves. This leads us to think that behavior change communication strategies are needed to realize higher fuel savings.[46]

Wood stoves

The two wood burning stoves included in the evaluation were aspirational stoves with features such as controllable flame, cell phone charging, and a lamp. A literature review revealed no previous KPTs conducted with the Biolite Homestove. The ACE1 stove was comprehensively evaluated in a study conducted in Lao PDR in early 2015. KPT analysis from this study showed that when used exclusively or near exclusively, the ACE1 stove reduced wood fuel consumption per person by approximately 40%[47].

Both ACE1 and Biolite HomeStove showed savings of approximately half of that seen in Lao PDR and significantly lower than those published by the manufacturers. These lower than expected savings are undoubtedly due to the low reported exclusive use of the stoves and significant rates of continued use of baseline stoves.

The move from rudimentary stoves such as three stove fires to the efficient and effective use of these more advanced stoves requires a significant behavioral shift that might have been particularly challenging in the older wood using population of this study. With further sensitization and subsequent integration into the cooking patterns it can be assumed that these stoves have the potential to achieve much higher fuel savings.

It should be noted that although some ACE1 stoves experienced issues related to particles blocking the fan function, most of these issues were fixed by the field team on arrival at the home and prior to the follow up KPTs. Replacement stoves were provided for issues other than fan blockages prior to KPTs. This meant that all stoves were functioning during the KPT, although the users of malfunctioning stoves might have had less time to become familiar with its use prior to the monitoring.

4.4 Functionality and durability

Short- term issues with functionality

During the course of the study several ACE1 stoves experienced technical issues, many of which could be avoided in the future with better user training and increased involvement of the distributor with the consumer.

The majority of technical issues were due to particles becoming lodged in the fan and preventing it from working. Once the field team received guidance from ACE on how to rectify this issue it was easily and quickly addressed. Participants were shown how to fix the issues themselves in the event of it re-occurring and follow up visits revealed that the participants had

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46 Structured kitchen observations to inform the design of fuel-saving behaviour change strategies are beyond the scope of this study.

47 Air Pollution and Impact Analysis of a Pilot Stove Intervention: Report to the Ministry of Health and Inter-Ministerial Clean Stove Initiative of the Lao PDR. University of California, Berkeley and Berkeley Air Monitoring Group 2015. Downloaded from http://www.kirkrsmith.org/publications/2015/

been able to successfully clear the fan themselves and maintain the functionality of the stove. The addition of this maintenance procedure to the product user guide would prevent this occurrence becoming a barrier to use in the future.

Other technical issues with the stove were due to the battery not being fully charged before use. This was due to a mis-communication and again could be easily be avoided with improved communication and training.

Two ACE1 stoves had issues with the circuit board due to liquid ingress. Subsequent communication with the ACE1 representative has highlighted that their team have introduced an intermediate solution to the issue by plugging the hole with sealant, which seems to be working well. They state, "However, future production models will see the hole replaced by a little bump, completely eliminating the issue."

Stove condition after 3 months

Poor durability can negatively impact a stoves adoption and continued use, its safety, performance, and subsequent ability to deliver benefits. Although laboratory methods are established and available, there is currently no standardized methodology to evaluate durability in the field. In absence of such methodologies this study assessed the durability of the stoves through in-field observation of the most used stoves according to SUMS data after 3 months in the home.

Although most were showing signs of 'wear and tear' such as corrosion and rust, which might negatively impact on the stoves aspirational nature, very few stoves experienced technical failures after 3 months in the study homes. Four stove types experienced no issues that could potentially impact on relative product quality and longevity**.**

Two Envirofit Econochar 1.0 stoves showed signs of deterioration that impacted on its use. Subsequent communication with the Envirofit representative states that, "*The model we have commercialized and recently released – "Econochar 4.0" – successfully address and resolves every concern noted in this study*" including, " *Improved pot support design and revised frame assembly configuration to eliminate any loosening of parts over time*."

Two ACE1 stoves showed problems with wires or pin from the solar panel to the stove. One stove was taken for repair; the other stove was still functioning. The exact cause for the damage seen in these stoves was not explored in detail and so it cannot be said whether they are due to improper use or technical failure.

The time frame for this study allowed assessment of the stoves only for a relatively short period; hence, we could only identify issues that occur within the initial uptake and use phase. Longer-term assessment of durability, involving use over different seasons, is required to provide a more comprehensive assessment of product quality and longevity.

Longer-term use depends on several interrelated factors one of them being the stoves durability but also the ability to access repair services and or spare parts. The stove manufactures all offer at least 1-year warranty on their stoves although ease of access to repair services varies.

4.5 Acceptance of the stove

Intervention stoves will not deliver their potential health, economic or environmental benefits if they do not meet the majority of the daily cooking and other stove-related requirements that the baseline devices meet.

When evaluating the level and nature of the participant's acceptance of the intervention stoves it should be considered that the stoves were randomly allocated within primary fuel group and the cook did not choose a particular stove type. Given an open market the participant might have selected a stove more suited to their personal needs.

Overall, integration in to the household kitchen activity was more pronounced in the charcoal stoves than the wood burning stoves. This higher level of acceptance might in part be due to the fact that the product design is more similar to the baseline stoves than the advanced wood stoves.

Regardless of stove type, all participants reported to like something about their intervention stove, with fuel savings and speed of cooking at the top of the list. Reported disadvantages of the intervention stove reflected the attributes missing from the stove that were available in their baseline device. Frequently reported disadvantages included the inability to use large pots and lower heat retention. Both of these attributes are required to cook matoke, a local staple food, and data showed this was the task most likely to be carried out on the baseline stove. The reversion to baseline stoves for certain tasks has been widely reported. Ruiz-Mercado (2011)[48] shows that cooks have preferences for specific cooking practices, in specific devices known as the stove adoption niche. The adoption niche depends on how well the stove attributes and design are able to carry out certain stove tasks.

Other determinants of adoption observed in this study include the availability of proper fuel to feed the intervention stoves. In the case of the Biolite HomeStove the participants moved back to the baseline fires/stoves when the wood was wet and or not cut to the required size.

4.6 Willingness to pay

Experiment influencers

We tested several experiment-specific factors to understand the effect of some of the experimental conditions on the WTP. The factors tested included the influence of time of the day (to understand if the time in between experiments allowed for communication across households that could bias results); the presence of others; and intervention stove price uncertainty during the trial period (participants were not revealed the priced of the stove until the experiments were conducted at the end of the trial period). The timing of the experiments had no effect, but we found that the presence of others during the experiment has a positive influence. Some surveyor comments indicate that participants received encouragement during the experiment possibly pointing at vested interests in the intervention stove ownership (e.g. others wanting to borrow the stove or having the participant test the stove for longer to get a

[48] Ruiz-Mercado, Ilse, Omar Masera, Hilda Zamora, and Kirk R. Smith. "Adoption and sustained use of improved cookstoves." Energy Policy 39, no. 12 (2011): 7557-7566.

better sense of the stove value). The positive effect of the presence of others on WTP was less marked when the other people present were children, maids, or female neighbors.

We asked participants the open question: "How did the fact of not knowing the price of the stove affect the way you used the stove?" to capture the influence of price uncertainty on results. People whose use of the intervention during the trial period was not negatively affected by price uncertainty were willing to pay more. Besides the fact of being able to better experiment with the intervention stove, it may be that this segment of the population is less risk averse and was therefore more willing to bid higher for the long-term benefits of the stoves.[49]

Present and other cognitive biases

We found a 35% increase in the per-installment WTP as compared to the full-price WTP, under equal payment conditions (i.e. 3 equal monthly installments in each case). We attribute these differences to cognitive factors where installments look easier to pay and cheaper than the full price of the stove. The effect of this question not only influenced the elicited WTP, but resulted in a statistically significant increase in the demand for the stoves. 28% of the participants who responded to installment WTP asked enumerators for help to calculate the full price of the stove (which could potentially help eliminate the low price perceptions of the per-installment elicitations). However, no evidence was found that asking for help to calculate the overall price affects WTP, but larger sample sizes may yield a significant effect (the installment WTP was applied to a third of the population).

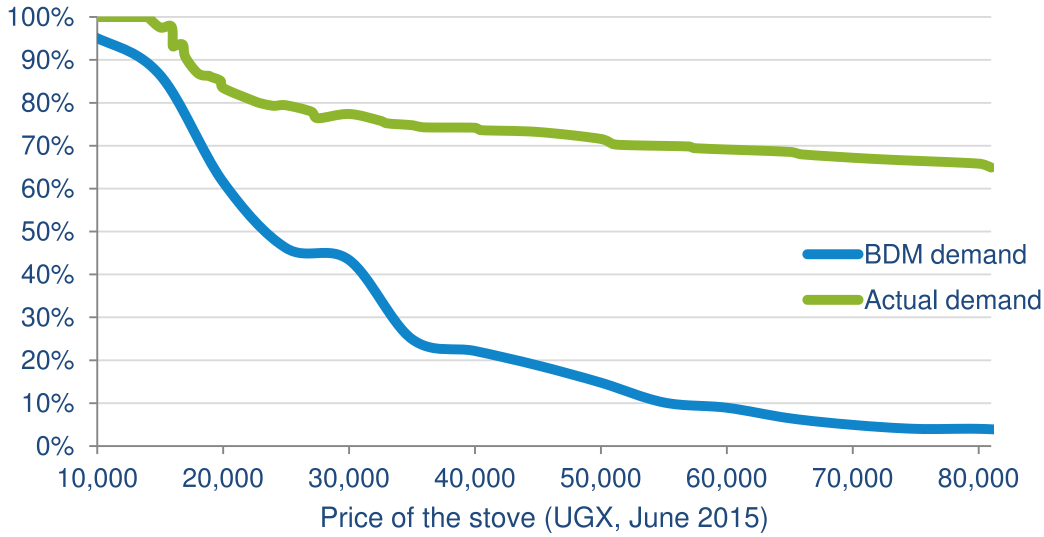
Although we only tested payments in three installments, we hypothesize that because the installment price has a strong anchor in the consumer mind and because accounting of the full price of the stove is not always performed, the addition of one installment would probably not have a major effect on the per-installment WTP. For example, it may be possible that people are willing to pay similar amounts for each of three installments as for each of four installments. This has the potential to increase the revenue per intervention stove.

At the beginning of the experiment we asked participants if they preferred to pay in a single lump-sum payment or in installments. Because participants who decided to pay in a single lump-sum were self-selected, we cannot be sure that this population is homogenous to the population that decided to pay in installments. For this reason, it is not possible to reliably estimate present bias in the study. However, we found that those willing to pay in a single lump sum outlined a WTP 20% smaller than those who preferred to pay in installments and who outlined a full price for the stove (note that the population paying in installments is divided between those that outline a per installment WTP and those that outline a full price WTP that is later split in 3 installments). This would be equivalent to a monthly 19% discount rate for 3 monthly installments. It is worth noting that typical microfinance loan interest rates are 2.5-4.5%/month, so present bias could be significant. The difference in total WTP between those that decided to pay in a single lump-sum versus those that decided to pay in installments and outlined the full price of the stove is not significant in the final demand models.

Difference between WTP methods.

[49] During the durability survey, we are collecting data on risk aversion and individual present biases to confirm these hypotheses.

Our analysis indicates that the Becker-deGroot-Marschak (BDM) method fails to predict the shape and magnitude of the demand as illustrated in the chart below:



During the three month durability study, a sample of users were asked "At what price would you think the product is expensive, but would still recommend a friend of family member to purchase one?" The enumerators then asked if the user would still recommend the stove if the price was UGX 5,000 more than the price they initially mentioned to understand if the users were still being conservative in their estimates. This WTP elicitation resulted in price estimates 84% higher than the BDM estimates, suggesting that this method, despite being a stated price (versus one that theoretically reveals true preferences like the BDM method), may be closer to the actual demand.[50]

Differences between WTP and WTA

The differences between WTP and WTA are well documented in the literature. The endowment effect[51] states that people ascribe more value to things they own. Another theory to explain the differences states that the loss of the product is felt differently than the gain of the product at the same utility level[52]. Echoing this theory in our case, participants fear more the loss of the stove utility (the stove utility is more inelastic) than the loss of the cash utility, even if the utility level is the same. Money may be not wisely spent or can even be stolen and participants feel that the cash benefit is only short-term, while the stove benefits last longer. A feeling captured among some participants is that "*money gets finished*."

Although these effects may partially explain the differences, we think liquidity constraints are the most important factor driving the very large differences. This means that participants do

[50] This method could not be compared against the demand because the samples were mostly of people who purchased the stoves and hence would provide a bias estimate of demand.

[51] Plott, Charles R; Zeiler, Kathryn (2005). "The Willingness to Pay–Willingness to Accept Gap, the "Endowment Effect," Subject Misconceptions, and Experimental Procedures for Eliciting Valuations". American Economic Review 95 (3): 530–545

[52] Hanemann, W. Michael (1991). "Willingness To Pay and Willingness To Accept: How Much Can They Differ? Reply". American Economic Review 81 (3): 635–647.

not have the cash at hand to pay the value they ascribe to the stove. Even if the financial utility of the intervention stove is large over time due to fuel savings, the money is likely already allocated among other pressing needs or people simply do not trust their savings discipline; also, these populations face uncertain and urgent demands which make their capacity to pay in the future unclear. Transaction costs to obtain the liquidity can also widen the WTP/WTA gap.

Factors influencing WTP.

Our statistical analysis found four key factors affecting WTP: whether participants were asked for a full price or an installment price, the behaviors around usage of the stove during the trial period in light of price uncertainty, the stove model, and income levels. Durability perceptions also affect WTP, but are better captured through the stove model in the statistical analysis. Interestingly, fuel savings did not figure in the list of WTP influencers. The reasons could be many, but possible reasons include that the connection between savings is weaker in light of variable intra-household daily fuel consumption and fuel stacking; cultural factors related to how cooks do their accounting (for instance reported fuel expenditure savings were different than KPT-related savings); or other. In other geographies, the authors have found that long improved cookstove pay-back periods erode the sense of savings.

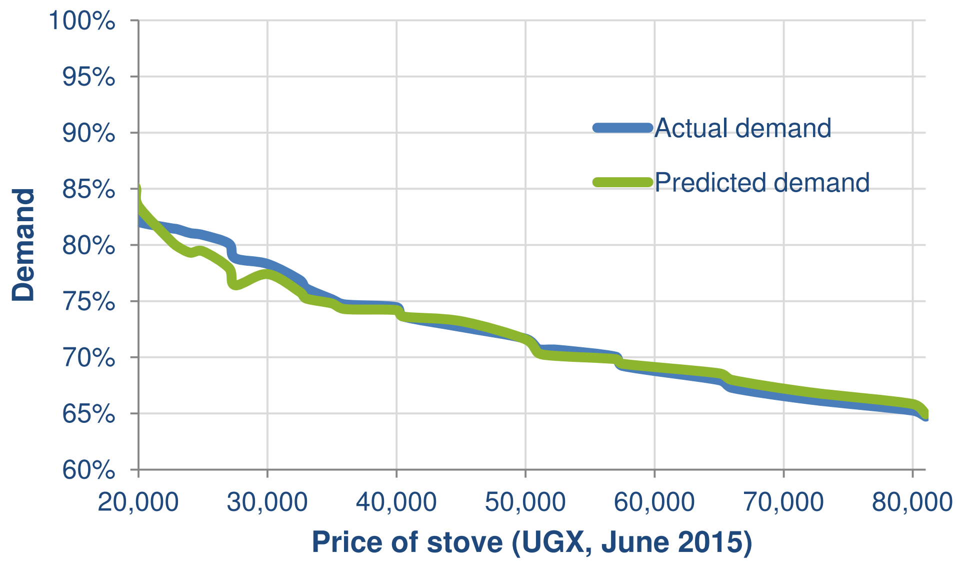
Comparison with other studies

Levine et al[53] obtained WTP estimates for Ugastoves in Kampala to understand liquidity constraints, present bias and poor information on the product attributes. However, based on the information made available from their report, their Ugastove WTP estimates at the median are significantly lower than those obtained in this study (~ USD $2.4-$4 versus $6.2-$8.4). We believe the reasons for the discrepancies could be partially explained by the fact that in Levine et al, the demand curve is based on first responses to BDM elicitations, whereas this study offered the possibility to bid again after the random price had been disclosed to obtain actual demand for stoves. Moreover, we found a difference in WTP based on the installment versus full price elicitation whereas Levine et al do not report eliciting "per installment" WTP. Inflation from the time when this other experiment took place (likely 2010) to now may also play a small role. Finally, the experiment conditions were likely different. Their sampling method placed participants more closely (every 6 households) and their sampling locations may have captured poorer segments of the population, however demographic details are not presented. Other experimental factors such as enumerator-participant interaction and the length of the trial period could also play a role.

Accuracy of the demand models.

The demand models summarized in appendix 7 accurately predict 80% of the time if the person will buy or not the stove (binary outcomes) under the experiment conditions. A comparison of the predicted demand (all stove models and payment modes included) against the actual demand shows minimal discrepancies. Above values of UGX 20,000 (June 2015), the maximum error is 3.2%. The following graph displays the predicted and the actual demand for the range of values included in the willingness to pay experiments (values below 20,000 UGX were omitted as the minimum cost of stoves included in the study was 21,645).

[53] Levine, David I., Theresa Beltramo, Garrick Blalock, and Carolyn Cotterman. "What impedes efficient adoption of products? Evidence from randomized variation in sales offers for improved cookstoves in Uganda." (2012).



5 Conclusions

Stove use

- Our analysis revealed that although differences in the average number of cooking episodes can be statistically significant between stove models, the fraction of traditional cooking displacement (average = 50% across stove models, with a maximum of 58% for Ugastove) is not statistically significant between the different stove models.
- Wood stoves are used less often than charcoal stoves. Although we could not ascertain baseline stove use prior to the dissemination of intervention stoves among the wood population, it is likely that the populations are distinct in terms of cooking behavior given the substantial fuel savings found among households with intervention wood stoves.
- Stove stacking is ubiquitous among the target population. This not only affects the magnitude of fuel savings, but the capacity to deliver measurable health results (especially in the case of wood stoves). In many cases the presence of at least two improved stove burners in the households are therefore necessary to complete the transition to the cleaner cooking.
- The SUMS analysis is bound by small sample sizes and the assessment period. Due these small sizes and to the failure to record temperature data over periods of the study, conclusions over the adoption of stoves over time cannot be reached with confidence. Qualitative research coupled with SUMS data may yield a richer picture of the adoption patterns in the absence of large sample sizes.

Fuel use and savings

- Overall, the fuel savings assessed in this study at the household level were modest with one charcoal stove not reporting statistically significant savings. Lab-tests or Water Boiling Test efficiencies generally predict more substantial savings. However, field conditions imply that fuel use is affected by a combination of factors. Notably, our study demonstrated that stove stacking is prevalent among the communities sampled with most intervention stoves being used along side baseline stoves.

- Among wood stoves average fuel savings were higher than among charcoal stoves, despite reporting a lower number of cooking episodes per day. This highlights the potential among wood populations to realize substantial savings, provided that users are adequately trained and sensitized on the use of stoves and after sales services robust enough to quickly address stove malfunctions (caused by the users or the stoves).

Acceptance of intervention stoves

- The study was able to assess the initial use and short-term acceptance of the intervention stove. Overall, integration in to the household kitchen activity was more pronounced in the charcoal stoves than the wood burning stoves.
- Longer-term acceptance will depend on the stove durability, ability to access repair/spare parts and availability of replacement stoves. In the case of Biolite and ACE1, continued availability of appropriate fuels will be a factor. Also whether it continues to meet needs of consumer and assuming there is no better accessible alternative will both play a role.

Durability

- Although most were showing signs of 'wear and tear' such as corrosion and rust, which might negatively impact on the stoves aspirational nature, very few stoves experienced technical failures after 3 months in the study homes.
- Issues that were encountered were either addressed promptly by the manufacturers or are now addressed by new stove models that became available during the course of the study.

Willingness to Pay

- Our analysis indicates that demand varies by stove model. Overall, the Ugastove and Briketi EcoStove models present the lowest WTP. These ICS models are sold in the study area at competitive prices, which may explain the outcomes, but perceived durability may explain the outcomes as well (see paragraph below). The Burn Jikokoa and Biolite HomeStove present the highest WTP values. The Biolite HomeStove and Burn Jikokoa stoves were sold in the study area but at much higher prices, which is likely to have preempted the users to pay more for them. Although the effects are not statistically significant, it is very likely that the Burn Jikokoa presents a higher demand than the Biolite HomeStove stove given the high user satisfaction and performance of the former.
- Perceptions of durability seem to influence willingness to pay (these perceptions are captured in the stove model and hence not included in the demand models) with more durable stoves fetching higher demand than models not perceived as durable. Hence, perceptions of durability point to likely value propositions of stoves in the market. This contrasts with fuel savings that do not increase demand based on our statistical analysis.
- Becker-deGroot-Marschak experiments, which have been used to determine demand for stoves in other studies, seem to be an inaccurate method to estimate demand. Responses to properly phased questions such as "At what price would you think the product is expensive, but would still recommend a friend of family member to purchase one?" seem to follow more closely the actual demand, despite being a stated (versus revealed) preference method. Nonetheless, the BDM method is useful to prevent price bargaining and to randomize prices for demand estimates.
- Income levels (as proxied through PPI ® indexes), price, stove model (capturing durability perceptions), and confidence in using the stove during the trial period were the factors affecting demand for stoves. This analysis points that people more likely to feel confident with trial products and wealthier households are likely early adopters of improved

cookstoves in the study area. The demand curves presented in appendix 1 capture the behavior of these groups.

- Pricing-wise, we found four distinct clusters of stoves: low cost, low WTP (Ugastove, Briketi Ecostove); medium cost, low WTP (Prakti Leo Char, Envirofit Econochar 1.0), medium cost, high WTP (Burn Jikokoa), and high cost, high WTP (ACE 1 and Biolite HomeStove). Depending on taxes, duties and shipping, the placement of stoves in one category or another may change; however, based on the best information we have, most stoves are likely to remain within their categories.