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A Preliminary Evaluation of the 'Akha' Gasifier Cookstove by Rural Households in Bangladesh

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A Preliminary Evaluation of the 'Akha' Gasifier Cookstove by Rural Households in Bangladesh

Building a TLUD-Cookstove / Biochar Ecosystem in Bangladesh 'goats2019'

Md. Golam Azom, Jannatul Ferdous, Stifen Hembrom, Milon Hossain, Mahbubul Islam, Andrius Kisku, Krishna Rani, Dipali Sarkar, Kishna Kuma Shingha, Md. Abu Sufian, Rupali Tudu, and Julien P. Winter. 2019.

Abstract

In 2016 two new technologies — a gasifier cookstove, and biochar — were introduced for the first time in rural Bangladesh. The stove, called the "Akha" was a natural draft, top-lit updraft (TLUD) gasifier. It principal benefits were very low smoke emissions, fuel efficiency, and the ability to make char as a by-product of cooking. Bangladesh is an ideal candidate for improving soil quality by applying biochar. The climate permits three crops per year and the soils are fertile, however crop yields don't reach their potential because soil organic matter levels are low. Thus when biochar is used to increase soil organic matter we can expect large increases in yield. This is critical for Bangladesh because it is a densely populated country (170 M people, >1000 per km^2) that will loose land to rising sea levels. Through an extension education program on TLUDs and biochar, Akhas were set up in 111 homes. These homes were surveyed for users' evaluations. All households gave the Akha a good-to-excellent performance rating for reduction of smoke and fuel efficiency. Emotionally, users experienced contentment and higher self-esteem. The county's rural population is under energy-stress with insufficient wood fuel to meet the demand. However, differences in household fuel security had no effect on their positive assessment of the Akha. The questionnaire asked about household socio-economic status. From this we did a multi-dimensional poverty analysis and stratified households into poor and non-poor categories. Poor households gave a positive, but significantly lower evaluation of the Akha than better-off households. There are now 250 households with Akhas, and a new survey will look closer into factors that could restrict ability of poorer households to benefit from the TLUD and biochar. The TLUD and biochar are synergetic technologies creating what we call a TLUD/biochar ecosystem, wherein the TLUD is a 'keystone' element, and biochar is an 'ecosystem engineer'. This project in Bangladesh could be a paradigmatic example to help other parts of the World sequester carbon into soil organic matter, and simultaneously adapt their food supply to harsh weather.

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A Preliminary Evaluation of the 'Akha' Gasifier Cookstove by Rural Households in Bangladesh

1. Synopsis

1.1 Introduction

In 2016, 'Akha' ® ND-TLUD[1] cookstoves and biochar were introduced at three locations in rural Bangladesh. The Akha cookstove reduces women's exposure to smoke and uses less fuel than traditional stoves. It also make char as a by-product of cooking. The char can be used as charcoal fuel, or as biochar to increase soil productivity. Together, these two technologies act synergistically to improve health, nutrition and economic security of households. This is a report of an exploratory survey conducted in 2017 to assess the initial reception of the Akha stove in rural homes.

Bangladesh is a low-lying country that in the 'bull's eye' of impacts from Global warming, because it will loose land to rising seas in the Bay of Bengal. The problem is particularly serious because the population density is already over 1000 people per km². However, we may be able to compensate for land lost by using biochar to increasing crop yields on higher elevation soils. Biochar is char that is used in biotechnology as opposed being burned as charcoal. The char is made by carbonizing plant residues at >450 °C. As biochar, it is able to adsorb plant nutrients and provide surfaces for microbial growth. Most importantly, biochar is resistant to decomposition, so is able to make long-term increases in soil organic matter by augmenting humus formed from decomposing plant residues and livestock manures. Because many of the soils have only 1% soil organic matter, there is a reasonable expectation that biochar will have a strong effect on crop yields. Bangladesh could be one of the best places in the World to use biochar, because it has fertile soils in need of organic matter, and has a climate that permits three crops per year. The extent to which biochar can compensate for land lost to rising sea levels is yet to be determined, but it can certainly make a large contribution.

However, the first problem to address is not what to do with biochar, but how to get it. That is where the Akha plays a 'keystone' role. Wood is the best type of biomass for making biochar, but the total forested area in Bangladesh is only ca. 17%, and that meets only half the demand for cooking fuel. The rest of the time, women burn low density plant residues and cow dung. TLUD cookstoves offer a solution, because they make char as a by-product of cooking. At the same time, they use around 35% less fuel than traditional stoves. Since TLUD stoves work by burning smoke, their emission of pollutants is very much lower than traditional stoves. Biochar made in an Akha has value for the household, either to increase the productivity of their home gardens and farms, or to be sold to neighbors or agricultural support businesses. Thus, TLUD stoves are an economically and ecologically sustainable source of biochar. Biochar provides extra motivation to adopted clean-

[1] ND-TLUD: a natural draft, top-lit updraft gasifier that works by partial combustion and pyrolysis of woody fuel producing pyrolysis gases (white smoke) and leaving solid char behind. The pyrolysis gases are flammable, and are burned at the top of the stove for cooking. Usually, about 20% of the original fuel dry matter remains as char.

cooking TLUD stoves.

The Akha (Model 01, Figure 1) is a natural draft, TLUD gasifier that was designed specifically for rural Bangladesh. In particular, it had a robust outer body made of concrete, and other components that are easy to make or purchase. It also has a hinged grate to make safe removal of the char easy. The Akha is intended to regional employment by being manufactured by small businesses. (See Section 2.1.1. The Akha Stove, for more details on Akha construction and fuel efficiency)

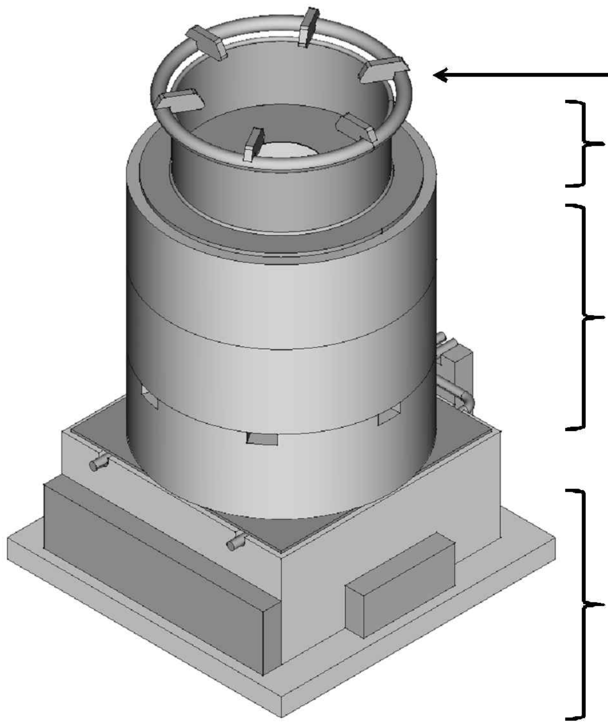


Figure 1. The Akha (Model 01) cookstove is composed of four modules. The modules are from bottom to top: (a) a base for receiving ash & char and controlling primary air, (b) a metal gasification reactor that is contained within (c) a concrete or clay stove body with (d) a gas burner and riser on top, and finally, (e) a pot holder. The illustration is an example of a cookstove designed to burn small pieces of wood. The base is 12 x 12 inches square and 5 inches tall. The stove body is 12 inches tall. The reactor inside the stove body (not shown) is 8 inches in diameter, and 10 inches tall.

In 2016, the Akha-Biochar Pilot Study was started by the Christian Commission for Development in Bangladesh (www; founded in Dhaka, 1973) to test the acceptance by rural families of Akha stove and biochar. The technology intervention is being conducted at three different locations in central and North-Western Bangladesh (Figure 2). Shibalaya is along a transportation corridor only 60 km west of Dhaka (14.4 million people). Manda is located in one of the best agricultural regions north of Rajshahi. Daudpur is located in the north east, and is the most rural of the locations. It is on drought-prone soil, and the study participants belonged to Santal and Oraon ethnic minorities. The standard of living was lower in Daudpur than the other two locations. (See Section 3. for a discussion of their comparative geography.)

Figure 2. Locations of the study.

The purpose of the Akha-Biochar Study was to establish a "TLUD-biochar ecosystem" at the three locations. We call this an 'ecosystem' because of the inter-connectedness of the technologies. The Akha TLUD performs the role of a 'keystone' element that makes biochar production in homes possible. The biochar performs the role of a 'ecosystem engineer' by increasing the efficiency of plant nutrient recycling (manures and composts) and fundamentally improving the properties of soils to support life. Initially, Akha stoves have to be accepted by women essentially on their own merits to reduce smoke and save fuel. During this time — over the course of several cropping cycles — gardeners and farmers witness the benefits of biochar. As the material impact of biochar becomes know, biochar acquires a 'commercial value' in the community. The value of biochar feeds back to the desire to use the Akha, because the Akha not only cooks but makes income or increases home garden productivity.

The current survey was conducted in August-September, 2017. At this point in time, 111 Akhas had been in homes from 2-16 months, but the biochar economy was still forming. The focus of this current survey it the Akha. The primary objectives were (1) to get women's opinions of Akha function, (2) to assess the variation in household fuel security which can limit Akha use, and (3) to use multidimensional poverty assessment to see if if there was any relationship between household economic status and evaluation of the Akha. (4) We asked if biochar was a necessary reason for using an Akha, but otherwise, it was villagers would not yet be able 'put a price' on the value of biochar.

1.5. Conclusions

1.5.1. Broad Acceptance of the Akha

There was almost unanimously high ratings for that Akha for functional performance, and subjective experiences. Because there were little negative response to the Akha, there was no substantive correlation between any of the parameters: fuel energy density (wet and dry season), functional performance indices (operation and smoke), or subjective experience factors (contentment and self-esteem). Saving fuel, low smoke pollution, faster cooking and making biochar were cited as virtues of the Akha. All of these could have been necessary conditions for Akha acceptance, but we only asked that question for making biochar. Seventy percent of the respondents in Daudpur said that making biochar was an essential property of the Akha, whereas in Shibalaya, 68% and Manda 78% of respondents said that making biochar was very important. The need to size fuel for the Akha, and the need to refuel the Akha if cooking was not completed on the first batch were not cited as major concerns.

1.5.2. Poverty and Akha Acceptance in Daudpur

As we saw in Section 4.2.7. (Figure MDPI), only in Daudpur did the households show a range of multidimensional poverty values. In Shibalaya and Manda, the households had only one or two 'deprivations.' Therefore, the effect of poverty on Akha acceptance could only be assessed for Daudpur.

The MDPI was used on the Daudpur households to see if standard of living had an effect on acceptance of the Akha cookstove. Specifically, we classified households as 'better off' if they had less than three depravations, and as 'poorer' is they had three or more depravations. We examined whether these two groups differed in using more energy-dense fuel (more wood and less leaves), gave the Akha a better evaluation for functional performance in operation and reduction of smoke, and whether Akha users were more content with the stove, and gained better self-esteem (eg. pride).

We found that in Daudpur, the Akha was almost unanimously well-received, and that the effect of standard of living was only weakly significant ($p < 0.1$), or not significant (Table MDPI Daudpur). Poorer households tended to use less energy-dense fuel in the dry season, tended to give a sightly less positive review for ease of Akha operation, and they were a little less contented with using an Akha. None of these lower values for the Akha were bad: the Akha was well received. However, there was a tendency ($p < 0.1$) for poorer household to be slightly less positive about the Akha. The overall conclusion of this study is that:

The Akha was well received by all households, but we must pay attention to poorer family's ability to adopt TLUD technology.

Table MDPI Daudpur. Effect of low standard of living (using a Multidimensional Poverty Index, MDPI) in Daudpur on the energy density of biomass cooking fuel, and the evaluation of the Akha.

MDPI †		Biomass Fuel Energy Density		Akha Functional Evaluation		Akha Subjective Evaluation	
category	n	Wet season	Dry season	Operation	Smoke	Contentment	Self-esteem
		— ($MJ\ L^{-1}$) —		——— (index: 0 to 4) ———			
Better off	26	5.44	4.28	3.62	3.45	3.74	3.18
Poorer	20	5.57	3.45	3.30	3.33	3.35	3.08
significance ‡		n.s.	0.09	0.09	n.s.	0.08	ns

† Forty-six households were grouped according the a multidimensional poverty index MDPI < 3 (better-off) or MDPI >= 3 (poorer). ‡ Probability that means within a column are not significantly different, or not significantly different (n.s.).

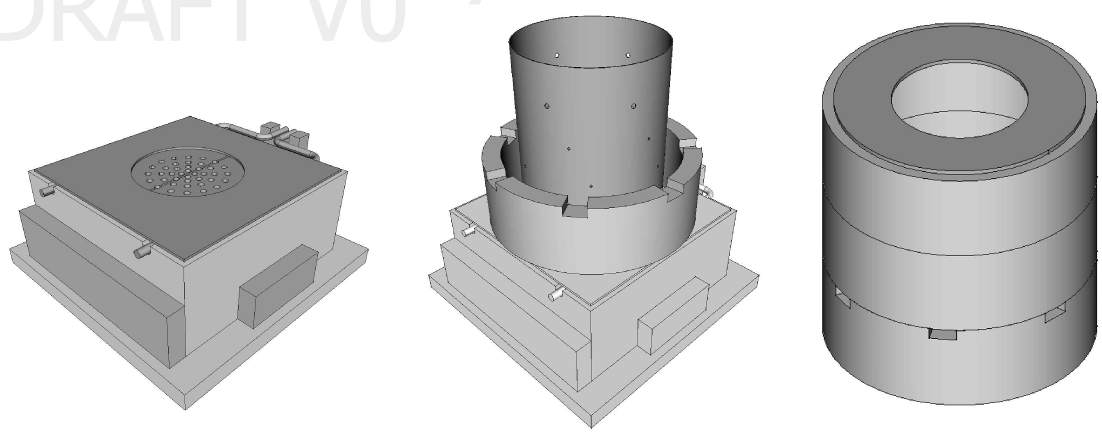
2. Methodology

2.1. Stoves

2.1.1. The Akha Stove

The Akha-Biochar Project was the first introduction of a natural draft, top-lit updraft (ND-TLUD), semi-gasifier cookstove, and biochar to rural homes in Bangladesh. The ND-TLUD stove was called the "Akha" (Model 01) (Figure 1 & x) was designed for Bangladesh by adapting principles from two metal ND-TLUD stoves called the "Peko-pe" (Paal Wendelobo, Norway) and "Champion" (Paul Anderson, USA). The Akha was a semi-permanent installation, with an outer body made of concrete, and a hinged grate for safely removing hot char. A short (2 min) video of Akha assembly can be found on YouTube.

An Akha (Model 01) was sent to Institute of Energy at the University of Dhaka for a Water-Boiling Test. In cold and hot starts, 30-31% of the energy in fuel was transferred to heat water. Simmering efficiency was around 24%. Emissions of CO were 9, 6 & 5 ppm CO, and for particulate matter (PM), emissions were 400, 300 & 200 μg PM10μm / m^3, and 200, 150 & 100 μg PM2.5μm / m^3 for cold start, hot start and simmering, respectively. These emissions were one quarter the amount measured above a traditional cookstove. Research is continuing to make the Akha even more efficient and cleaner.



(a) Base module (b) Reactor and outer body (c) Outer body and gas concentrator ring.

Figure x. Akha (Model 01) partially dissassembled.

2.1.2. Traditional Stoves

With a couple of exceptions, all of the households used traditional cookstoves prior to the introduction of the Akha. The traditional stove was an enclosed type of 'three stone fire'. It looked like a clay volcano, with a hole at the top for heat, flame and smoke to escape. There was a hole in the side of the stove for stoking the fire with fuel. Some traditional stoves had more than one mouth (Figure 2.). Although very basic, traditional stoves have some advantages: (1) they cost nothing to make, (2) they are versatile and could burn any type of biomass fuel including wood and low density leaves and straw, (3) they enclosed a fire from wind, and created draft in their height. Importantly, traditional stoves make households were completely self-sufficient in cooking. A couple of households had improved combustion stoves with a chimney to conduct smoke out of the home, but these women were well experienced with traditional stoves.

Figure 2. An example of traditional cookstove with two mouths, and one stoking hole.

2.1.3. CONTROLLED COOKING COMPARISON OF STOVES.

As part of training women to use the Akha, they performed Controlled Cooking Tests to compare fuel use and time saved (Figure 3). Both the Akha and a traditional stove were used to cook 500 g of rice in 1 liter of water, then sauté vegetables, for a total cooking time of about one hour. Both stoves used the same wood fuel, with the Akha batch-loaded once with vertical pieces, 15-21 cm long and 3-4 cm thick, and the traditional stove stoked continuously from the side with pieces 35-50 cm long and 2-4 cm thick.

Controlled Cooking Tests (CCT) simulated actual cooking conditions better that Water Boiling Tests (the standardized international test for comparing of stoves). The results from the CCT were remarkably consistent (Table 1), given that different woods were used, and different people performed each test.

The Akha saved 36% of fuel compared to a traditional stove (Table 1). However, this was an ideal scenario: the test was conducted under expert guidance, and with air-dry (10-12% moisture) wood fuel. Lower efficiencies may occur if the water content of the fuel is higher, if the TLUD had to be reloaded to complete cooking, and if the operator lets the char burn off. Continued testing will compare different cooking tasks, and types of fuel.

The Akha saved 12% of the cooking time compared to the traditional stove. This was due to a faster start-up of the Akha, and more efficient energy transfer to the pot, compared to the traditional stove. The time saved could change with duration of cooking, and if the TLUD has to be refueled.

Table 1. Controlled Cooking Tests comparing a traditional stove with the 'Akha' gasifier stove, conducted by women in the 'Akha User Group' workshops.

			Traditional Stove		Akha Stove		
Location	Number of Tests	Wood Fuel	Fuel Used	Cooking Time	Fuel Saved	Time Saved	Residual Char
	(n)		(kg air dry)	(min)	(%)	(%)	(% of fuel) ‡
Shibalaya	14	Mango	2.8 ± 0.1	65 ± 5	-38 ± 4	-14 ± 5	21 ± 2
Manda	19	Mixed †	2.9 ± 0.1	68 ± 2	-35 ± 4	-11 ± 4	21 ± 1
Daudpur	9	Eucalyptus	2.8 ± 0.1	65 ± 7	-36 ± 7	-11 ± 8	19 ± 4
Overall	42				-36 ± 3	-12 ± 3	20 ± 1

Mean ± 95% confidence interval. † Mango, Mahogany, or Eucalyptus fuel. ‡ Char as a percent of the mass of air-dry fuel burned.

2.2. Selecting and Training Participants

2.2.1. Akha User Groups

The Akha ND-TLUD and biochar technology was introduced to households through “Akha Users Groups”. These were groups of 10 to 20 women (± husbands) who attended a series of workshops where they learned how to assemble an Akha, prepare fuel, and cook on a TLUD. The workshops were run by CCDB staff, with occasional visits by research and extension agronomists from universities and the Bangladesh Agricultural Research Institute. As part of the instruction, they performed a Controlled Cooking Test, where they prepared the same food on an Akha, and on a traditional stove, and recorded the time and fuel saved by using the Akha rather than a traditional stove. They also learned about how biochar can be used to increase the yield in vegetable gardens by planting demonstrations in pots containing local soil with varying amounts of biochar and manure mixed in.

Figure 3. Women of a Akha Users Group perform a controlled cooking test to compare fuel consumption by the Akha versus a traditional stove. On average the Akha used 36% less fuel.

2.2.2. Selecting Akha Households

After the attending the workshops, women had an Akha installed in their homes, and were given supporting instruction by project staff to make sure they used the TLUD correctly. By receiving an Akha, participating households agreed to be co-investigators evaluating the suitability of the Akha for rural homes. They collected their biochar to be weighed monthly at the CCDB campuses. They could keep the biochar for their own use, or sell it to CCDB for use in local agricultural trials through "Biochar User Groups". They also expected to be periodically interviewed for their assessment of the Akha.

Note that the participants were not a random sample from their respective communities, but rather families that demonstrated an interest in learning about the Akha and biochar by paying a modest fee to participate in an Akha Users Group. In order to get an Akha, they had to demonstrate further interest by preparing fuel. They had to sign an agreement to be participants in the study, and to return their Akha to CCDB if the lost interest. In addition, the participants in Shibalaya and Manda were Bengali, and the participants in Daudpur were Urao (20%), and Santal (80%) ethnic minorities.

It was important to select participants (rather than randomly distribute the Akha) to ensure that the Akha got a serious evaluation, and was not treated trivially. If the Akha had been given out freely, many people might not have taken the time to learn how to use it, and the TLUD would get undeserved bad reviews. Bad news travels fast, and is hard to correct. In addition, the people who stepped forward to trial the Akha were innovative, early adopters of new technologies. They would be the most reliable spreaders of knowledge to friends and acquaintances.

Figure 4. Akha User Group women taking an Akha home. They were assisted with set-up of the stove, and provided with extra assistance with stove use, if required.

2.3. THE SURVEY

Between August 16 and September 25, 2017, the women were interviewed for this report. They would have been using an Akha anywhere between two to sixteen months.

The objective of this survey was to get the first formal assessment of Akha by rural women. This study had two main questions: (1) what do women think about the Akha, and (2) did household circumstances — especially standard of living — have an impact on their views? A positive reception of the Akha would supply crucial evidence to justify scaling-up the dissemination of Akah-biochar technology. The survey also hoped to identify any technical, or socio-economic problems that should be addressed in future research and development.

This report presents the survey results in the order in which the questions were asked. The main topics were:

1) Household socio-economic circumstances
2) Fuel: household fuel security, and problems in fueling the Akha.
3) The functional performance of the Akha
4) The subjective experience of using an Akha.
5) Concluding questions: the importance of making char; recommending the Akha to a friend.

In a broad sense, the survey was an argument moving the respondents toward their final concluding recommendation. In this way, the survey reminded respondents of topics that could help them evaluate the Akha. In particular, negative topics about fuel security, preceded questions about Akha function, and if they would recommend the Akha. If a sequence of questions could in anyway bias a conclusion, then a survey should lean toward refutation, rather than confirmation, of the acceptance hypothesis. If the minds of respondents are prepared by the sequence of questions to refute the hypothesis (that "the Akha is the best stove ever"), but fail to do so, then the overall conclusion of the survey is more sound.

The survey was conducted by at Shibalaya by Md. Abu Sufian, Dipali Sarkar; at Manda by Jannatul Ferdous, Krishna Rani, Andrius Kisku; and at Daudpur by Rupali Tudu, Kishna Kumar Shingha, Milon Hossain, Stefen Hembrom, and Md. Golam Azom.

The project team pre-tested the questions at Shibalaya, Manda and Daudpur, then conferred to make any adjustments. Scheduling the interviews was at the respondents' convenience. Interviews were conducted by a team of at least two interviewers. There was at least one female interviewer in each team, and at Daudpur there was at least one ethnic interviewer for language and cultural interpretation. Interviews were conducted in the homes of Akha users in the presence of both husband and wife, with the wife being the primary respondent.

Many of the questions had fixed, Likert-type answers with five choices ranging between 0: Never, 1: Rarely, 2: Sometimes, 3: Often 4: Mostly; or 0: Unimportant, 1: Somewhat important, 2: Equally important (compared to 'a reference'), 3: Very important 4: Essential. Open-ended questions were included to corroborate the answers from fixed questions, assess the respondents' priorities, and reveal any other issued that the respondents considered to be important. Likert-type questions were unfamiliar to the respondents, and 25% of the women respondents were illiterate. To convey the meaning of Likert-type answers, a symbolic chart was used with the largest symbol for the highest value and no symbol for zero. Respondents were also given verbal clarity about the relationship between a question and the scale. Respondents pointed to the desired symbol. In general, the procedure worked well. Time taken to select a symbol was the most frequent problem. Illiteracy didn't pose much of a problem for understanding the questions.

3. Study Locations

3.1. Study Locations

The Akha stove and biochar were field-tested in three communities by staff from the Christian Commission for Development in Bangladesh (CCDB, est. 1972). CCDB had campuses in the area, and a strong working relationship with the local people. The communities were situated the Unions (smallest geopolitical entity) of Shibalaya, Manda and Daudpur, in the Districts of Namiknj, Naogaon and Dinajpur, respectively (Table LOCATIONS, Figure Locations). The CCDB campuses had accommodation, office and meeting facilities for rural development projects.

Table LOCATIONS. Locations of the Akha field trials, the number of homes involved, and their ethnicity.

Study Locations				Study Participants		
District	Upazila	Union		Villages	Homes	Ethnicity of Participants
			(N, E)	(n)	(n)	
Manikganj	Shibalaya	Shibalaya	23.832°, 89.826°	9	37	Bengali
Naogaon	Manda	Manda	24.763°, 88.703°	7	28	Bengali
Dinajpur	Nawabganj	Daudpur	25.385°, 89.120°	8	46	Santal (80%), Oraon (20%)

† Santal people also spelt as Saontal. Oraon or Kurukh people, also spelt as Urao and Urang.

3.1.1. Shibalaya Union

Shibalaya Union was 60 km west of the capital city, Dhaka, and 20 km west of Manikganj. It was adjacent to a highway leading to the Paturia ferry terminus that accesses South-Western Bangladesh, which was an important transportation corridor.

Shibalaya is on the Low Ganges River Floodplain, at the confluence of the Padma (Ganges) and Brahmaputra rivers. The region has no agroecological constraints (BARC, 2000) besides flooding. The soil has low (1.1 to 1.7%) to medium (1.7 to 3.4% m/m)) soil organic matter. The subsoils are neutral pH, and the topsoils are slightly acid (5.6 to 6.5 pH) (Soil Resource Development Institute maps).

By 2020, Dhaka City (population 14.4 million) is expected to become the third largest city in the World, as people migrate from rural Bangladesh in search of jobs. Much of the urbanization is unplanned, and there is extreme poverty in growing slums. There are recurrent episodes of flooding, and living conditions are getting worse in Dhaka city. Manikganj Pourashova is a growing suburban, satellite city of Dhaka. It is experiencing rapid economic development as people leave Dhaka in search of better living conditions in terms of transportation, food support, and residences. (Sayed and Haruyama, 2016).

The economy of Shibalaya Union benefitted from its proximity to cities, but development in the Shibalaya Union was limited because of annual flooding of the Padma and Brahmaputra rivers. Flooding can be severe when rivers are high, and especially if there is a backwater pressure from storm or tidal surge in the Bay of Bengal (Rahman, Goel and Arya, 2013). Extreme poor were 7-15% of the population (2nd quintal) in Shibalaya Upazila in 2010 (Bangladesh Bureau of Statistics and World Food Programme, 2104, poverty maps).

In the District of Manikganj there was no forest (Table AGR_LAND_USE), but trees were common in homesteads where they supplied shade, wood and fruit. Aside from flooding, the were no agroecological constraints on farming (BARC, 2000), and a substantive area had two and three crops per year. The net cropped area in Manikganj was 63% in 2014-16 (Table AGR_LAND_USE), but 36% of Manikganj was unavailable for agriculture due in large part to urbanization.

Table AGR_LAND_USE: Regional land use in agriculture (BBS, 2017)

Land Use	District		
	Manikganj (Shibalaya)	Noagoan (Manda)	Dinajpur (Daudpur)
		— (%) —	
Forest	0.0	0.8	2.1
Not available for cultivation	35.8	17.4	20.5
Culturable waste land	1.2	0.1	0.1
Current fallow land	0.3	0.5	0.0
Single cropped	13.3	20.0	6.3
Double cropped	30.5	39.6	45.3
Triple cropped	18.7	21.5	25.4
Quadruple cropped	0.3	0.1	0.1
Net cropped	62.8	81.2	77.2
Gross cropped	131.6	164.2	173.7

Data from the Yearbook of Agricultural Statistics — 2017, Bangladesh Bureau of Statistics.

3.1.2. Manda Union

Manda Union is 45 km north of Rajshahi (population 800,000) along the Rajshahi-Naogaon Highway. It is on Tista Meander Floodplain (agroecological zone) with the Atrai and Shiba running through it from north to south. Occasionally, these rivers can flood, and there was a flash flood along the Atrai River in the summer of 2017. The soil is very low (<1% m/m) to low (1.1-1.7%) in organic matter. The subsoils are neutral pH, and the topsoils are slightly acid (5.6 to 6.5 pH) (Soil Resource Development Institute maps). Biochar would improve the crop yields in this region by raising both the organic matter and pH of these soils.

In the District of Noagoan, Agriculture is the main economic activity covering 80% of the land (Table AGR_LAND_USE). Sixty percent of the land has two to three crops per year. Like Manikganj tree cover is associated with homesteads rather than forests. Manda is favorable for agriculture with three crops of rice per year. The region has no agroecological constraints (BARC, 2000), but is prone to drought years. Noagoan District is suitable for a wide range of field crops (Table SUITABLE_CROPS). Extreme poor were less than 6% of the population (1st quintal) in Manda Upazila in 2010 (Bangladesh Bureau of Statistics and World Food Programme, 2104, poverty maps).

Table SUITABLE_CROPS: Regional suitability of major field crops.

Crop	District		
	Manikganj (Shibalaya)	Noagoan (Manda)	Dinajpur (Daudpur)
Aus rice (Apr-Aug)	Moderately suitable	**Not** suitable	Less suitable
Aman rice (Apr-Dec)	Less suitable	Suitable	Suitable
Boro rice (Dec-May)	Suitable	Moderately suitable	**Not** suitable
Wheat	**Not** suitable	Moderately suitable	Moderately suitable
Maize	**Not** suitable	Less suitable	Moderately suitable
Potato	Less suitable	Less suitable	**Not** suitable
Lentil	Less suitable	Moderately suitable	**Not** suitable
Mungbean	Less suitable	Moderately suitable	Moderately suitable
Gram	Suitable	Moderately suitable	**Not** suitable
Jute	Suitable	**Not** suitable	Less suitable

Summarized from cropping zone maps from the Bangladesh Agricultural Research Council.

3.1.3. Daudpur Union

3.1.3.1. Geography

Daudpur Union is located 50 km southeast of Dinajpur (population). It is not as close to large urban centers as Shibalaya and Manda. Some of the roads are unpaved and slippery in the rainy season. Agricultural is the main economic activity, but it is often constrained in the winter by low soil moisture (BARC, 2000). In 2010, 16-24% of the population in the Nawabganj Upazila were extremely poor (Bangladesh Bureau of Statistics and World Food Programme, 2014, poverty maps).

Daudpur Union is on the Barind Tract. The level, gray terrace soils are very low in soil organic matter (<1%). The subsoils are slightly acid (5.6 to 6.5 pH) and the topsoils are strongly acid (4.5 to 5.5 ph). Low soil moisture is an agroecological constraint, and the region is prone to drought years (Soil Resource Development Institute maps). Biochar would improve the crop yields in this region by raising both the organic matter and pH of these soils.

3.1.3.2. Adivasis

Within the Daudpur Union, the Akha-Biochar Project selected ethnic Santal and Oraon households to test the Akha. Santal and Oraon peoples have experience discrimination by the dominant Bengali-Muslim community for decades. Once, uncontested owners of the land, they have faced discrimination, especially since the partition of India in 1947, that has left them landless and economically marginalized (Barkat et al., 2009).

The Santal and Oraon peoples consider them selves to be 'adivasis' or indigenous peoples. This position is controversial in Bangladesh, and is not recognized by the Government. The Government prefers to call them 'small ethnic minorities.' In truth, just about everyone in Bangladesh has ancient DNA, so the arguments for special rights based on indigeneity are not so strong (compared to Australia, or the Americas). However, that Santals and Oraons have historically had their basic human rights violated (including their right to identify as a People) is beyond question. On that basis, they deserve special attention. All the same, it is not likely that they will get their land back any time soon, especially by appealing to indigenous rights. Instead, Barkat (2015) argued that there should be agrarian reform that lifts up all rural poor and marginalized people, regardless of ethnicity.

Since Santals and Oraons have a strong connection to the land, TLUD and biochar technologies are particularly appropriate for their economic development.

3.2. The Participating Villages

Economic characteristics of the participating villages were recorded by Project survey staff. The objective was to document the diversity of agricultural and other enterprises, and support facilities for business and social activities. To place this study in a broader context, a number of the questions were the same as the 2010 Census questions conducted by the Bangladesh Bureau of Statistics.

Consistent with its proximity to a large city, the villages in Shibalaya had a more diverse economy, agriculture, economic facilities, and social facilities than Manda and Daudpur (Table ECON). There were more employment opportunities for women in the villages of Shibalaya than Manda and Daudpur. However, Shibalaya experienced a higher frequency of natural disasters, that can result in a reversal of family fortunes. Given its diverse economy, proximity to Dhaka, and situation on a transportation corridor, it is expected that public awareness of TLUD and biochar technology will disseminate faster from Shibalaya than from Manda and Daudpur.

The participating villages in Manda and Daudpur were agricultural, and had no cottage or medium industries (Table ECON). In Manda, the agriculture was in field and horticultural crops. The villages were well served with banking and markets. Much of their food was shipped to the city of Rajshahi.

The participating villages in Daudpur had ethnic Santal and Urao households and would be less affluent than nearby Bengali-Muslim villages. Roads leading to Santal and Urao villages were often unpaved, and difficult to travel in the monsoon season. Santal and Urao families were mostly landless, and many work as casual day-laborers, which was not the case in Manda. Subsistence agricultural enterprises, including poultry, ruminants and tree fruits, were more common in Daudpur than Manda. Santal women work outside the house (Akan et al., 2015) in agriculture, and as day-laborers (Table ECON).

Table ECON. Economic activity, social and natural resources, natural disasters, and women's employment in the sub-districts

	Union		
	Shibalaya	Manda	Daudpur
Number of Villages	9	7	8
Activities accounting for 75% economic activity of the village neighborhood			
Agriculture	9/9 †	6/7	7/8
Forestry	1/9		1/8
Fishing	9/9		
Business/Hotel/Restaurant	9/9	3/7	1/8
Casual/Daily Labor	9/9		7/8
Small & Cottage Industry	6/9		
Medium to Large Industry			
Other	8/9		
Activities accounting for 75% of agricultural in the village neighborhood.			
Field crops	9/9	6/7	7/8
Horticultural crops	9/9	3/7	3/8
Fish farm	9/9		
Poultry rearing	9/9		5/8
Poultry hatchery	1/9		
Dairy farm	6/9		
Mixed livestock	9/9		7/8
Tree fruits	9/9		5/8
Other	8/9		
Economic facilities are in the village neighborhood (BBS, 2010) ‡			
Branch of a Bank	8/9	7/7	2/8
Market or bazar	9/9	7/7	7/8
Food godown / temporary purchase center	2/9	7/7	2/8
Cold storage	2/9	1/7	
Fertilizer shop	6/9	7/7	6/8
Pesticide shop	8/9	7/7	6/8
Other	6/9		

† Ratio of number of villages with the property / total number of villages participating in the Akha study. ‡ Questions also asked in the 2010 Census by the Bangladesh Bureau of Statistics.

Table ECON. Continued

	Sub-district		
	Shibalaya	Manda	Daudpur
Social facilities are in the village neighborhood (BBS, 2010) ‡			
Club (recreational)	7/9	2/7	4/8
Play or sports ground	7/9	5/7	4/8
Community Center	2/9		2/8
Other	7/9		
Natural resources are accessible to the village neighborhood (BBS, 2010) ‡			
River or canal	9/9	3/7	4/8
Beel	9/9	2/7	7/8
Pond	9/9	6/7	7/8
Forest	2/9		4/8
Khash land in char area	9/9		2/8
Grazing field	8/9		
Other	8/9		
NGOs active in the village	9/9	5/7	7/8
Natural disasters in the last five years? (BBS, 2010) ‡			
Flood	9/9	flash flood	
River erosion	9/9		
Drought	8/9	6/7	7/8
Hail (Rock rain)	9/9	3/7	1/8
Violent wind (tornado, cyclone)	6/9		1/8
Pestilence stricken	6/9		
Poultry plague	9/9	4/7	2/8
Devastating human epidemic	9/9		
Other	9/9		
Main activity of women in the village or community? (BBS, 2010) ‡			
Day Laborer	4/9		7/8
Agriculture	4/9		7/8
Salaried Job	6/9		
Other	8/9	7/7	

† Ratio of number of villages with the property / total number of villages participating in the Akha study. ‡ Questions also asked in the 2010 Census by the Bangladesh Bureau of Statistics (BBS).

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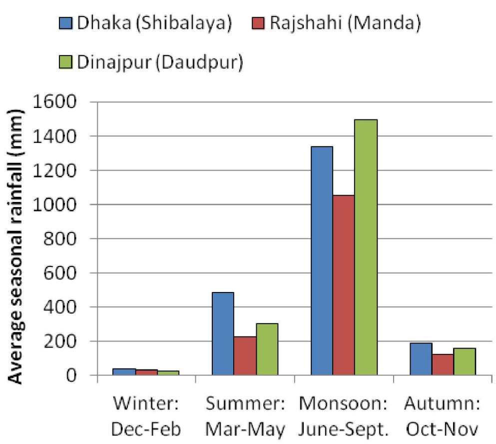
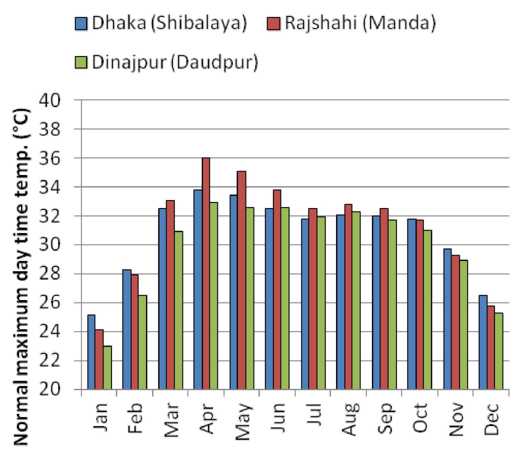
3.3. Climate and Weather

Shibalaya, Manda and Daudpur experience the same seasonal patterns in climate (Figure CLIMATE) (Khatun, Rashid and Hygen, 2016). (1) In winter (December-February) a ridge of sub-continental high pressure extends up to northwestern part of Bangladesh, and temperature begins to fall. Winds very light winds tend to be dry and northerly. (2) Summer or Pre-Monsoon (March - May) can be some of the hottest months. Due to intense heating of the land surface, a low pressure develops over Bihar, West Bengal of India, and adjoining northwestern part of Bangladesh. The low pressure draws moist air in the afternoon from the Bay of Bengal that can result in severe thunderstorms. (3) Southwest Monsoon (June - September) results from intensifying low pressure over northwest India and Bangladesh that draw in southwesterly to southern trade winds. (4) Autumn or Post-Monsoon (October - November) brings south to southeast winds and noticeably falling temperatures. However, cyclonic disturbances form over the Bay of Bengal during this season. The seasonal changes in rainfall have a strong effect on the use of biomass cooking fuel. Wood is stored for use the rainy season, and loose biomass is burned in the dry season (see Fuel Use and Security of Supply).



Average cumulative seasonal rainfall (1981-2014)



Monthly normal maximum temperatures (1981-2010)

Figure CLIMATE: Average rainfall and maximum temperature recorded at Bangladesh Meteorological Department weather stations nearest the Akha study locations.

4. The Survey

4.1. Household Socio-Economic Survey

4.1.1. Purpose of the Survey

This study had two main questions: (1) what do women think about the Akha, and (2) did household circumstances — especially standard of living — have an impact on their views? In this section, we describe the socio-economic properties of the households to set the context of the study, and start to answer the second question about whether only well-off facilities found the Akha acceptable.

Traditional cookstoves cost nothing to build because they are made from clay mud. They can burn all kinds of biomass fuel, including low density leaves or rice straw which is also free. By contrast, improved cookstoves like the Akha have to be purchased, and require dense fuel like wood or briquettes. The demand for wood is greater than the supply across Bangladesh. There are many competing demands for family income, such as clothing, schooling, medication, employment supplies and cell phones. Families with low cash incomes, and having difficulty to obtain wood or briquettes, may judge it better to stick with a no-cost traditional stove, and non commercial fuel. This is a common problem for the acceptance of improved cookstoves.

Like other improved cookstoves, the Akha saves wood, because it burns more efficiently than a traditional stove. Unlike other cookstoves, however, TLUDs automatically make char, as well as save fuel. Char has a value. Thus, making char could more than compensate for the cost of running an Akha, and as a consequence, become a critical enabler for Akha acceptance by low income families. In that case, the Akha should receive broad acceptance across a wide range of household circumstances. All the same, we expect that families will keep a traditional stove for low-density fuels. (Having more than one type of cookstove is called 'stove stacking'.)

The participating households were surveyed for socio-economic properties. The purpose of gathering this data was (1) to describe the families: who was involved, and what was the range of their circumstances; in other words, what was the range of circumstances under which the Akha was tested; and (2) to see if a family's socio-economic conditions affected to how the Akha was received. Some of our questions were similar to those used by the Bangladesh Bureau of Statistics in their census, and household income and expenditure surveys, so that this study could be placed in a boarder context. However, it is important to remember that the participating households were not randomly chosen, so we can't assume that they reflected all Shibalaya, Manda or Daudpur.

4.1.2. Head of Household

Traditionally, the husband is the head of household in Muslim, Santal and Oran households (Uddin, 2012), and that was the case for all participants from Shibalaya and Manda. In Daudpur, three of forty-six households were headed by single women. On average, heads of households were in their forties (Shibalaya 42 yr, Manda 47 yr, Daudpur 45 yr) (Figure AGE).

Despite husbands being the head, most respondents said that wives had a voice in important decisions, such as household purchases and sales. Husbands, alone, were the decision-makers in 30% of the participating homes in Shibalaya and Daudpur, and 7% in Manda. For the other homes, however, the opinion of wives — on the Akha and biochar — mattered in most of the participating households. Ethnic communities have different customs, and shared decision-making was more common in traditional Santal and Oraon families than Muslim families (Uddin, 2012). However, we can't appeal to ethnic differences in our case, since our communities were in different geographic circumstances, and our households were not randomly chosen.

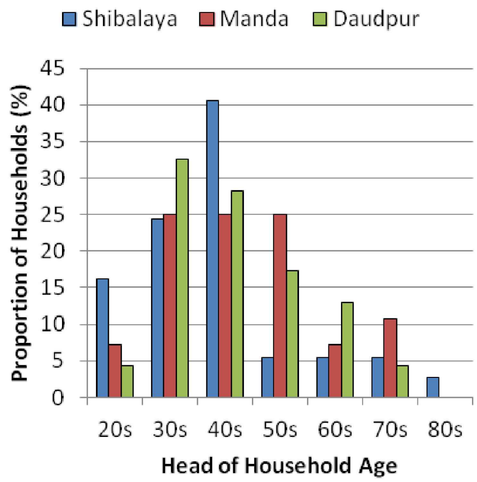


Figure HH_AGE. Age of the head of household.

Higher levels of schooling increase people's capability to adopt new ideas. Five years of schooling was most common for the heads of household at all locations, followed by eight years. The average level of schooling was lower for the Urao and Santal families in Daudpur. Less than five years of schooling can mean low literacy and numeracy. We did not ask about the highest level of education attained by any member of the family, which would have been a good question, because the younger generation can help their elders.

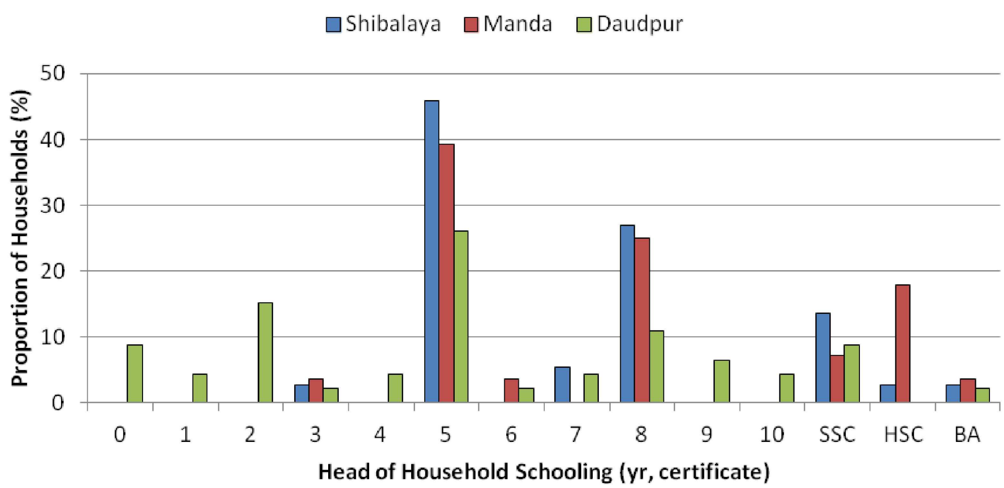


Figure HH_SCHOOLING. Level of education of the heads of households in terms of years of schooling, or having received a Secondary School Certificate (SSC), Higher Secondary Certificate (HSC), or a Bachelor's Degree (BA).

Most heads of household in Shibalaya were employed in small trade (shop-keepers buying and selling necessary goods, vegetable vendors, wood and steel furniture shops, tea stalls, saw mills, restaurants, etc.) and in Daudpur they were employed in farming. Since many households in Daudpur didn't own land (below), employment in agriculture was mostly as casual workers and share cropping. The greatest diversity in occupations was in Manda, because the project participants were close to the Manda Upazila commercial and administrative center and Hat Bazar. They also had good communications by river and road that linked them to a diversity of agricultural and non agricultural services.

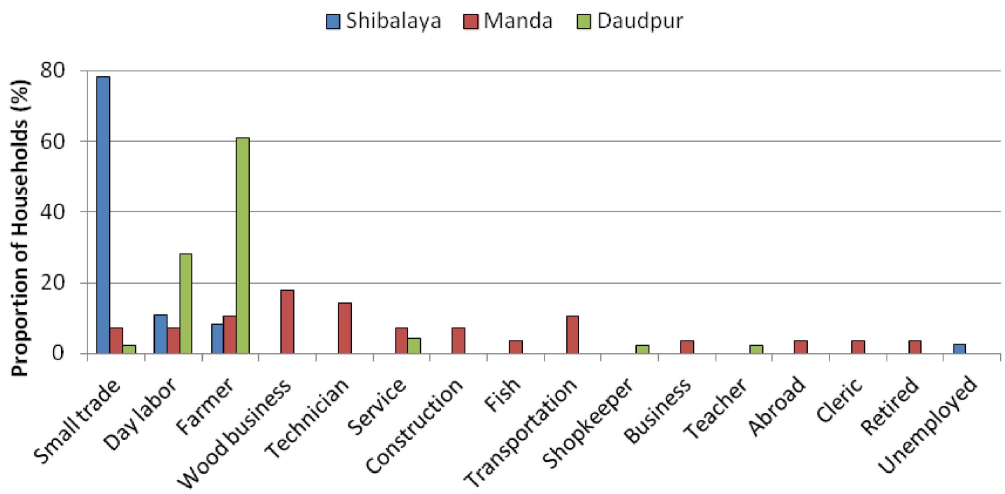


Figure HH_OCCUPATION: What is the major occupation of the head of the household?

4.2.3. Family Size

Family size as set as the number of people living in one household or at on hearth. The mean family size was around four people for Manda and Daudpur, but was closer to five people in Shivalaya (Figure FAMILY SIZE). Family size was used to calculate per capita family income (below). Larger families without a corresponding increase in income can lead to lower resources for dependent family members (e.g. < 15 years old, or > 64 years old). In Daudpur, family size and per capita family income were negatively correlated (below). Families of eight or more could be two or more generations with occurs more often in Muslim families than Santal and Oraon families (Uddin, 2012)

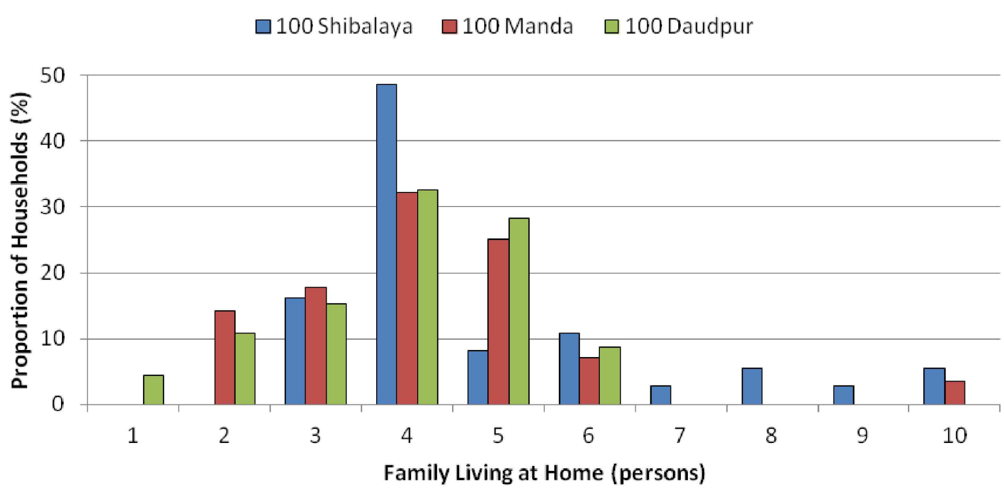


Figure FAMILY SIZE. The number of people living at home.

Some households had family members living away from home, but regularly returning to visit (Table LIVING AWAY). When family members migrate to find work, they can transmit knowledge of new technologies. Family members visiting back home are often a source of supplemental income that can support the purchase of commercial goods and services. One quarter of the households in Shibalaya and Daudpur had at least one family member living away. Shibalaya was on a transportation corridor, and only 60 km from Dhaka, a city of 18 million. For Daudpur, family members may be living away because of a shortage of economic opportunities locally, especially for ethnic minorities. Agricultural employment can be seasonally intermittent. Based only on the total numbers of family members living away (and not considering where they went and what they did), we would predict that knowledge of the Akha and biochar would diffuse faster from Shibalaya and Daudpur than from Manda. Economic interactions may play a large role in diffusing knowledge from central Manda.

Table LIVING AWAY. The proportion of households with family members living away from home, but visiting regularly.

Location	Number of family living away			
	1	2	3	Total
	— (%) —			
Shibalaya	22	3		25
Manda	4	4		8
Daudpur	15	7	2	24

4.2.4. Household Income

An adequate income gives families to access commercial goods and services, such as improved cookstoves, commercial cooking fuels, medications, school supplies, employment supplies, modern technology, etc. Per capita household incomes were lower in Daudpur than Shibalaya and Manda (Figure PER_CAPITA_INCOME). Although a high income suggests wealth, income may not be an accurate indicator of the standard of living, because people with low incomes may be operating in an informal economy, and people with high income may be indebted. Well educated, young people with career potential, may have a starting low income. In addition, the cost of living may vary across a country, and increase with proximity to urban centers or areas of higher economic output. Daudpur was the most agrarian of the three locations, and the most distant from cities. At Daudpur there was substantive non-monetary exchange of goods and labor (fuel wood collecting rights, share cropping, exchange of agricultural produce). Santal and Oraons had wood collecting rights from a near-by forest. A large proportion of families in Shibalaya worked in small trades (79%, Figure HH_OCCUPATION), and the modal income between 2000 - 2500 Tk/mo/capita reflected that activity. The greater diversity in occupations (Figure HH_OCCUPATION) in Manda resulted in a broader range of incomes than at the other two locations.

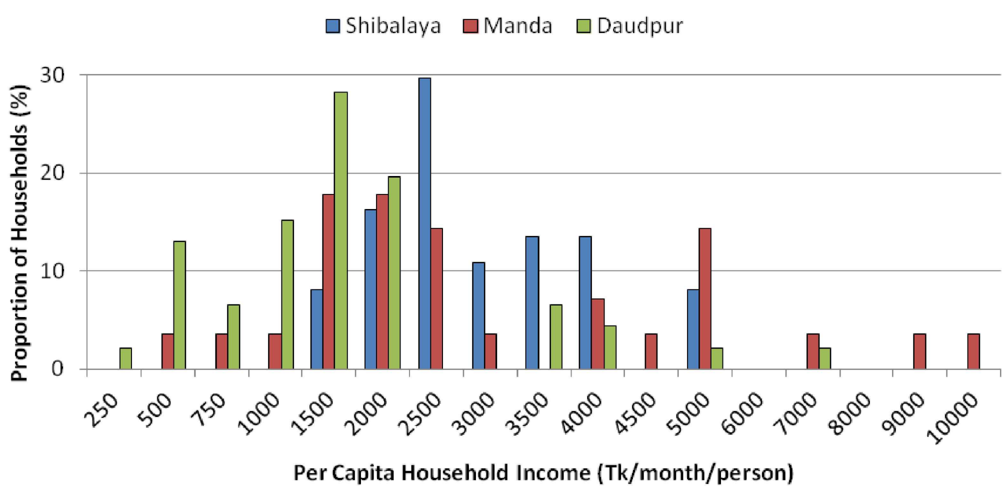


Figure PERCAPITA_INCOME. Households per capita income was calculated by dividing the declared household income by the number of family living at home. As of July 1, 2018, 1000 Tk = 10 Euro.

What should we take to be a high income, or extreme poverty? The World Bank income level for extreme poverty would be less than $1860 Taka per month (based on an extreme poverty level of <$2 per day, and a purchasing power parity of 31 Taka per international dollar (www, accessed 18-10-2018)). However, this doesn't take into account a non-monitory, barter economy. Following the 'Cost of Basic Needs' method, Barkat (2015) set the lower poverty line at 866 Taka per capita per month, and 1025 Taka per capita per month for the upper poverty line. Thirty-six percent of the households in Daudpur were less than or equal to 1000 Taka person month (Figure PERCAPITA_INCOME).

4.2.4. Housing

The quality of housing can be an indicator of wealth. Housing was categorized according to the permanence of the structure. (1) 'Pucca' homes were made of concrete, and were durable. (2) 'Semi-Pucca' homes had permanent concrete walls, and a corrugated steel roof that would require replacement when it rusted out. (3) 'Kutcha' homes had weather-resistant walls made of corrugated steel, or mud and bricks, and corrugated steel roofs. (4) 'Jhupri' homes were temporary structures having thatch or mud walls, and a thatch roof. They would require constant tending during the rainy season. Living in a jhupri home would be a sign of poverty.

Over 80% of Manda households had concrete or brick walls of a permanent nature (Figure HOUSING) indicating that these participants were relatively affluent. In Shibalaya 97%, and in Daudpur 89% of the study's participants lived in semi-permanent homes made with corrugated steel. None of the participants lived in temporary jhupri structures.

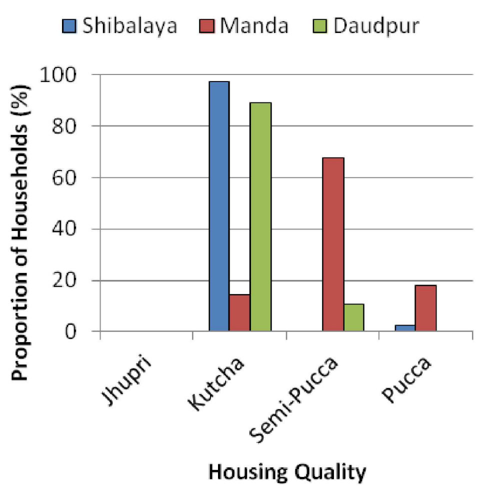


Figure HOUSING. Housing of the study's participants.

4.2.5. Drinking Water and Latrines

The facilities for providing drinking water and latrines can be indicators of household wealth, although safe water is generally available thanks to efforts by the Government of Bangladesh.

In Shibalaya, Manda and Daudpur, everyone got water from a tube well (except one household in Manda that used a mortar-lined well). No dangerous levels of arsenic were detected in wells that had been tested (100%, 30% and 6% of wells had been tested in Shibalaya, Manda and Daudpur, respectively).

Latrines can be evaluated in three ways: (1) Durability: pucca = concrete, and kutcha = wood and corrugated steel; (2) Sanitation: the ability of people to use the facility cleanly and avoid contamination by feces; and (3) Environmental Impact: sealed vs. non-sealed holding tanks that leak to watercourses and groundwater. Then there was the additional category of 'none' for no facilities at all. A large number of households in Shibalaya (41%) and Manda (64%) had high quality latrines (Table SANITATION). We used lack of saltation as an indicator of poverty: 42% of households in Daudpur, and one household in Manda had a non-sanitary latrine, or no latrine.

Table SANITATION: Sanitation facilities in the participating households.

Durability	Sanitation	Water Seal	Proportion of household by Location		
			Shibalaya	Manda	Daudpur
				— (%) —	
Pucca	Sanitary	Sealed	41	64	15
Pucca	Sanitary	Non sealed	3	7	9
Kutcha	Sanitary	Sealed	57	25	35
Kutcha	Sanitary	Non sealed			
Kutcha	Non Sanitary	Non sealed		4	35
None	None	None			7

It is unlikely to find non sanitary pucca latrines, and non-sanitary, sealed kutcha latrines.

4.2.6. Land Ownership

Land ownership is an important measure of wealth, but not owning land doesn't necessarily mean poverty, since families may have good non-agricultural employment. However, in the present case, having agricultural land gives a family a way to directly benefit from biochar, which could create a greater incentive to use an Akha stove. Families with agricultural land may purchase biochar from their neighbors. Owning land with trees gives better access to fuel. Families without land may value char made in the Akha a source of income, or as charcoal.

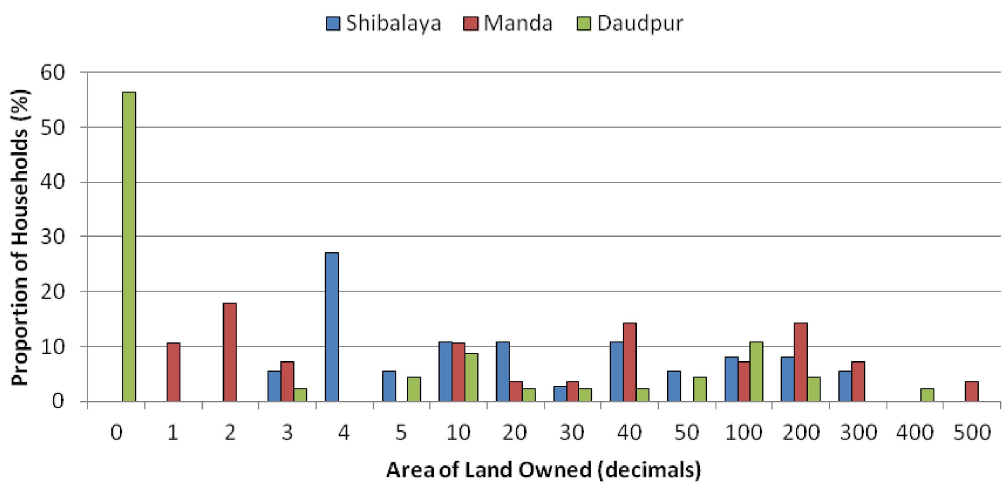


Figure LAND OWNED. Area of land and owned by households at Shibalaya, Manda and Daudpur. One decimal = 0.01 acre = 40.5 m².

In Shibalaya and Manda, all participating households owned some land (Figure LAND OWNED), however a large proportion of them (ca. 45%) didn't use any of their land for gardening or farming (Figure TOTAL ARRABLE).

In Daudpur, were agriculture was the main economic activity, 55% of the households were landless (Figure LAND OWNED), yet many heads of household worked in agriculture (Figure HH_OCCUPATION). Fifty-two percent of the households farmed land that they didn't own, of which 43% owned no land themselves. Only 9% of this land was held by renting. The rest of the land was worked under some non-monetary exchange, or share-cropping arrangement. Given the large participation in agriculture, many Daudpur households should be able to make direct use of biochar to increase food production.

[Barkat, (2015) defines functionally landless as having <50 decimals (45x45 m²), excluding land for the homestead]

4.2.7. Multidimensional Poverty

Overall, there was board variation in the types of households that tested the Akha cookstove. However, there were no clear relationships between the socio-economic variables across the three locations. In particular, there was no general correlation between age and education of head-of-household, family size, income, land owned, and land cultivated. There were a few localized correlations ($p < 0.05$). In Shibalaya, were positive correlations between age of the head of household and: family size, income, and land owned. In Manda, income and area of land owned were correlated. In Daudpur, there was a negative correlation between family size and per-capita income. However, ad hoc correlations are of no use for making predictions in other regions of rural Bangladesh. Instead, we took the multivariate poverty approach (Mack and Lansley 1985; Barkat et al., 2009; Alkire et al., 2015) whereby it is the number of deficiencies experienced by a household that matters, rather than any particular kind of deficiency.

We hypothesized that poverty would be the main impediment for adopting the Akha and biochar technology, in large part because it would affect the affordability of the Akha, and access to wood or compressed biomass fuels that a TLUD burns. By contrast, the traditional stoves were made at no cost, and could burn loose biomass. Poverty was not assessed on the basis of one variable, such as lack of income, education or land, but by counting multiple deprivations over a range of issues that effect food, shelter, etc., and the capacity for self-improvement (Mack and Lansley 1985; Barkat et al., 2009; Alkire et al., 2015). Both ratio and categorical variables can be used.

Eight variables were selected from the questionnaire, and criteria selected for designating the respondent's answers to the questions as 'deprived' or 'non-deprived' (Table POVERTY CRITERIA). The criteria were chosen to be appropriate to the cultural conditions and economy of rural Bangladesh.

For each household, their responses to the eight socio-economic questions were designated as deprived=1 or not-deprived=0, and the results summed across all variables into a multidimensional poverty index (MDPI). Thus, a household scoring MDPI=0 would be 'not-deprived' on all variables, and a household scoring MDPI=8 would be 'deprived' on all eight variables. For the present study, the highest poverty score possible was MDPI=6, because nobody had a jhupri dwelling, and nobody used open source water for drinking.

Only in Daudpur did the participating households show a substantive range in MDPI values (Figure MDPI). In Daudpur, 43% of households were rated as deprived in three or more of the socio-economic variables. In Shibalaya and Manda, a number of households were deprived in one variable, such as holding land to cultivate, (Table POVERTY CRITERIA), but that alone didn't make them poor. That just mean that the didn't make their living in agriculture. With the MDPI method, we evaluate poverty as possessing multiple deprivations.

Table POVERTY CRITERIA. Socio-economic criteria for poverty, and the proportion of households at each location that met those criteria.

Socio-Economic Variables	A variable was scored 'deprived' if its value was:	Frequency of a 'deprived' score by location		
		Shibalaya	Manda	Daudpur
			— (%) —	
Head's schooling	< 5 years	3	4	35
Head's occupation	day labor, none	14	7	28
Per capita income	<= 1000 Tk/mo	0	11	37
Land owned	0	0	0	57
Land farm + garden	0	43	46	33
Housing	jhupri	0	0	0
Sanitary latrine	FALSE	0	4	41
Drinking Water	open source	0	0	0

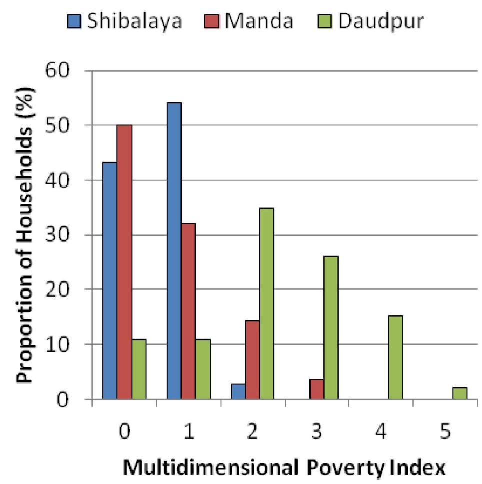


Figure MDPI. Frequency distribution of household deprivations.

4.2. Fuel Use and Security of Supply

4.2.1. Introduction

The energy supply for a household could (should?) have an impact on the acceptance of the Akha and biochar technology. What sources of biomass energy do they use, how secure is the supply, who collects the fuel, is drying fuel difficult, etc.? The Akha is a "Champion / Peko-pe" style TLUD stove that burns wood or compressed biomass. If that type of fuel is in short supply, then a family will not make good use of the Akha, and will not will not get the maximum benefit out of the char produced.

The households participating in the Akha evaluation were asked a series of questions about their biomass fuel. The purpose was the same as the for the socio-economic question: (1) characterize the participating households, and (2) see we if we can abstract their situation into a single fuel security variable to correlate with Akha acceptance.

4.2.2. Energy-Starvation

Most of the rural population burns wood and loose plant residues in traditional stoves. Wood makes up less than half of the fuel, because the average tree cover of Bangladesh is only ca. 17%, whilst the rural population is ca. 900 people per square kilometer. The rest of the fuel comes from cow dung and low density biomass such as leaves and straw. Although households make do, the fact that they burn leaves and straw is a strong symptom of energy-starvation. The demand for wood has reduced tree cover to the extent that only half the wood fuel needs can be met. ND-TLUDs like the Akha only burn wood or biomass compressed into briquettes. A list of trees used by the households is in given in Table TREE SPECIES. (Footnote: Given the level of energy-starvation, has tree cover stabilized at the lowest level that the people are willing to accept, or could it go even lower? In other words, could the demand for biochar drive tree cover even lower, or have we already reached the bottom?)

There are two distinct seasons in Bangladesh; a wet season and a dry season (October to April). Most loose biomass fuel was burned in the dry season, and wood was collected and stored to be used in the wet season, when it dry leaves were not available.

In controlled cooking comparisons with a traditional stove, the Akha (Model 01) was more energy-efficient than a traditional stove, burning 36% less wood (or cooking 1.56 times longer on the same amount of wood). Unfortunately, the Akha needs to burn <50% less wood before wood can be used for cooking year-round, so households will still keep a traditional stove to burn loose biomass in the dry season. The Project is trying to extend the use of the Akha by helping the villagers to develop compressed briquettes from cowdung and loose biomass. All the same, household fuel-security could affect the willingness of women to accept an Akha.

Table TREE SPECIES. Frequency of tree species households reported as being used for cooking.

Fuel Species Names		Location		
Scientific	Common	Shibalaya	Manda	Daudpur
			— (%) —	
Mangifera indica	Mango	32	33	34
Artocarpus heterophyllus	Jackfruit	4	3	8
Eucalyptus camaldulensis & other spp.	Eucalyptus			40
Swietenia mahagoni, macrophylla	Mahogany	28	36	6
Acacia auriculiformis	Akashmoni		1	4
Shorea robusta	Sal			8
Syzygium cumini	Plum			1
Dalbergia sissoo	Shishu	1	22	
Acacia lebbeck	Kala koroi	8	1	
Syzygium jambos	Rose Apple	16		
Ziziphus mauritiana	Boroi	3		
Polyalthia longifolia	Debdaru	1		
Psidium guajava	Guava	1		
SUBFAMILY Bambusoideae	Bamboo	1		
Syzygium samarangense	Jamrul	3		
Azadirachta indica	Neem		1	
Artocarpus chaplasha	Chamble	1		
Zea mays (cobs)	Maize mocha	2		

4.2.3. Collecting and Sizing Wood

Women were responsible for gathering half to three-quarters of the fuel (Table FUEL COLLECTORS), but husbands also helped. We would expect women to welcome anything about the Akha, such as improved cooking efficiency, that reduced time spent collecting fuel. Traditionally, there is a stronger division of labor between adult men and women in Muslim households than Santal and Oraon households (Uddin, 2012). This may be reflected in the greater sharing of fuel collecting between husbands and wives in the rural setting of Daudpur than Manda. In Daudpur, women reported that muddy roads in the wet season, and high temperatures in the dry season, made fuel collection difficult.

Wood for a traditional stove requires less size-reduction than wood burned in an Akha. All the fuel for a run of the Akha is loaded as a batch into the reaction cylinder. Sticks or chunks of wood should not be much more than 3 cm thick at the narrowest point, because the center of the wood has to rise to at least 450-550 °C for thorough pyrolysis, and wood is not a good conductor of heat. The sticks have to be less than the length of the reaction cylinder. By contrast, wood for a traditional stove doesn't need to be so thin, and can be any length.

Table FUEL COLLECTORS. Who in the household is responsible for gathering fuel?

Fuel Gatherers	Sub-district		
	Shivalaya	Manda	Daudpur
	— (%) —		
Husband	11	25	24
Wife	**51**	**75**	**50**
Wife & Husband	32	0	20
Others†	6	0	6

† Other adults, wife & children, children, family

Since wood the maximum size of wood is smaller for an Akha than for a traditional stove, women may find that sizing wood is burdensome (Table FUELING). However, since the Akha is batch-loaded, and doesn't require stoking, women can size fuel while the Akha is running. However, in Shibalaya, Manda and Daudpur, women never-to-rarely saved time by preparing wood whilst cooking, and only rarely-to-sometimes found sizing fuel for the Akha burdensome (Table FUELING).

The air is humid during must of the wet season and women sometimes-to-often found that supplying dry wood was more difficult for the Akha than a traditional stove (Table FUELING). Traditional stove can tolerate wood that has a higher moisture content than the Akha, because wood dries as it is fed into the combustion chamber. The optimum moisture content of wood for the Akha is 12% or less. As fuel moisture content increases beyond 16%, it burns less efficiency. At a moisture content of 20%, the Akha emits unburned smoke. The Akha will not burn wet wood.

Table FUELING. Do women save time to prepare fuel while the Akha is running, and is fuel sizing burdensome? How difficult is it to get dry wood in the rainy season?

Comparing the burning wood in an Akha to a traditional cookstove, …	Sub-district		
	Shivalaya	Manda	Daudpur
	— (mean [0 … 4]†) —		
… can you prepare Akha fuel whilst cooking?	0.35	0.61	0.35
… is fuel preparation for the Akha burdensome (excess work)?	1.80	1.91	1.80
… is supplying dry wood more difficult for the Akha in the rainy season?	2.61	2.22	2.61

† Answers: (0) Never, (1) Rarely, (2) Sometimes, (3) Often, (4) Mostly

4.2.4. Fuel Security

Given the endemic shortage of wood, we asked a series of eight questions to assess household fuel security (Figure FS), and derive summary variable that could be compared with Akha acceptance. The questions were applied to the wet season and the dry season, because of changes in the patterns of fuel use.

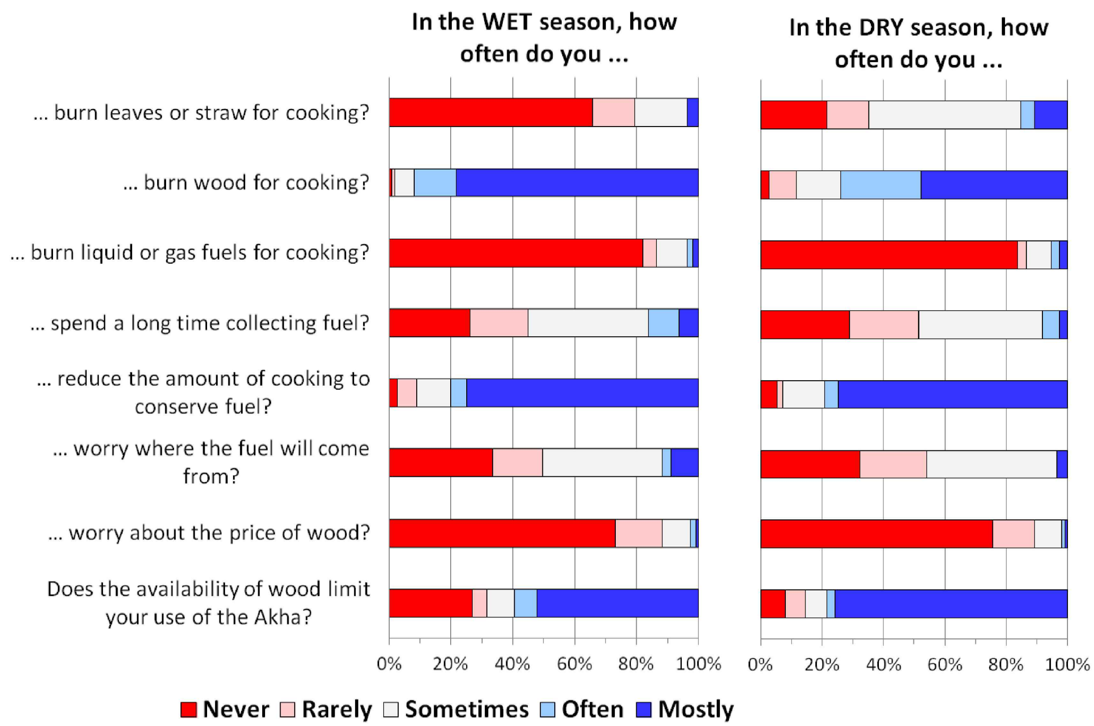


Figure FS. Responses to fuel security questions combined across all three study locations.

Over all locations, the majority of households were energy-starved and limited their cooking time to conserve fuel (Figure FS). In the dry season, they burned more leaves and straw than wood, reserving wood for the wet season. Only a few households (twenty) burned some hydrocarbon fuels such as kerosene or liquid petroleum gas (propane). There wasn't much difference between the wet and dry season for time spent collecting fuel, and a few households spent a long time collecting fuel. (Recall, women did most of the collecting.) Despite the shortage of wood fuel, very few households worried about their source of fuel; half the households never, or rarely worried about their source of fuel, regardless of time of year. The price of wood was not a big concern (but a follow-up question revealed some concern about price in Shibalaya and Manda; see below). Respondents said that two situations almost never happened: borrowing wood from a neighbor, and buying wood on credit.

When the fuel security questions (Figure FS) were compared between study locations, the households in Daudpur showed more signs of energy stress than households in Shibalaya and Manda (Table FS). The use of leaves was most common in Daudpur, whereas the use of hydrocarbon fuels was most common in Manda. Households in Daudpur spend most time collecting fuel, and were more likely to reduced cooking to conserve fuel than Manda. Surprisingly, few respondents in Shibalaya felt that the supply of wood limited their use of the Akha, whereas in Manda and Daudpur, the supply of wood often-to-mostly limited their use of the Akha.

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Table FS. Differences between study locations in responses to fuel security questions.

Variables	Wet Season			Dry Season		
	Shibalaya	Manda	Daudpur	Shibalaya	Manda	Daudpur
		— (MJ L^{-1}) —			— (MJ L^{-1}) —	
Energy Density †	7.3 b ‡	9.0 a	6.3 c	7.1 x ‡	9.1 x	6.6 y
Biomass En. Density †	6.2 a	5.9 a	5.6 a	6.2 x	5.9 x	5.5 y
		— (never=0 : mostly=4) § —			— (never=0 : mostly=4) —	
burns leaves	0.3 b	0.2 b	1.1 a	0.4 y	0.2 y	1.1 x
burns wood	3.8 bc	4.0 ab	3.4 c	3.8 y	4.0 x	3.4 z
burns hydrocarbons	0.3 b	0.7 a	0.2 b	0.2 y	0.7 x	0.3 y
long time collecting fuel	0.9 b	1.6 a	1.9 a	0.9 y	1.5 y	1.9 x
cooks to conserve fuel	3.4 ab	3.0 b	3.7 a	3.4 x	3.0 x	3.7 x
worry about fuel supply	1.3 bc	0.9 c	1.8 a	1.3 y	1.0 z	1.8 x
worry about fuel price	0.7 a	0.5 a	0.1 b	0.8 x	0.5 x	0.1 y
wood limits Akha use	0.9 b	3.1 a	3.5 a	0.9 x	3.1 x	3.5 x

† See the text for the method of calculation.

‡ Values within a row and Season that are followed by the same letter were not significantly different ($p > 0.05$) according to Kruskal-Wallis Tests.

§ Mean responses calculated by assigning the values 'never'=0, 'rarely'=1, 'sometimes'=2, 'often'=3, and 'mostly'=4. See Figure FS for the full questions.

4.2.5. Energy Density Indices

Combining questions into summary indices is useful for comparing energy security with other variables such as measures of life-style, acceptance of the Akha stove, and the production and use of biochar. Index variables can be precise indicators, if the component questions are correlated. However, in the present survey, only the first three questions (Figure FS) on burning wood, leaves or hydrocarbons were correlated. The answers to the other questions about collecting, conserving, supply and price were largely independent of each other (viz, the paired correlation coefficients were low ($r < |0.3|$), and multivariate relationships were weak: Kaiser-Meyer-Olkin criterion = 0.53-0.59; Cronbach's Alpha = 0.48), so they were not combined into an index.

When families chose to burn leaves, wood or hydrocarbon fuels they more up and down an 'energy ladder' from bulky, low energy fuels to concentrated, high energy, commercial fuels. At the bottom of the ladder, fuels are free, and at the top they are pricy. We represented this energy ladder by estimating the average energy density (ED: MJ L^{-1}) of household fuel from the first three questions in Figure FS. Providing the household didn't use electricity for cooking, the ED could be a good a proxy for energy security, because burning higher ED fuels is usually a reflection of wealth, less time spent collecting fuel vs. time spent cooking, and more energy-efficient cooking.

Estimated energy density was calculated for each household using the formula:

$$ED_H = \sum_f \left(ED_f \times L_f\right) \Big/ \sum_f L_f$$

where f is the type of fuel (leaves, wood, LPG-propane), ED is the energy density (leaves = 1.0 MJ L^{-1}; wood = 6.9 MJ L^{-1}; LPG-propane = 27.3 MJ L^{-1})[2], and L is the Likert-type response for burning a fuel ('never'=0,

[2] Energy density was calculated by multiplying the bulk density of fuel beds (leaves = 0.050 kg m^{-3}; wood = 0.45 kg m^{-3}, assuming 25% fuel bed voids) or liquids (LPG-propane = 0.59 kg m^{-3}) by

'rarely'=1, 'sometimes'=2, 'often'=3, and 'mostly'=4). ED_H is an estimate of the mean energy density for a household, which would be most accurate when only one type of fuel was being burned, starting at 1.0 MJ L^{-1} for burning only leaves, 6.9 MJ L^{-1} for only wood, and 27.3 MJ L^{-1} for only LPG-propane. Intermediate values would be less accurate, because they were based on respondents' estimates of fuel use, rather than the actual mass of fuel burned. Average ED_H values for study locations are presented in Table FS. The frequency distribution of ED_H values is shown in Figure ED, from which different patterns of fuel use from wet to dry seasons were identified (Table ED). Because the ED_H was calculated using 5-point Likert-type questions, the ED_H values fell into discrete values (Figure ED) determined by the ratios of the three types of fuel. We also calculated biomass energy densities (BED_H) from the ratio of leaves to wood burned.

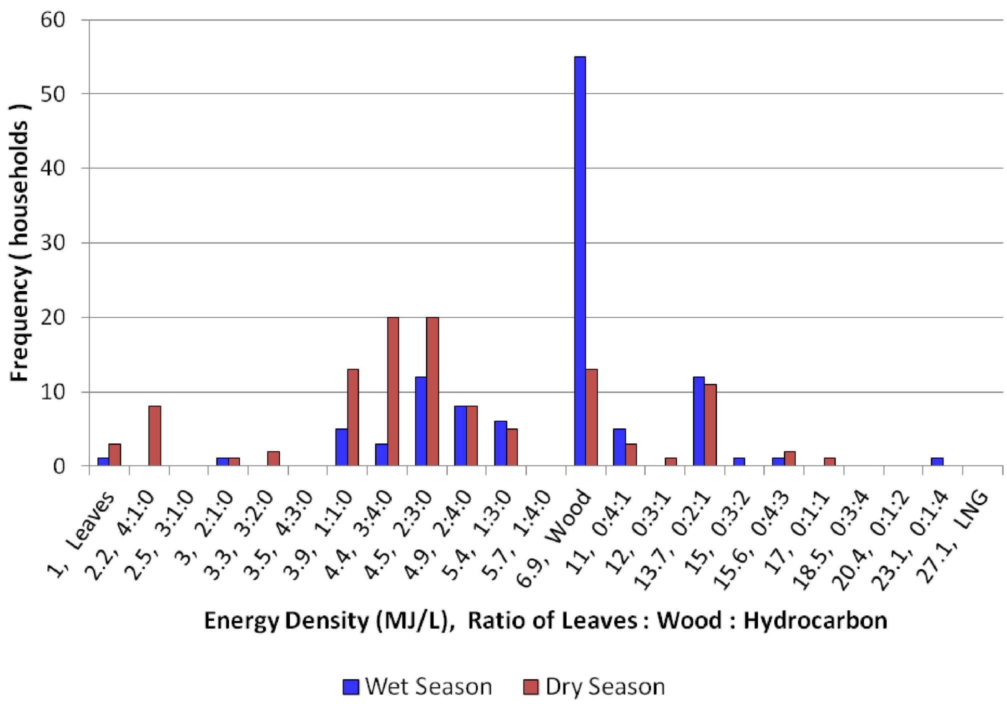


Figure ED. The frequency distribution of cooking-fuel energy density, ED_H, and corresponding ratio of leaves:wood:hydrocarbon across 111 households in Shibalaya, Manda and Daudpur.

During the rainy season, half of the 111 households in this study burned only wood (Figure ED), but when the dry season came, the number of wood-burners dropped to only 10%, as many households used leaves and straw to conserve their wood. By looking at changing patterns in fuel use from the wet to the dry season, we were able to place households into different categories (Table ED). Sixteen percent of households burned hydrocarbons all year, and most of those homes were in Manda. Eleven percent burned only wood all year at all three locations. The greatest proportion of households, 40%, burned wood in the rainy season, and leaves and wood in the dry season. Another large proportion, 34% burned wood and leaves all year round. Only one household burned only leaves all year. When the energy strategies of participating households were compared between locations, the those in Manda had the greatest energy security, followed by Shibalaya, with households in Daudpur being least energy secure.

lower heating values (19 MJ kg^{-1} for leaves, 15.4 MJ kg^{-1} for wood, and 46.4 MJ kg^{-1} for LPG-propane).

Table ED: Fuel use strategies from the wet season to the dry season.

Fuel Strategies			Locations				Mean Energy Density, ED_H		
Categories	ED_H Criteria ‡		All Locat.	Shibal.	Manda	Daudp.	Wet	Dry	Dry-Wet
Wet•Dry †	Wet	Dry							Wet
	— (MJ L^{-1}) —		——— (%) ———				— (MJ L^{-1}) —		(%)
HC•HC	>6.9	>6.9	16	14	36	7	13.5	13.5	0
HC•WL	>6.9	<6.9	2	3	0	2	13.3	4.7	-65
W•W	6.9	6.9	11	11	11	11	6.9	6.9	0
W•WL	6.9	<6.9	40	41	43	37	6.9	4.5	-36
WL•WL	2.5><6.9	<6.9	31	32	11	41	5.0	4.2	-17
L•L	<2.5	<2.5	1	0	0	2	1.0	1.0	0
Mean Energy Density (MJ L^{-1})				7.3	9.0	6.6	7.5	5.8	-22%
Households burning leaves (%)				76	54	83			
Number of observations (n)			111	37	28	46	111	111	111

† Wet to dry season fuel strategy symbols: HC: hydrocarbon. WL: wood and leaves. W: wood. L: leaves

‡ Energy density criteria for the wet and dry seasons used to categorize the patterns of household fuel use. E.g., for a household to have ED_H > 6.9 they had to be using some hydrocarbon; for have ED_H = 6.9, they had to be using wood.

Following the formal questions, the Akha users were asked for their general comments on fuel quality and supply. Open questions reveal a family's priorities, and any issues that the previous questions had not covered. They corroborated the findings that households in Daudpur were on average less energy secure than in Shibalaya and Manda.

In the wet season, Akha users said that getting dry fuel was the main challenge. Regardless of the type of stove, when the moisture content of fuel increased, more fuel and longer cooking times were needed to prepare meals. High humidity during the wet season slowed down the drying of fuel. Rainfall made collecting and transporting fuel more difficult, especially in Daudpur were unpaved roads became muddy and slippery. Because of these challenges, most of the fuel was collected during the dry season, but some households said that they had trouble finding covered storage space. In Shibalaya and Manda, Akha users said that the price of wood increased in the wet season.

In the dry season, people in Shibalaya and Manda were more relaxed about the supply of fuel, despite burning more leaves (Table FS) and less wood. Households said that dry fuel was easily available, and the price for wood declined from the wet season. Dry fuel burned hotter and faster than moister fuel in the wet season, so cooking efficiency increased. People in Daudpur also benefitted from dry fuel, although some households said that collecting and transporting fuel was still a problem. They complained about the physical stress of collecting fuel under a hot sun. A few households said that they had to go a long way to collect fuel, and could be scolded by land-owners.

4.2.6. Conclusion

The fuel-use and fuel security is a crucial context for Akha stove. Household energy-stress was reflected in the need to burn poor-quality fuels, and to limit cooking to conserve fuel. Households managed types of fuel according to seasonal changes in rain and humidity by burning wood in the rainy season and loose plant residues in the dry season. Finding enough storage space to keep wood dry can be a problem. Energy stress was highest for the households in Daudpur, and least in Manda. Our observations were broadly typical for rural Bangladesh.

Conservation of wood fuel was important in Shibalaya and Manda, because the price of wood rose during the rainy season. For the Santal and Oran people of Daudpur, wood was not a commercial fuel, but instead was collected from the countryside. For them, the physical duress of collecting and transporting wood under the hot sun of the dry season, or the slippery roads of the wet season, was the 'price' of wood.

The energy density of fuel burned by a household may be a good indicator of their fuel-security, and could correlate with acceptance of the Akha. Energy density for all combustible fuels (ED_H), including hydrocarbons, should correlate with household standard of living. Energy density of biomass fuels (BED_H) is more narrowly-focused than ED_H, and sould relate more closely to the supply and management of biomass fuels, especially a household's desire to conserve wood.

ND-TLUDs like the Akha burn wood or compressed biomass, but not loose plant residues. Greater cooking efficiency of the Akha than a traditional stove should be attractive to households trying to get the most cooking out of their wood. However, the Akha was not as of tolerant of damp fuel as a traditional stove. These factors will play a role in women's assessment functional performance and subjective experience of using an Akha. Will the households experiencing the highest energy stress be able to take sufficient advantage of the Akha?

4.3. Functional Performance of the Akha

4.3.1. Functional Performance Survey

The Akha was designed to use wood, briquettes or cakes for fuel, but traditional stoves were much more versatile since they also burned low density leaves and rice straw. In rural Bangladesh, there was insufficient wood to burn year-round, so it was likely that most homes would keep a traditional stove. Therefore, if the Akha was to succeed, it had to burn wood or compressed biomass better than a traditional stove. The women were asked a series of questions about the functional performance of the Akha. Their past experience of burning wood in a traditional stove was used as a basis for comparison. The general hypophysis was, simply put, that much better performance of the Akha is a necessary precursor to its acceptance.

The women gave a very favorable assessment of Akha functional performance (Figure FP). The greater majority of women found that the Akha cooked faster, used less fuel, produced much less smoke, and was easier to light, control heat (turndown), and extinguish than a traditional stove. They also found that it was much easier to clean out the ash/char, and required less attention when operating, so that they could perform other tasks. Although the greater majority of women gave the Akha high marks, a minority of women were less positive. We had no reason to believe that the minority views were invalid (because of circumstances or interview), so we should follow-up to find out the reasons for their difficulties. In future, we recommend to replace 'Mostly' with 'Always' in the set of possible answers; that may make the frequency distribution of answers less skewed.

There were some regional differences between Shibalaya, Manda, and Daudpur in women's assessment performance. The differences in assessment could be for many reasons, such as differences in culture, socio-economic status (Figure MPDI), and fuel. Also, each region had different interviewers, instructors and visitors (Section 4.4.4.). In general, the performance of the Akha was less positively reviewed in Daudpur, than in Shibalaya and Manda ($p < 0.05$). Eighty-five percent of women in Daudpur said that the Akha 'Mostly' used less fuel, whereas the response at the other two locations was almost 100%. At Daudpur, 52% said that the Akha was 'Mostly' easier to light, and 57% said that it was 'Mostly' easier to extinguish, whereas at Shibalaya and Manda the response was greater than 85% for both questions.

For smoke-emission properties, more women in Shibalaya found that the Akha went out unexpectedly than at Manda and Daudpur ($p < 0.05$). Women in Manda didn't think that the bottom of their pots were as soot-free as in Shibalaya and Daudpur.

In summary, the women gave a very positive assessment of the Akha's functional performance, which was encouraging for the future acceptance ND-TLUD technology in rural Bangladesh. However, there were some minority opinions that were less enthusiastic, and the cause of these should be looked into. Conclusive evidence will come in a year when we find out who is still using the Akha, and if not, why not.

4.3.2. Functional Performance Indices

Women's answers on Akha functional performance were combined into summary variables, or indices, that simplified, and strengthen the interpretation of the survey. Using Principal Component Analysis (PCA) (Figure FPI) we found two sets of correlated questions: (1) questions about operating the Akha, and (2) questions about the reduced emission of smoke and soot. For each respondent, their answers to correlated questions were averaged to make functional performance indices (FPI) FPI-Operation and FPI-Smoke. FPI-Operation was the average of questions FP1-5 (Figure FP) about fuel saving, time saving, turndown, ease of lighting and ease of extinguishing the Akha. FPI-Smoke included questions FP6-8 (Figure FP) about unexpected flameout (reverse coded before averaging), clean pots, and less smoke for the Akha compared to a traditional stove. An index, FPI-All, was the average of all the questions in FPI-Operation and FPI-Smoke.

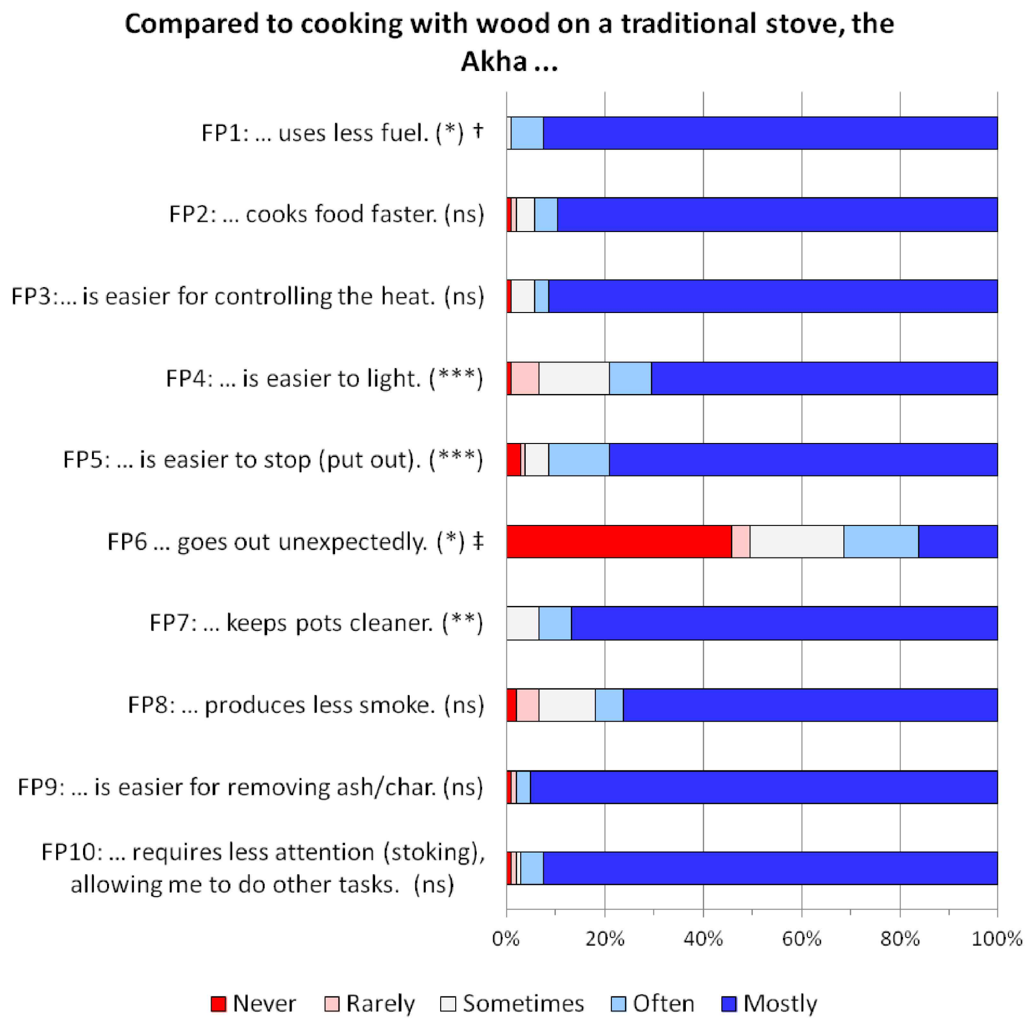
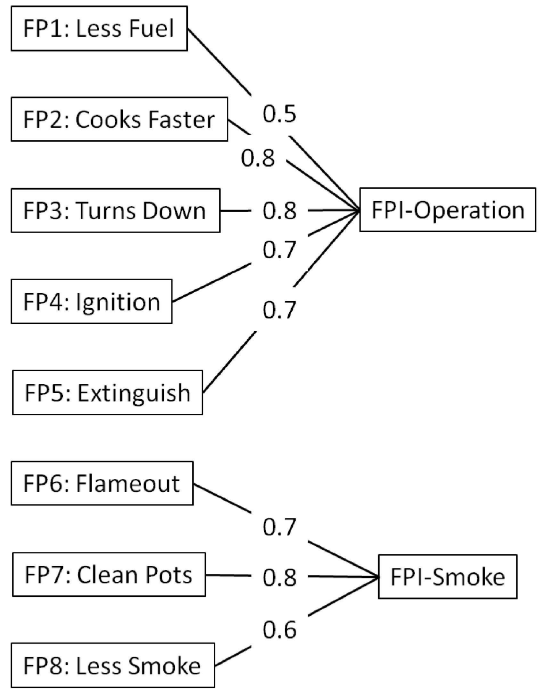


Figure FP. Assessment by Akha users of its functional performance compared to a traditional stove. † Significant differences in the distribution of answers between geographic locations according to a Kruskal-Wallis Test: ns, *, **, *** indicate non-significant, or significant at 0.05, 0.01 or 0.001 levels of probability. ‡ Note that 'Never' is the best answer for this question.

Two questions were not included in the indices. Question FP9 about ease of removing ash/char was not included in the PCA, because there was insufficient variation in the answers (almost everyone said 'Mostly'). The question FP10 about attending the fire and multitasking was dropped from the PCA, because its was cross correlated with both principal components. The respondents may have found this question ambiguous: was intended to ask about the reduced need to constantly tend the Akha fire, or it could also be interpreted as being about the ability of a cook to multitask? In future, the reduced need for stoking, and the ability to of a woman to multitask should be asked as separate questions.

Figure PCA. Principal component analysis of functional performance questions identified two major components, FPI-Operation and FPI-Smoke. The numbers on the straight lines are loadings (correlation coefficients) of the observed variables on their respective principal components. (Oblique PCA on 97 observations, outliers were removed; Kaiser-Meyer-Olkin test = 0.62 and Croncbach's Alpha = 0.73)



There were geographic differences in Akha Functional Performance indices (Table FPI). The average FPI-operation of respondents was lower in Daudpur than in Shibalaya and Manda. Differences between locations for FPI-smoke were not as pronounced. FPI-smoke was lowest in Manda, but Manda was not significantly different from Shibalaya. Women in Daudpur responded most favorably to the reduction of smoke-related issues.

Some women had been using the Akha for sixteen months, whereas others had the Akha for only two months. Neither FPI-All, FPI-Operation, nor FPI-Smoke showed a significant ($p < 0.05$) effect of duration of ownership. Women liked the Akha regardless of how long they had been using it.

We can see from Table FPI that indices help to organize the questions into compatible groups to simplify the testing of hypotheses. Although the questions within an index are correlated, we don't need to assume that the questions are causally connected in any way. For example, a correlation between igniting and extinguishing the Akha does not exist within the Akha, except by being two separate properties created by a cleaver designer. A correlation could arise, however, through differences in the skills of the cooks; a skillful cook will say that the Akha 'Mostly' has properties better than a traditional stove, but a bad cook may say that the Akha has these properties only 'Sometimes'. This may be revealed may through asking the women subjective questions about their understanding of the Akha and their attitudes toward it; then comparing those answers to FPIs.

Table FPI. Akha Functional Performance Indices averaged across respondents at three geographical locations.

Location	FPI		
	all	operation	smoke
	— (range from 0 to 4) —		
Shibalaya	3.68	3.94 a †	3.26 ab
Manda	3.56	3.92 a	2.98 b
Daudpur	3.52	3.56 b	3.45 a
	ns ‡	***	*

† values within a column followed by the same letter are not significantly different.

‡ ns, *, ***: non-significant, or significant main effect of location at $p < 0.05$ and 0.001, respectively

4.3.3. Summary

To summarize women's assessment of Akha performance compared to a traditional stove, there was a strong consensus that the Akha produced much less smoke, conserved fuel and time, and was easier to operate. These findings are an essential step toward validating the Akha TLUD technology for Bangladesh. The questions could be grouped, and averaged to make two index variables: one for general stove operation, and as second for reduced smoke production. When questions were grouped, we found that the most variation in respondents' evaluation of the Akha centered on stove operation, with positive, but less effusive reviews of the Akha from women in Daudpur compared to Shibalaya and Manda. The length of time women had been using the Akha had no effect on their answers.

4.4. Subjective Experience of the Akha

4.4.1. Overview

When people have a positive experience of a new technology, that experience can be an important predictor technology acceptance (Rodgers, xxxx). Did the women find the Akha difficult to understand, and operate? If it was easy, then the women are likely to be happy; if it was difficult, then they may get frustrated. Did the women find that the new technology brought then status and prestige? Was the new technology more comfortable to use than the old technology?

A set of seven Subjective Experience Questions (SEQ), with Likert-style answers, were used to assess women's emotional satisfaction with an Akha (**Figure SEQ**). The main purpose was (1) to see how women felt about using the Akha, and (2) to find the best questions to combine into 'subjective experience factors' (SEF) that could be compared with other aspects of the survey such as fuel security and poverty.

Our survey (below) showed that the women's experience of the Akha was very positive (**Figure SEQ**). Using exploratory factor analysis (EFA), we found that six of the questions could be combined into two groups of experiential factors, that we called 'Contentment' and 'Self-Esteem' (**Figure EFA**). The level of Contentment was similar across all locations, but Self-Esteem may have been enhances in Shibalaya by frequent visits by researchers. These two factors, Contentment and Self-Esteem, were compared with Akha functional performance, fuel security, and standard of living, as discussed later in the Section 4. Synthesis.

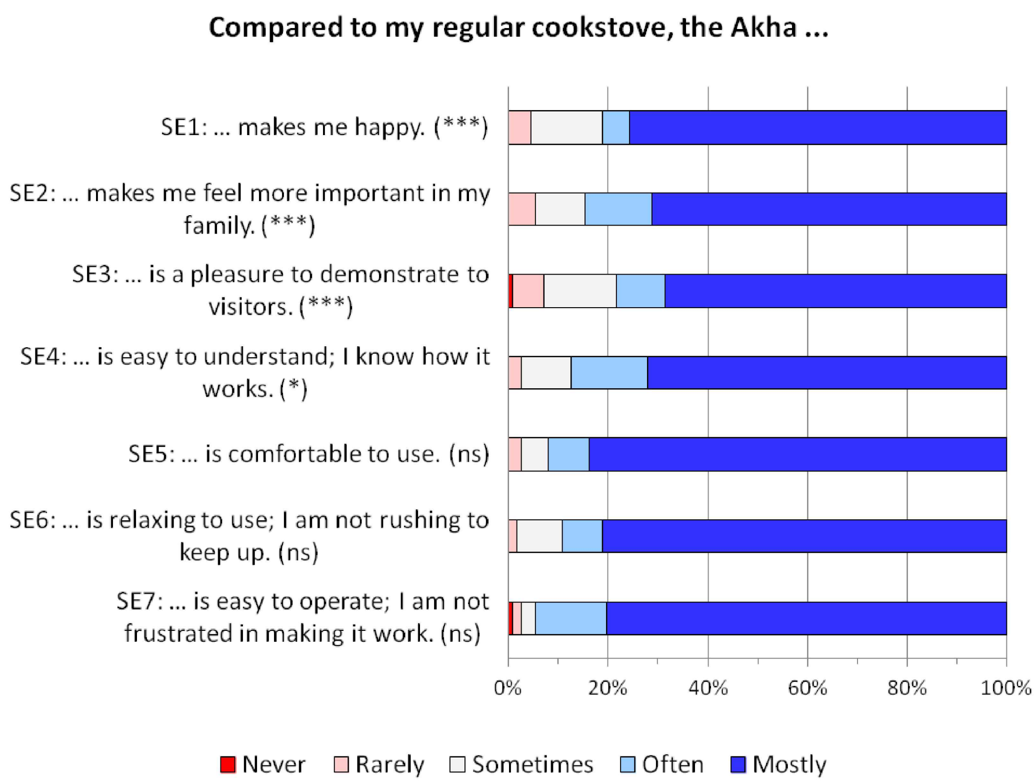


Figure SEQ. The frequency distribution of answers to the Subjective Experience (SE) questions from the Shibalaya, Manda and Daudpur locations. The regular stove was a traditional Chula (except for five 'Bondhu Chula' chimney stoves in Manda). ***, *, and 'ns' denote significant difference in responses between locations at $p<0.001$, $p<0.05$ or not significantly different according to a Kruskal-Wallis test (KW). When the KW test was significant at $p<0.001$, the responses were more favorable in Shibalaya ($p<0.001$, Wilcoxon test) than Manda and Daudpur (which were similar, $p>0.05$).

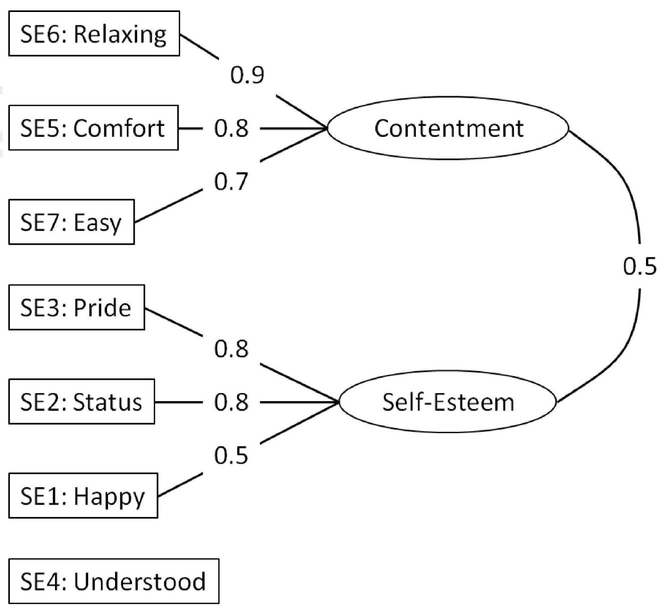
4.4.2. Good Subjective Experience

Eighty percent or more of the Akha users in Shibalaya, Manda, and Daudpur said that using the Akha was a positive experience for all seven questions (**Figure SEQ**). There was no difference between the three locations for questions about comfort (SE5), stress-level (SE6), and ease of use (SE7). However, there was a strong difference between locations for questions about happiness (SE1), improved role in the family (SE2), and pleasure in showing off the Akha to friends (SE3): to these questions, Akha users in Shibalaya gave a more favorable response ($p < 0.001$) than users in Manda and Daudpur (for which the response to questions SE1-3 were similar). Below, we hypothesize that more frequent visits by professional at Shibalaya than the other locations had a positive effect on the Akha experience for women.

4.4.3. Contentment and Self-Esteem

Although the questions focused on different aspects of the Akha experience, some questions may be correlated, because they reflect more general, 'hidden' (latent), psychological constructs. We used exploratory factor analysis (EFA) (**Figure EFA**) to estimate the shared variance between questions, and found that the respondents gave similar answers to questions SE1-3 and SE5-7. Based on the nature of these questions, we called SE1-3 'Contentment' and SE5-7 'Self-Esteem.' Accordingly, we combined the answers to questions to get two latent variables, Contentment and Self-Esteem. These were summary variables that simplified our interpretation of the survey, and increased its reliability. Contentment and Self-Esteem were correlated ($r = 0.5$).

Figure EFA. Exploratory Factor Analysis found that the Subjective Experience questions fell into two related groups (latent variables) we named 'Contentment' and 'Self-Esteem'. The numbers on the straight lines are loadings (correlation coefficients) of the observed variables on their respective latent variable. The number on curved line is the correlation between the two latent variables. Question SE4 was 'orphaned' being only weakly loaded on both latent variables r=0.23 & -0.24. The root mean square of the residuals (RMSR) for this model was 0.02, and the comparative fit index (CFI) was 1.002 or good. The total variance explained by the two factor model was $r^2 = 0.55$.



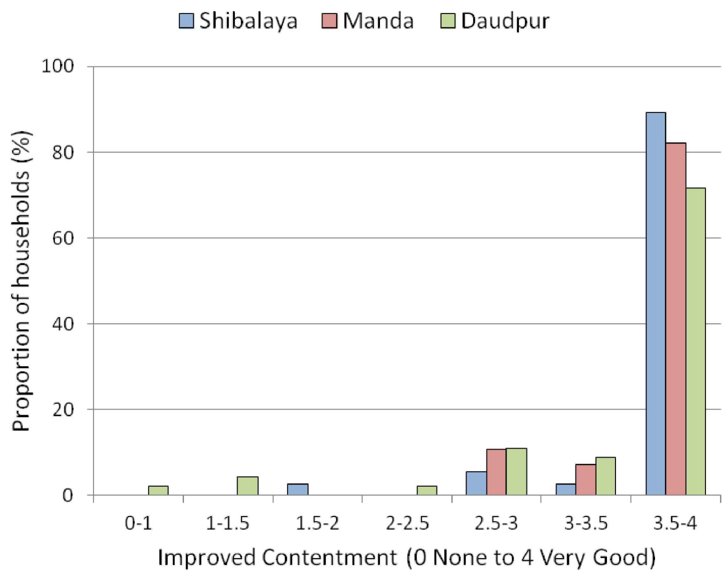
Factor analysis was also used to identify problem questions that the respondents found ambiguous, or interpreted differently than we expected (**Figure EFA**). Question SE1 on happiness was not as strongly correlated to Self-Esteem ($r = 0.5$) as SE2 and SE3 ($r = 0.8$), so it may have been received as vague, and will need of rewording. Question SE4 about whether the women understood the Akha was an 'orphan' being largely independent of the other questions. Comprehension is an important psychological state, so we recommended that this topic be expanded with a set of question on various aspects of understanding, such on which fuels work best, stove control, stove predictability and the mechanism of stove operation.

4.4.4. University Professors Enhanced Women's Self-Esteem

Differences in women's Contentment and Self-Esteem were compared between Shibalaya, Daudpur and Manda (**Figure C&SE**). Contentment was not significantly different across the three locations ($p>0.3$) (**Figure C&SE a**). However, the Self-Esteem of Akha users was significantly higher in Shibalaya than in Manda and Daudpur ($p < 0.001$), and moderately higher in Manda than Daudpur ($p < 0.05$) (**Figure C&SE b**). Even though Self-Esteem was lower in Manda and Daudpur, 70% and 60% (respectively) of the respondents gave a satisfactory score of 3 or more, and very few respondents said that having Akha had little or no positive effect.

Self-esteem developed in a social context that extended beyond the properties of the Akha. Compared to Manda and Daudpur, the Self-Esteem of women at Shibalaya may have been enhanced by more frequent visits from interested professionals such as the media, government scientists, university professors, their students, and project staff. Shibalaya was only 60 km from Dhaka, were CCDB was headquartered. The frequency of visits, and conversations would impress on the families the importance of their role in evaluating new ideas for all of rural Bangladesh. All three locations were visited by specialists, because Akha User Groups and Biochar User Groups were efforts at rural extension education. Agronomists advised farmers on field trials with biochar. Women should have felt important, because they, with their Akhas, were the keystone element making biochar possible. They felt that making biochar was an important-to-essential feature of the Akha (Section 4.5.4.).

(a) Contentment



(b) Self-Esteem

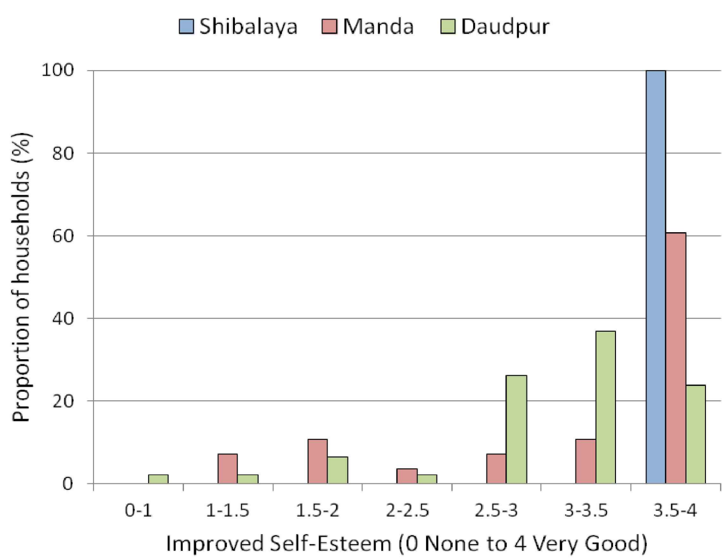


Figure SE_Factors. Frequency of Contentment and Self-Esteem scores compared across the three study locations: Shibalaya, Manda and Daudpur. Contentment was the average of questions SE5-7, and Self-Esteem was the average of E1-3 for each respondent. Fig. 3a: locations were not significantly different ($p > 0.3$). Fig. 3.b: Shibalaya >> Manda > Daudpur ($p < 0.001$, $p < 0.05$; Wilcoxon tests).

4.5. Open Questions

4.5.1. What Mattered The Most?

At various points in the survey, respondents were asked an open question about what mattered to them the most. The purpose of open questions was to allow Akha uses to express their priorities, which helped the researchers to place emphasis on different results from the survey, and give a more reliable evaluation of the Akha. Open questions can also reveal unexpected issues. The open questions showed that making biochar, low emissions of smoke, faster cooking, and saving fuel were what the women felt were the most important features of the Akha. Negative comments were rare.

4.5.2. Akha Performance and the Cooking Experience

Following the Functional Performance (FP) questions, and after the Subjective Experience (SE) questions, we asked the women an open question on what mattered most to them. The previous FP and SE questions set the context for an open question. The interviewers took notes which were later abstracted into key-concepts that could be counted. The results from both open questions were similar, so their results were combined (Table KC). Faster cooking, saving fuel, and low smoke were top priorities.

Some important features of the Akha were not emphasized by the women. These included the ability to turndown the heat, and ease of lighting. The hinged grate in the Akha was not mentioned. That did not mean that these features were unimportant in the stove's design. The hinged grate was essential to the safe collection of char.

(FOOTNOTE: Negative comments on the stove were uncommon. That may have accurately reflected the women's views. However, the questions may need to make it clearer that we are receptive to both positive and negative opinions. The trick is to ask a question in a way that doesn't bias the frequency of 'key-concepts'. These questions focused on the stove, and not fuel preparation and biochar. A broader perspective may come from asking 'why they would (or would not) recommend the Akha to a friend'.)

Table KC: The frequency of key concepts that mentioned by Akha users when asked for their impression about the functional performance of the Akha, and the cooking experience.

Relative frequency of key concepts †

100	Faster cooking	17	Easy to cook	2	Stand to cook
92	Low smoke	13	No stoking	2	Cooler to operate
90	Saves fuel	8	Burns well	2	Turndown heat
50	Cleaner	5	Comfortable to operate	2	Easier to light
42	Biochar	5	Nice stove	2	Good if working properly
38	Multitasking	5	FUEL QUALITY	2	Wood burns a long time
37	Improved health	3	Like a gas stove	2	NEEDS REFUELING
33	Earn money	3	No ash	2	Cooks for five
23	Happy		Negative responses are capitalized		

† The frequency of phrases were expressed as a percent of the frequency of 'Faster cooking' which occurred 60 times.

file: Akha_vs_Traditional_WordCloud.xlsx

4.5.3. Why Recommend Akha to a Friend?

Akha users were asked, "Would you recommend the Akha to a friend?" (Table RTF), then asked to give three reasons why, or why not (Figure RTF). The purpose of the second question was to get the respondents to consider their beliefs and attitudes to several topics simultaneously: the Akha, fuel preparation, and the creation of char (biochar); then give us the reasons for their recommendation. [Footnote below]

Out of 111 respondents, 86% said "Strongly Yes," they would recommend the Akha, 10% said "Frequently Yes," only 4% were equivocal, and there were no negative responses (Table RTF). That was a very strong endorsement for the Akha.

Table RTF. Response of Akha uses to the question, "Would you recommend the Akha to a friend?", with possible answers, (0) "Strongly No" (1) "Frequently No" (2) "Half yes, half no; or no opinion" (3) "Frequently Yes" (4) "Strongly Yes"

Answers	Location (Sub-district)			
	Shibalaya	Manda	Daudpur	Overall
		— (%) —		
Half yes, ...	0	4	7	4
Frequently Yes	22	7	2	10
Strongly Yes	78	89	91	86
No. Respondents (n)	37	28	46	111

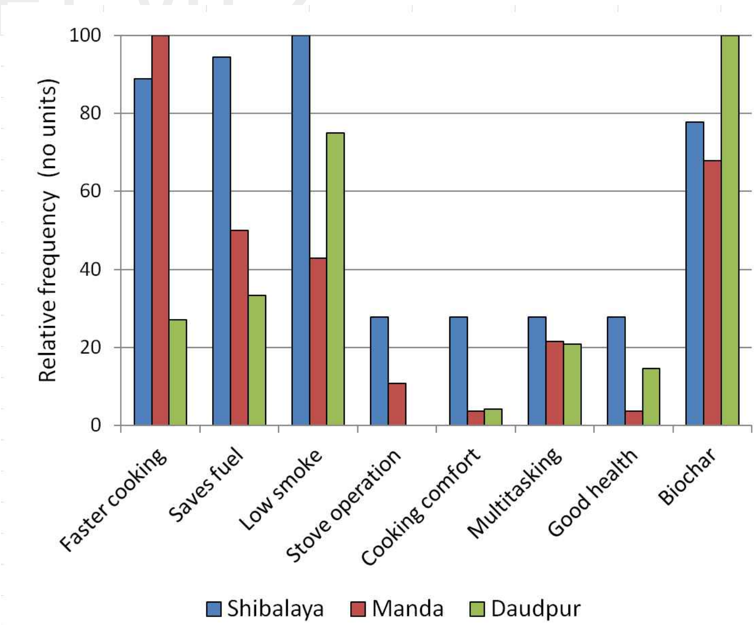


Figure RTF: Reasons why women would recommend the Akha to a friend. Reasons were categorized, counted, and expressed as a proportion of the frequency of the most important reason.

The reasons for recommending the Akha to a friend were simplified into eight categories (Faster cooking, Saves fuel, etc., Figure RTF), counted, then expressed as a proportion of the most popular category (assigned 100 units). Combined over all three study locations, the most frequent reasons were Biochar = 100, Low smoke = 89, Faster cooking = 78, Saves fuel = 69, Multitasking = 28, with other reasons <20 in relative ranking.

(FOOTNOTE: We asked for three reasons in order of importance, thinking that this ranking could be used to weight the frequency of answers. Subsequently we felt that any ranking (e.g., 1x, 0.66x, 0.33x) would be biased. By asking only three reasons, we exclude a variety of lesser reasons. It may be better to leave this question entirely open for women to mention as much or as little as they wish, then count the 'key concepts'.)

Reasons for recommending the Akha varied between Shibalaya, Manda and Daudpur (Figure RTF). Biochar was most important at Daudpur. Faster cooking was most important at Shibalaya and Manda. Saves fuel and Low smoke were also top reasons for recommending the Akha in Shibalaya. Differences between locations were not unexpected. However, they may not be easy to explain because of complex interactions between extension education by Akha User Groups, and biochar agronomy, culture, fuel supply, economy, geography, etc. Furthermore, the study's sample size was too small to draw firm conclusions. We need hundreds of Akhas in use for more than one year before regional differences can be scrutinized. For the moment, we show that geographic variation can exist.

The previous open questions (Table KS) following FPS and SES found that the most frequently mentioned features of the Akha were Faster cooking = 100, Low smoke = 92, Saves fuel = 90, and at a lower frequency was Biochar = 42. The reason's for recommending the Akha to a friend could have a broader scope in the minds of the respondents than just Akha function, so Biochar became the top reason. The recommendations to a friend may more reliable than the open questions following FPS and SES questions.

4.5.4. Is Making Biochar Essential?

The importance of biochar production was corroborated by a direct question (Table EB) that compared biochar-making to clean cooking, etc.. Similar to recommendations to a friend, 70% of respondents in Daudpur said that biochar-making was an essential condition for using the Akha; Shibalaya was next at 30% and in Manda was last at 9%. Combining those respondents who that said biochar was very important or essential, there were 98% in Shibalaya, 88% in Manda, and 90% in Daudpur.

Table EB. Compared to other properties of the Akha, such as clean, efficient cooking, how important is making biochar in deciding to use the Akha rather than another type of stove?

Answers	Location *		
	Shivalaya	Manda	Daudpur
		—— (%) ——	
Unimportant			
Somewhat Important	2		9
Equal to clean cooking		13	2
Very Important	**68**	**78**	20
Essential	30	9	**70**
No. respondents (n)	37	23	46

* All locations were significantly different from each other, p < 05, according to a Kruskal-Wallis tests.

Most of the women considered biochar-making to be a critical property of the Akha. This property was not found in ordinary combustion stoves (that simultaneously burn pyrolytic gas and char) such as the traditional Bangladeshi stove, the Bondhu Chula, and rocket stoves. Over the past thirty years, the adoption of clean cookstove in Bangladesh has been slow. Making biochar may be the critical factor that enables widespread adoption of the Akha cookstove. Awareness in the communities of the importance of biochar should increase over then next year as people witness its use in homestead gardens, and fields crops, and as it starts to develop a commercial value.

4.5.5. Comments

Negative comments were uncommon. Asking why women would recommend, or not recommend, the Akha to a friend attempted to get the respondents to integrate several topics, such as using the Akha, preparing fuel, using or selling char. However, this question was unlikely to return negative reasons if the respondent recommend the Akha. Recall that 86% said "Strongly Yes," they would recommend the Akha, 10% said "Frequently Yes," only 4% were equivocal. We shouldn't expect comments on the supply of wood fuel, and breaking it up of the Akha when the recommendations are very positive.

Respondents' priorities could also be used for weighting questions when combining them into indicator variables.

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