Supplementary Material: In-Home Emissions Performance of Cookstoves in Asia and Africa

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1. Study Sites and Project Stoves

1.1 EPA Project Locations

1.1.1 Benin

The Éclair stove, developed by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), was the intervention technology evaluated in Benin (see Figure SM1). The charcoal burning Éclair is produced in four different designs of varying size and shape, all of which are constructed from recycled metal with secondary air holes intended to more fully oxidize the fuel carbon. It is locally manufactured by GIZ-trained artisan producers. Four different Éclair designs were measured with no statistically significant difference between performances of different designs, so all stoves were assessed as a single group.

The cross-sectional study took place along the southern coast of Benin in two urban cities, Cotonou and Porto Novo, and the peri-urban community Ouidah (see Figure SM2), where charcoal is the dominant cooking fuel. Although traditional charcoal stoves were varied in this region, the Cloporte stove was predominantly used and, therefore, primarily sampled as the baseline reference stove. The Cloporte is a metal, conical stove that is either square or circular and comes in various sizes (see Figure SM1)

A total of 35 samples were collected in July and August of 2013. The small conical Éclair was sampled in 13 homes, the large conical in 3, the small gaz in 5, and the large gaz in 3. The baseline stove was assessed in 11 homes. Participant households were recruited by GIZ.

Figure SM1. Éclair Petit (top left), Éclair Gaz Grand (above) and Cloporte (direct left).

Figure SM2. Benin study sites.

1.1.2 India

1.1.2.1 Maharashtra

The Oorja, shown in Figure SM3, is a forced air gasifier stove, optimized for use with pellets made from compressed sugar cane crop residue. First Energy, our partner program for this study region, manufactures and sells the Oorja and the pelletized biomass used in the stove.

The study took place in peri-urban neighborhoods around Kolhapur, Maharashtra, India. The stove/fuel combinations were varied with a wide combination of stoves and fuels being used to achieve cooking tasks. Common fuels were LPG, wood, and dung, as well as kerosene and pellets in some homes. The traditional mud chulha, shown in Figure SM3, was sampled as the relevant baseline scenario.

The traditional mud chulha and the Oorja stove were sampled in October 2010, at the end of the rainy season. The traditional chulha and the Oorja were sampled in six and nine homes, respectively. The households using the Oorja were chosen from a list of customers supplied by the distributors, and the homes using the traditional chulha were identified in the same neighborhoods.

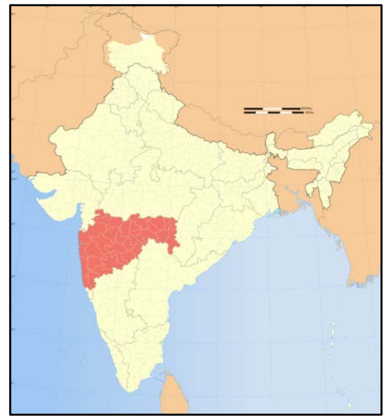

Figure SM3. Traditional mud chulha (left), Oorja (middle), and study location in India (right).

1.1.2.2 Gujarat

The Eco Chulha, designed and produced by Alpha Renewable Energy, Pvt. Ltd., was the intervention stove studied in Gujarat, India. The Eco Chulha, shown in Figure SM4, is based on force-draft gasification technology. It is made out of stainless steel and contains secondary air holes and an electric fan for forcing air circulation through the combustion chamber in order to burn residual gas for more complete combustion. The fan can be powered via an electrical outlet or a lithium-ion battery, which can be charged with a solar charger. The Eco Chulha can be used with a variety of fuels but wood was primarily used and sampled in the study region.

The study locations in Gujarat were located in rural communities around the Anand district (Figure SM6), where cooking is traditionally done on mud chulhas and wood is the primary fuel. The village of Manpura in the Anand district recently established a manufacturing plant of fuel wood pellets, which were used by some of the homes around this village as fuel in Eco Chulha stoves.

A total of 40 homes were sampled in August 2013: 16 traditional mud chulhas (Figure SM5) as a baseline comparison group, 16 Eco Chulhas using wood, and 8 Eco Chulhas using wood fuel pellets. Homes were recruited by members of the Self Employed Woman's Association (SEWA), and all participants had owned and operated the Eco Chulha for four or more months at the time of the test.

Figure SM4. Eco Chulha stove

Figure SM5. Traditional chulha

Figure SM6. India study site location.

1.1.3 Uganda

In Uganda, the effects of displacing charcoal with liquefied petroleum gas (LPG) were studied with Wana Energy Solutions, a local supplier of household LPG and stoves. LPG stoves were one, two, or four burner stoves.

Emissions tests were conducted in urban and peri-urban neighborhoods to the south of central Kampala (Figure SM7). The stove/fuel combinations in this area were varied and usage patterns were dynamic. The most common fuels were charcoal, wood, and LPG. The traditional and LPG stoves are shown in Figure SM8.

A total of 33 emissions samples were collected in August 2012: 5 three-stone fire wood stoves, 14 charcoal stoves, and 14 LPG stoves. LPG users were identified from a list of Wana Energy customers, and the baseline charcoal user group was selected to provide comparability with the LPG users.

Figure SM7. Uganda project site location.

Figure SM8. Ugandan metal charcoal stove (left), traditional ceramic charcoal stove (middle) and an LPG two-burner stove (right).

1.2 CEPS Project Locations

1.2.1 Kenya

The intervention stove in Kenya was the Jikoakoa, shown in Figure SM10, which was developed by BURN Design Lab and manufactured in Nairobi by BURN Manufacturing. The Jikokoa is a charcoal stove constructed of metal, with a stainless steel combustion chamber and an ash tray that can be adjusted to regulate primary airflow. A prototype version of the Jikokoa (Jikokoa 2) (Figure SM10) was also tested, which had secondary air holes designed to help lower CO emissions. Differences in performance were not statistically significant between the two versions so the two were assessed as a single group. More information on the Jikokoa can be found at http://www.burnmfg.com/.

Figure SM9. Kenya project site location.

The study site in Kenya was in the urban community of Kwangware in Nairobi (Figure SM9). The primary fuel in this area was charcoal, with some wood and LPG also used. The Kenyan Ceramic Jiko (KCJ) was also assessed (Figure SM10), as it is the most widely used charcoal stove in the area. The KCJ has a metal-clad ceramic liner, three pot supports, and metal legs.

The monitoring campaign for the KCJ took place in February and March of 2013 at the beginning of the rainy season, with follow up monitoring for the Jikokoa and Jikokoa 2 in April and May, respectively (rainy season). The project included 25 households for the initial baseline KCJ measurements with the first follow-up successfully measuring 18 Jikokoa stoves and the second follow-up measuring 10 Jikokoa 2 stoves.

Figure SM10. The Kenyan cerramic jiko (KCJ) (left), the Jikokoa (middle), and the Jikokoa 2 (right).

Figure SM11. Uganda project site location.

1.2.2 Uganda

The BioLite HomeStove was assessed in Uganda (see Figure SM13). The rocket-style stove has a thermoelectric generator (TEG), which converts waste heat into electricity, powering a fan and USB port (more information can be found at www.biolitestove.com). The HomeStove has a stainless steel combustion chamber with a cast-iron bottom and pot support.

The study site in Uganda was in a peri-urban community outside of Kampala on Wakiso road (Figure SM11)[1]. The primary fuels in this area were wood and charcoal, with LPG available, but not commonly used. Traditionally, the three-stone-fire (TSF) and charcoal stoves are used for cooking in this region. The traditional charcoal stoves vary in construction and design, but are primarily ceramic with a fuel grate and three pot rests.

A baseline sample of 20 households using traditional technologies was collected in March 2013 (between the dry and rainy season). In early August, the households were given a HomeStove and representatives from BioLite and CIRCODU led a small stove use training. The follow up monitoring of the HomeStove sampled 16 homes in late August/early September, which is also between the rainy and dry season.

Figure SM12. Three-stone-fire (left) and traditional ceramic charcoal stove (right) in Uganda.

[1] An additional 10 homes using traditional charcoal stoves, and 3 homes using TSFs from the community of Seguku (also in the Kampala area), were added to the dataset. These homes were part of a USEPA study led by Berkeley Air, for which almost identical methods were used.

Figure SM13. Biolite HomeStove (left). The TEG unit and USB port (right) are housed in the orange enclosure.

1.2.3 Vietnam

1.2.3.1 Southern Vietnam

In Southern Vietnam, a locally produced "High Efficiency Stove" (HES) was tested. The HES has three pot supports, a metal-clad ceramic liner, and is primarily designed for use with charcoal. A fraction of HESs in this area are made with a door cut in the top providing an opening for wood, in which case the stove is a duel fuel stove.

The project was located on the Mekong Delta in the village of Châu Lăng (Figure SM14), a rural community near the border of Cambodia in the An Giang district. The primary fuel type in this region was wood, with charcoal and crop residues also commonly used. Most homes also had access to electricity, although it was not used for cooking in rural areas of this region. The baseline stove assessed was a wood burning, ceramic stove common throughout the Mekong Delta. The stove had three pot supports and upper and lower fuel shelves. Fuel loaded into the top shelf descends in to the combustion zone, but can be removed and placed on the lower shelf to lower the power level.

Figure SM14. Vietnamese study site locations.

Community leaders in the nearby city of Tri Ton facilitated the project in Châu Lăng, arranging 40 households to sample over 10 days. Half of the homes selected used the traditional stove and half the HES. A community organizer from Tri Ton acted as a local guide, translating from Khmer to Vietnamese and directing the team to the homes of the participants. Sampling was conducted in June, 2013, which is in the rainy season.

Figure SM15. South Vietnam Stoves: Traditional Mekong Delta Wood Stove (left) and the "High Efficiency Stove" or HES (right).

1.2.3.2 Northern Vietnam

The stove studied in Northern Vietnam was a rice husk gasifier (RHG) (Figure SM16). The RHG stove is batch fed from the top and constructed of metal. Forced air is introduced into the stove via a separate blower fan, which is commonly available in Vietnam.

The study took place in the Phú Binh district (Figure SM14), a rural, agricultural region of the Thai Nguyen province. Wood and crop residues (primarily rice husks and straw) are the most common fuels in rural areas of this province. The traditional stove in the region was a metal support stand for pots, with cooking fires lit underneath (Figure SM16).

The field team worked with the Phú Binh District Farmers Union to select 20 households using the rice husk gasifier stove (RHG) and 20 households using the traditional stove. Sampling was conducted in August, 2013, which is the rainy season for the region.

Figure SM16. North Vietnam: Traditional North Stove (left), and Rice Husk Gasifier (right) with the blower fan housed in the blue and yellow casing.

2. Methods

2.1 Emissions Sampling

Emissions sampling was conducted during uncontrolled cooking events in participant's homes. Cooks were instructed not to alter their fuel, stove use, or cooking practices. Emissions species measured at all sites were carbon dioxide (CO2), carbon monoxide (CO), and particulate matter (PM2.5). USEPA project sites included additional measurements of elemental carbon (EC), organic carbon (OC), methane (CH4), and total non-methane hydrocarbons (TNMHC). All samples were collected directly above the stove using a three-pronged stainless steel sampling probe (Figure SM17).

A three-sided aluminum curtain was placed around the stove to minimize impacts from air currents. Real-time concentrations of CO and CO2 were measured using a TSI IAQ-CALC 7545 (TSI Inc., USA), and gravimetric measurements were taken to quantify PM2.5 mass deposition. The sample air stream was passed through a BGI Triplex cyclone (BGI, USA) at 3 liters per minute to remove particles larger than 2.5 microns in diameter. When EC and OC were measured at USEPA project sites, sample air passed through a cyclone at 3 LPM and was then split into two streams of 1.5 liters per minute by constant-flow SKC sampling pumps (SKC Inc., USA). One sample line drew air through a Teflon filter to determine PM2.5 mass deposition, followed by a quartz filter (Pall Incorporated, USA) to collect only gas phase OC. The other sample line passed air through just a quartz filter to collect EC and, due to the absence of the Teflon filter, gas and particle phase OC. Quartz filters were sent to Sunset Laboratory for EC and OC analysis by the thermal-optical method [1]. Elemental carbon was assumed to be the same as black carbon (BC), the light-absorbing component of the particulate emissions, which is a common assumption for source characterization studies [2]. Subtracting gas phase OC from the combined gas and particle phase OC yields the OC component of PM2.5. Mass deposition of PM2.5 was determined gravimetrically by weighing the Teflon filters before and after sampling in a constant humidity and temperature room on an electronic microbalance with 0.1µg resolution (Mettler Toledo, USA).

At EPA sample sites, emissions samples were collected for additional CH4 and TNMHC analysis. Sample air was pumped into a Kynar sample bag (CEL Scientific) that was in-line with the secondary quartz filter sample line and filled at a constant rate of 0.2 liters per minute throughout the measurement period. A small fraction of this sample was then transferred to a 0.5L metalized bag (Calibrated Instruments, Inc.) after the completion of the sample and transported back to the Berkeley Air laboratory for analysis of CH4 and TNMHC. The remainder of the Kynar bag sample was fed into the TSI IAQ-CALC 7545 for verification of the average CO and CO2 sample concentrations. Post-field lab samples were analyzed for CH4 and TNMHC using a Perkin Elmer 8500 gas chromatograph (Perkin Elmer, USA) with dual flame ionization detectors. CH4 was separated using a 6ft x 1/8" column packed with 80/100 mesh Carbosphere (Grace Davidson, USA) and total hydrocarbon samples were run through a 2ft x 1/8" glass bead packed column (Grace Davidson, USA). CH4 was subtracted from total hydrocarbons to determine TNMHC. All gases were quantified using 5-point calibration curves (all r2>0.995) made from NIST traceable calibration gas.

Emissions factors were determined using the carbon balance approach, as has been done in previous studies of stove emissions and is described in the WBT 4.2.3 protocol [3–6]. Flow rates and sample volumes were adjusted for temperature and pressure, which were recorded before and after each event.

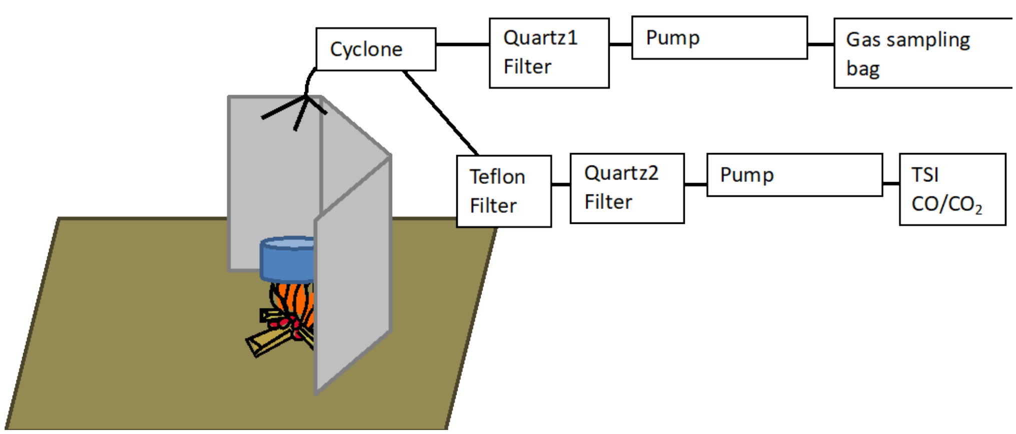

Figure SM17. Emissions sampling setup over an Éclair stove in Benin (left), an Eco Chulha stove in India (right), and as a diagram (bottom).

2.2 Fuel and Event Characteristics

Before beginning the emissions test, all fuels apportioned for the sample event were weighed separately. Upon completion of the test, fuel remaining in the stove was immediately weighed, separating the ash from the char using an ash screen. If fuelwood was used, the moisture content was measured with an Extech M0210 moisture meter.

Information on event type and number of people being cooked for was collected to account for differences in energy demand between events. To normalize for the different energy demands across gender and age, people were weighted according to the standard adult convention2 used in the Kitchen Performance Test Protocol [7]. Cooking events were weighted at 1.0 for meals and 0.5 for preparing beverages such as tea or heating milk.

2.3 Fuel Carbon and Energy Analysis

Rice husks from Vietnam, charcoal from Benin, and wood pellets from India were analyzed for energy, ash, and carbon content at Colorado State University. Charcoal samples from Kenya were analyzed at the University of Nairobi. Carbon and energy characteristics of other fuels were taken from the WBT 4.2.2 protocol or other peer-reviewed literature. Fuel characteristics are presented in appendix B.

2.4 Operational Conditions

Observations of stove condition and the participant's operational methods during sample collection were recorded to better understand correlations between these functional variables and stove performance. Factors associated with cooking with biomass, such as lighting technique, pot characteristics, fuel size/conditions, and others, were recorded and may assist in understanding differences in stove performance. Other variables were also documented such as fanning the fire, moving a stove indoor or outdoor, and resting a pot directly on top of charcoal. Qualitative descriptions of stove condition and quantitative evaluation of stove age were also recorded to help understand differences in stove performance unrelated to user operation.

2.5 University of California, Irvine Collaboration

Additional funding provided by USEPA allowed collaboration with University of California, Irvine (UCI) in Benin. An additional 21 field samples were collected by UCI during the field campaign in Benin. Although UCI's sampling technique differed slightly from Berkeley Air's methods, the same fundamental approach was used and identical performance metrics are reported. Quality assurance and control protocols were followed by both organizations in order to ensure the reported data-set is cohesive and illustrative of the stove performance in Benin. Two co-located samples were collected to confirm equivalent relative performance of the instrumentation used by Berkeley Air and UCI.

2.6 Quality Control and Assurance

2.6.1 Equipment Checks and Calibration

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[2] "Standard adult" equivalence factors defined in terms of sex and age Gender and age fraction of standard adult: child 0-14 years = 0.5; female over 14 years = 0.8; male 15-59 years = 1; and male over 59 years = 0.8.

Instrumentation was checked weekly to ensure consistent and accurate data collection. A quality assurance checklist and corresponding data entry sheet were filled out weekly with specifications detailing all instruments' functional status to track and record performance over time. These checks included:

- Testing fuel scale accuracy against a pre-weighed standard weight.
- Checking the battery and standard resistance of the moisture meter used to measure wood moisture content.
- Recording the UCB-PATS baseline temperature and photoelectric signal as well as cleaning the UCB-PATS photoelectric chamber.
- Pre- and post-project calibrations of TSI air quality CO/CO_2 monitors.
- Co-located measurements by partner research teams and Berkeley Air when possible to certify instrument agreement.
- In-field unused CO/CO_2 monitor to be used as a standard for comparison to other monitors while used in the field.
- Ensuring that supplies inventory is sufficient.
- Cleaning equipment.

Three TSI Indoor Air Quality Monitors were calibrated before and after each field campaign at the Berkeley Air lab with NIST traceable gas calibration standards from MESA Specialty Gas (400 ppm CO, 5000 ppm CO2, and zero grade nitrogen). Post calibration, a correction adjustment was entered into the instrument per the manufacturer's instructions. For CEPS project sites, calibration standards were also available at the project sites and calibrations of TSI monitors were done weekly. At USEPA sites, we tracked changes by only using two of the three TSI instruments for sample collection while the third unused TSI acted as a control for comparison. An inter-comparison sample using all three instruments was done at the end of each field campaign and then data from the two instruments used in the field were adjusted to match the equivalent response of the control.

In Benin, two co-located samples by UCI and Berkeley Air allowed for comparisons of instrument function in an effort to report a continuous data-set with synchronized stove performance metrics. Sample probes were installed over the stove combustion plume as closely to one another as possible. Absolute values of emission species varied some between the two sets of instruments, as expected with a fluctuating plume from an outdoor cookstove. However, the relative concentrations correlated and the sample ratios agreed, with modified combustion efficiency differing by <1% between the respective instrument installations. Real-time measurements of PM2.5 made by UCI using the TSI DustTrak particle monitor were adjusted based on co-located gravimetric samples.

A TSI Primary Calibrator 4146 was used to measure the air flow directly at EPA project sites from both sample lines and the bag sample line before and after each sampling event. For CEPS project sites, a rotameter was used for measuring sample line flows, which was calibrated on site with a TSI Primary Calibrator 4146.

2.6.2 Quality Control of Data

Survey form data was input daily and reviewed to check for transcription errors and suspect entries. Subsequent cross-checks of the hard-copy survey form and the electronic database were performed prior to data analysis. A final data review was done while in the report drafting phase to review calculation correctness and overall completeness of the database.

During CEPS projects, when Berkeley Air personnel was not present, data was remotely screened after upload to a cloud-based platform (Online Data Kit). The field team uploaded the data from a cellular device on a daily basis during the monitoring campaign. Each data set was then checked for consistency, accuracy and completeness. Any problems that could potentially compromise the data quality and completeness were immediately communicated to the field team, who in turn checked the data against written records and made any edits necessary.

3. Results and Discussion

3.1 Firepower and Fuel Consumption

Firepower is a measure of energy used per unit time and provides a diagnostic measure of how the stove is being operated. Average firepower over a complete cooking event was determined by dividing the fuel energy consumed during the event by the total event time. The median firepower for all stoves included in this study is plotted in Figure SM18, which ranged between 1 and 10 kW. Within countries, traditional stoves were almost always operated at higher power than their non-traditional counterparts, with the exception of the Eco Chulha in India and the Éclair in Benin, which were similar to the traditional chulha and Cloporte in operative power, respectively. Across countries, baseline firepower was low in African countries where primarily charcoal stoves are used versus South and Southeast Asian countries where cooking is traditionally done on wood stoves. This trend is expected due to both the nature of charcoal versus wood combustion as well as the generally higher thermal heat transfer efficiency of charcoal stoves when compared to less sophisticated traditional wood stoves. The HES in Southern Vietnam, which was designed for use with charcoal, demonstrated nearly identical firepower with both charcoal and wood use, both of which are lower than the traditional South Vietnamese stove. In Northern Vietnam, the rice husk gasifier demonstrated bi-modal performance behavior relative to PM emissions, however, this duality was not reflected in firepower, which remained relatively similar. In India, the Eco Chulha was operated at higher firepower when consuming pellet fuel than when used with wood. This is likely due to the difference in fuel characteristics, as pellets have higher surface area and tend to be low in moisture, enhancing combustion rate. In Kenya, Benin, and Uganda, the intervention charcoal stoves were operated at lower power. Improvements in stove design over traditional charcoal stoves improve thermal transfer efficiency and result in a lower power operation required to complete tasks. In Uganda, the charcoal stove, Homestove gasifier, and LPG stoves all operated around 3 kW power, nearly one third of Ugandan TSF median power.

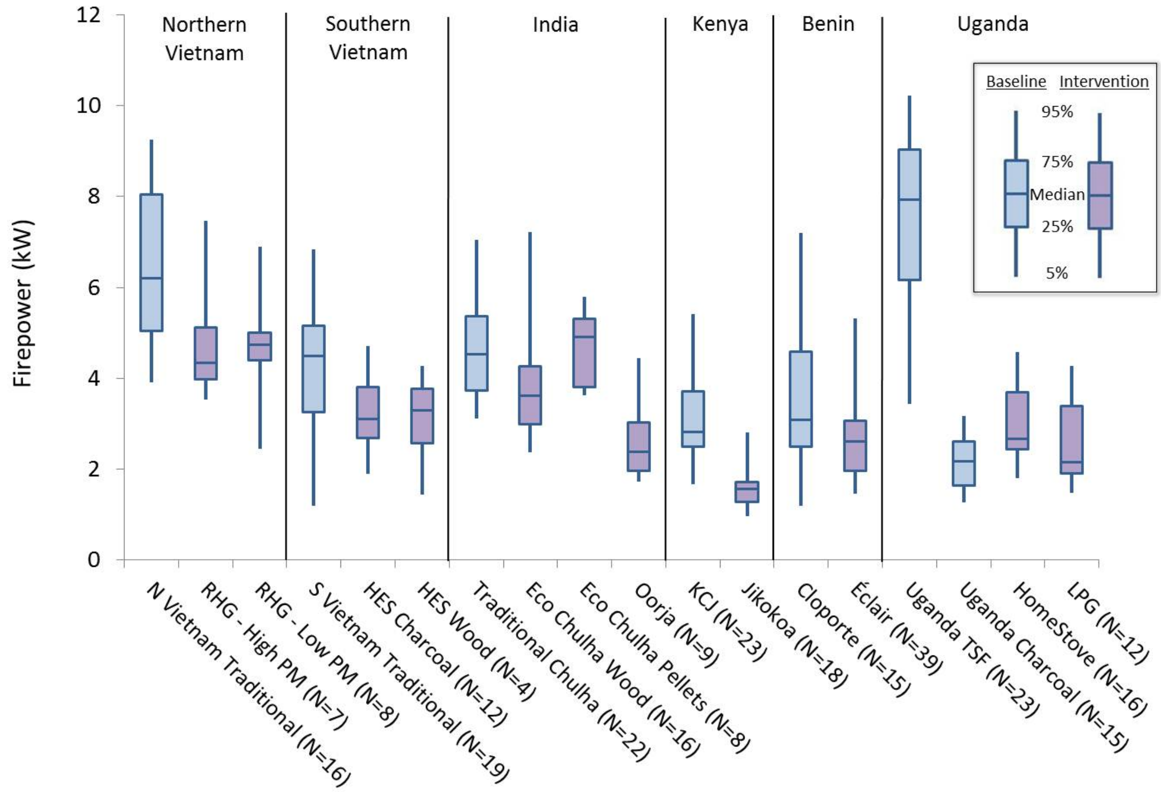

Figure SM18. Cookstove operating power for all study stoves. Firepower is reported as average energy per unit time (kW).

3.2 Modified Combustion Efficiency

Modified combustion efficiency is a measure of how completely the carbon contained in the fuel is being oxidized and is therefore an indicator of how clean the combustion process is. Complete combustion would yield 100% CO2 and no products of incomplete combustion, such as PM, CO, or CH4. MCE is reported as a ratio of CO2 versus combined CO and CO2 (MCE: CO2/[CO2+CO] as carbon).

Most intervention stoves demonstrated improved combustion efficiency over traditional stoves other than the HES in Southern Vietnam which, when used with charcoal and wood, had a median MCE of 85% and 90%, respectively, versus the traditional stove MCE of 92%. In Benin, the Éclair intervention stove showed similar combustion efficiency to the traditional Cloporte stove, both around 87%. Both forced draft stoves in India, the Eco Chulha and the Oorja, demonstrated increased combustion efficiency over the traditional chulha, with the Eco Chulha with pellets exhibiting the highest median MCE of all the solid biomass stoves in the study at 98%. The wood burning Eco Chulha and the pellet burning Oorja had similar median MCE's of ~95%. The Jikokoa improved the combustion of charcoal in Kenyan households by approximately 5% over the KCJ's 83%. Both the HomeStove and LPG stoves showed dramatically increased combustion efficiency over Ugandan TSF and charcoal stoves, with LPG showing median MCE of 99%, and the HomeStove performing similarly to the other forced air stoves at 96% MCE. In Northern Vietnam, the RHG MCE is higher than the traditional stove, with both the high and low PM operation modes appearing to exhibit relatively clean combustion at 95% MCE. Although the MCE of the high PM rice husk stove was relatively good, a large fraction of carbon was emitted as particulate matter, which is not included in MCE.

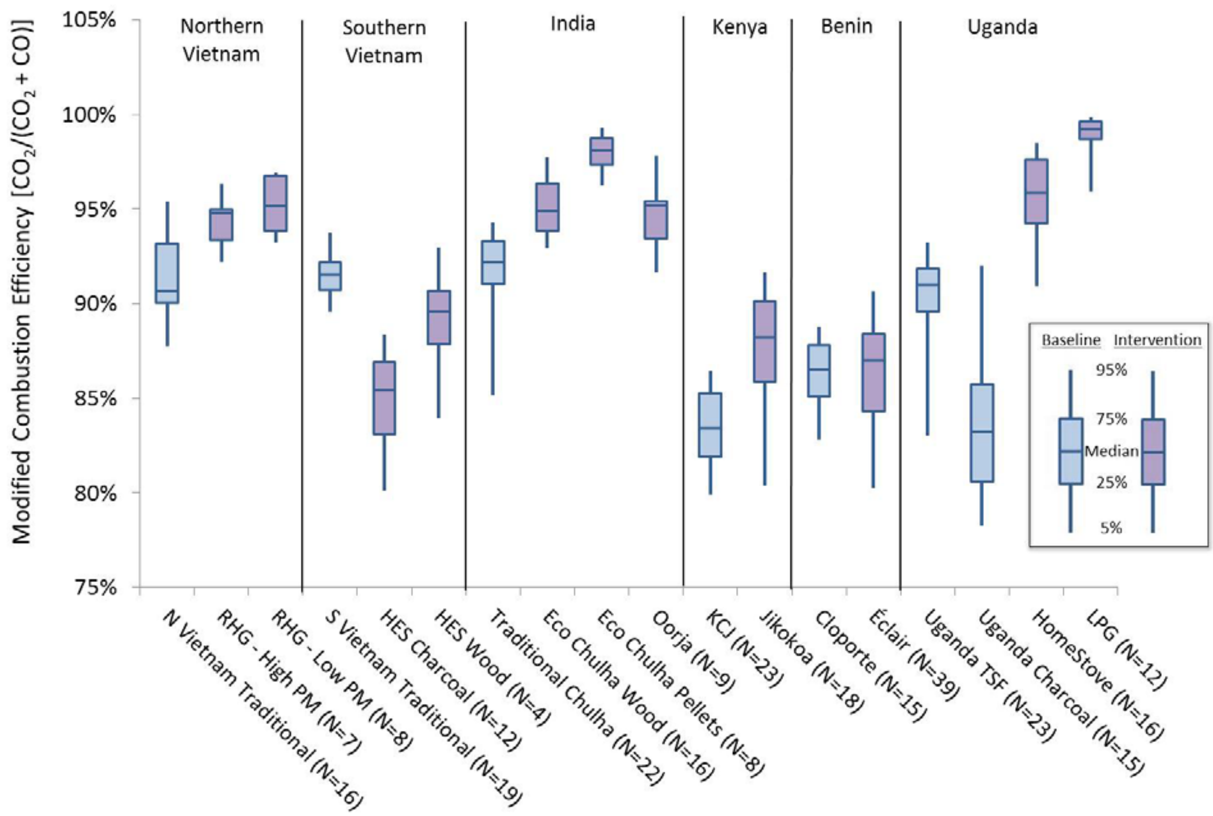

Figure SM19. Modified combustion efficiency (MCE) for all stoves studied. MCE is a measure of completeness of combustion and is represented as the percent of carbon containing species that is emitted as CO_2 (MCE: CO_2/[CO_2+CO] as carbon).

3.3 Fuel Consumption

Fuel consumption, presented as megajoules (MJ) per standard adult (SA)3 meal, is used in the Kitchen Performance Test Protocol and normalizes for the number of people for whom the stove is being used.[7] Event type is also accounted for by applying a greater weight to high energy tasks, such as cooking a full meal, than preparing only lower energy tasks, such as tea. Reporting fuel consumption in terms of energy is useful for comparing across and within study sites where fuels used contain different energy densities.

Within each country, baseline fuel consumption per SA meal varies widely. The overall lower variability of fuel consumption in homes using intervention stoves seems to indicate traditional stove quality may contribute to variability more than other possible factors, such as individual meal sizes and cooking technique, as these would likely manifest as variability in the intervention stove groups as well.

The distribution of baseline fuel consumption per SA meal is similar across countries. In African countries and India, median fuel consumption in homes using traditional charcoal stoves is lower than those using traditional wood stoves, most likely due to charcoal's better heat transfer efficiency.[8] Median fuel consumption in Vietnamese homes using traditional wood burning stoves appeared lower than homes

[3] "Standard adult" equivalence factors defined in terms of sex and age Gender and age fraction of standard adult: child 0-14 years = 0.5; female over 14 years = 0.8; male 15-59 years = 1; and male over 59 years = 0.8.

in India and Uganda using wood burning traditional stoves, however, due to the highly variable nature of fuel consumption measurements, these differences are not statistically discernible (p>0.05).

Intervention stoves at the African and Indian project sites consumed less fuel in by between 35% and 65% compared to their traditional counterparts. In Northern Vietnam, although the RHG had little to no effect on median fuel consumption, the use of a common agricultural waste material, such as rice husks, provides an affordable, renewable fuel regardless of its fuel efficiency in the stove. In South Vietnam, the HES, a stove originally designed for use with charcoal but adapted to accommodate wood, used almost twice as much fuel energy per SA meal when used with wood fuel than charcoal, although this difference is not significant (p=0.12).

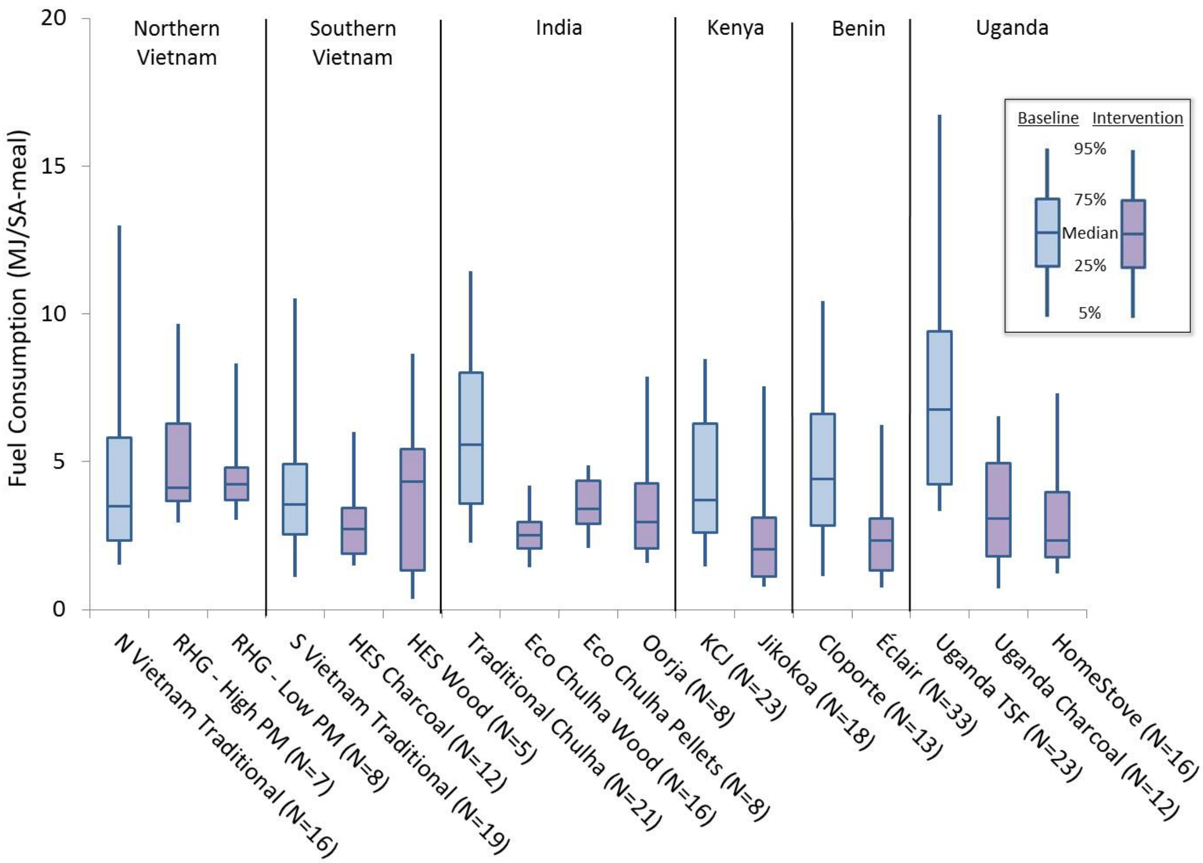

Figure SM20. Fuel Consumption for households using study stoves in terms of energy per standard adult meal (MJ/SA-meal).

3.4 Yellow flame from LPG combustion

While the majority of the LPG stoves had blue flames typical of normal combustion, a small fraction had yellow flames as shown in Figure SM21 below.

Figure SM21. Example of an LPG stove with a yellow flame, one of three samples which had detectable $PM_{2.5}$ emissions.

Appendix A: Detailed Stove Performance Results

Stove metrics for all stoves measured include mean, standard deviation (SD), coefficient of variation (CoV), sample size (N), 95% confidence intervals (95% CI), minimum (Min) and maximum (Max) sample values, and median. The difference between respective baseline and intervention stoves is reported as percent difference (% Diff). A student's t-test was used to determine statistical significance (p-values) of differences in stove metrics. Differences that are statistically significant (p-valu e< 0.05) are bolded.

Table SM1. Benin: Combustion efficiency and fuel consumption statistics.

Cloporte

	MCE	Power (kW)	Fuel Consumption Per Event (g)	Fuel Consumption Per Event (MJ)	Fuel Consumption Per SA-Meal (g)	Fuel Consumption Per SA-Meal (MJ)	Standard Adults
Mean	86.2%	3.9	584	17	180	5.4	3.3
SD	2.2%	1.9	280	8.2	106	3.1	1.3
CoV	2.5%	49%	48%	47%	59%	58%	40%
N	15	15	15	15	13	13	13
95% CI	1.1%	0.97	141	4.2	58	1.7	0.71
Min	81.4%	1.5	130	4.0	46	1.4	1.3
Max	89.0%	9.2	1020	30	443	13	6.2
Median	86.5%	3.2	647	18	145	4.4	2.8

Éclair

	MCE	Power (kW)	Fuel Consumption Per Event (g)	Fuel Consumption Per Event (MJ)	Fuel Consumption Per SA-Meal (g)	Fuel Consumption Per SA-Meal (MJ)	Standard Adults
Mean	86%	2.7	319	9.3	108	3.2	4.0
SD	3%	1.1	154	4.5	116	3.3	3.0
CoV	4%	41%	48%	48%	107%	105%	75%
N	39	39	39	39	36	36	36
95% CI	1%	0.36	49	1.4	38	1.0	0.97
Min	78%	1.2	74	2.0	22	0.59	0.50
Max	94%	5.8	689	20	699	20	18
Median	87%	2.6	260	7.8	79	2.2	3.3
% Diff*	0.05%	**-30%**	**-45%**	**-46%**	-40%	**-41%**	22%
p-value	0.96	**<0.05**	**<0.05**	**<0.05**	0.06	**<0.05**	0.41

*Statistically significant differences are bolded.

Table SM2. Benin: Emission rate statistics.

Cloporte

	Emission Rates CO_2 g/min	Emission Rates CO g/min	Emission Rates $PM_{2.5}$ mg/min
Mean	26	2.5	26
SD	9.7	0.81	21
CoV	38%	32%	81%
N	15	15	14
95% CI	4.9	0.41	11
Min	8.1	1.0	2.0
Max	52	4.1	73
Median	26	2.5	25

Éclair

	Emission Rates CO_2 g/min	Emission Rates CO g/min	Emission Rates $PM_{2.5}$ mg/min
Mean	19	1.8	20
SD	9.9	0.92	21
CoV	53%	50%	107%
N	39	39	39
95% CI	3.1	0.29	6.7
Min	6.8	0.61	0.98
Max	46	4.8	87
Median	16	1.5	13
% Diff*	**-27%**	**-28%**	-24%
p-value	**<0.05**	**<0.05**	0.34

*Statistically significant differences are bolded.

Table SM3. Benin: Emission factor statistics.

Cloporte

	g/kg						g/SA meal						g/MJ					
	CO_2	CO	CH_4	$PM_{2.5}$	EC	OC	CO_2	CO	CH_4	$PM_{2.5}$	EC	OC	CO_2	CO	CH_4	$PM_{2.5}$	EC	OC
Mean	2184	221	7.4	2.3	0.49	1.9	381	38	1.2	0.45	0.093	0.59	74	7.5	0.25	0.077	0.016	0.063
SD	288	38	3.9	1.7	0.65	2.2	214	19	0.66	0.43	0.12	1.1	12	1.4	0.13	0.055	0.021	0.076
CoV	13%	17%	52%	72%	134%	118%	56%	51%	57%	97%	133%	180%	16%	18%	53%	71%	134%	121%
N	15	15	15	14	11	11	13	13	13	12	10	10	15	15	15	14	11	11
95% CI	146	19	2.0	0.87	0.39	1.32	116	11	0.36	0.25	0.077	0.66	5.9	0.69	0.067	0.03	0.013	0.045
Min	1945	159	0.30	0.22	0.0086	0.16	97	8.9	0.087	0.021	0.00072	0.014	65	5.4	0.010	0.0076	0.00029	0.0055
Max	2869	283	14	6.1	2.09	7.9	890	70	2.3	1.4	0.34	3.5	101	9.5	0.49	0.21	0.069	0.27
Median	2083	212	6.9	2.2	0.25	0.92	356	35	1.2	0.36	0.039	0.21	69	7.1	0.23	0.073	0.0080	0.031

Éclair

	g/kg						g/SA meal						g/MJ					
	CO_2	CO	CH_4	$PM_{2.5}$	EC	OC	CO_2	CO	CH_4	$PM_{2.5}$	EC	OC	CO_2	CO	CH_4	$PM_{2.5}$	EC	OC
Mean	2200	220	7.5	2.4	0.25	.97	242	26	0.75	0.22	0.023	0.075	75	7.5	0.26	0.081	0.015	0.03
SD	365	53	8.7	2.1	0.25	.84	291	32	1.3	0.24	0.029	0.076	14	1.8	0.29	0.073	0.01	0.03
CoV	17%	24%	115%	89%	100%	87%	120%	124%	173%	109%	125%	101%	19%	24%	114%	90%	94%	91%
N	39	39	39	39	24	24	36	36	36	36	24	24	39	39	39	39	23	23
95% CI	115	17	2.7	0.67	0.1	.34	95	10	0.42	0.078	0.012	0.030	4.5	0.57	0.091	0.023	0.00	0.01
Min	1656	68	1.2	0.18	0.0	0.11	39	2	0.056	0.018	0.0	0.0	58	2.4	0.038	0.0062	0.00	0.0036
Max	3055	357	55	9.5	.87	3.31	1773	187	7.8	1.1	0.13	0.31	107	13	1.85	0.34	0.03	0.11
Median	2069	218	5.7	1.9	0.18	0.75	186	18	0.42	0.16	0.013	0.045	70	7.7	0.20	0.065	0.0064	0.026
% Diff*	0.74%	-0.36%	1.2%	3.5%	-49%	-49%	-36%	-32%	-36%	**-51%**	**-75%**	**-87%**	2.2%	.82%	2.4%	5.6%	-46%	-49%
p-value	0.88	0.96	0.97	0.90	0.13	0.08	0.12	0.20	0.27	**<0.05**	**<0.05**	**<0.05**	0.69	0.91	0.94	0.84	0.16	0.09

*Statistically significant differences are bolded.

Table SM4. India: Combustion efficiency and fuel consumption statistics.

Traditional Chulha

	MCE	Power (kW)	Fuel Consumption Per Event (g)	Fuel Consumption Per Event (MJ)	Fuel Consumption Per SA-Meal (g)	Fuel Consumption Per SA-Meal (MJ)	Standard Adults
Mean	91.6%	4.9	1184	21	340	6.2	3.9
SD	2.7%	1.8	581	10	204	3.4	1.3
CoV	2.9%	37%	49%	48%	60%	55%	34%
N	22	22	22	16	21	21	21
95% CI	1.1%	0.75	243	4.9	87	1.5	0.56
Min	84.6%	2.8	319	6.1	114	2.2	1.8
Max	95.0%	11	2707	42	967	16	7.2
Median	92.2%	4.5	1171	22	294	5.6	3.8

EcoChulha XXL - Wood

	MCE	Power (kW)	Fuel Consumption Per Event (g)	Fuel Consumption Per Event (MJ)	Fuel Consumption Per SA-Meal (g)	Fuel Consumption Per SA-Meal (MJ)	Standard Adults
Mean	95.2%	4.0	527	11	126	2.6	4.4
SD	1.7%	1.7	302	5.8	51	1.1	1.9
CoV	2%	42%	57%	53%	40%	43%	43%
N	16	16	16	16	16	16	16
95% CI	0.9%	0.83	148	2.8	25	0.55	0.92
Min	92.4%	2.4	214	4.9	57	1.3	0.80
Max	97.9%	8.9	1416	28	267	6.1	9.5
Median	94.9%	3.6	453	10	123	2.5	4.0

EcoChulha - Pellets

	MCE	Power (kW)	Fuel Consumption Per Event (g)	Fuel Consumption Per Event (MJ)	Fuel Consumption Per SA-meal (g)	Fuel Consumption Per SA-Meal (MJ)	Standard Adults
Mean	97.9%	4.7	843	15	201	3.5	4.8
SD	1.2%	0.90	156	2.8	63	1.1	2.4
CoV	1%	19%	18%	19%	31%	31%	49%
N	8	8	8	8	8	8	8
95% CI	0.8%	0.62	108	1.9	44	0.75	1.6
Min	96.0%	3.6	665	12	109	1.9	2.3
Max	99.4%	6.0	1084	19	289	5.0	9.4
Median	98.1%	4.9	788	14	198	3.4	4.4

Oorja

	MCE	Power (kW)	Fuel Consumption Per Event (g)	Fuel Consumption Per Event (MJ)	Fuel Consumption Per SA-meal (g)	Fuel Consumption Per SA-Meal (MJ)	Standard Adults
Mean	94.8%	2.5	780	13	236	4.0	3.8
SD	2.2%	0.95	321	5.6	152	2.6	1.3
CoV	2.3%	37%	41%	42%	64%	65%	34%
N	9	9	9	9	7	7	7
95% CI	1.4%	0.62	210	3.7	113	1.9	1.0
Min	91.3%	1.6	484	8.5	92	1.6	2.8
Max	98.0%	4.7	1518	26	542	9.4	6.6
Median	95.2%	2.2	680	11	189	3.1	3.6
Traditional Chulha Versus Eco Chulha with Wood							
% Diff*	**4%**	-17%	**-55%**	**-49%**	**-63%**	**-57%**	13%
p-value	**<0.05**	0.16	**<0.05**	**<0.05**	**<0.05**	**<0.05**	0.34
Traditional Chulha Versus Eco Chulha with Pellets							
% Diff*	**7%**	8.4%	-33%	-37%	-33%	**-39%**	15%
p-value	**<0.05**	0.81	0.12	0.10	0.07	**<0.05**	0.19
Traditional Chulha Versus Oorja							
% Diff*	**3.6%**	**-48%**	**-34%**	**-37%**	-31%	-35%	-0.7%
p-value	**<0.05**	**<0.05**	**<0.05**	**<0.05**	0.23	0.14	0.96

* Statistically significant differences are bolded.

Table SM5. India: Emission rates summary statistics.

Traditional Chulha

	CO_2 g/min	CO g/min	$PM_{2.5}$ mg/min
Mean	30	1.8	179
SD	12	1.3	113
CoV	41%	70%	63%
N	22	22	22
95% CI	5.1	0.53	47
Min	16	0.87	67
Max	57	6.6	594
Median	28	1.5	152

EcoChulha - Wood

	CO_2 g/min	CO g/min	$PM_{2.5}$ mg/min
Mean	24	0.76	50
SD	10	0.42	45
CoV	43%	55%	90%
N	16	16	16
95% CI	5.0	0.20	22
Min	13	0.26	8.9
Max	51	1.7	162
Median	21	0.59	28

EcoChulha – Pellets

	CO_2 g/min	CO g/min	$PM_{2.5}$ mg/min
Mean	29	0.39	28
SD	5.7	0.26	18
CoV	20%	68%	65%
N	8	8	8
95% CI	4.0	0.18	13
Min	22	0.12	2.2
Max	37	0.98	53
Median	31	0.33	30

Oorja

	CO_2 g/min	CO g/min	$PM_{2.5}$ mg/min
Mean	14	0.49	23
SD	5.0	0.28	21
CoV	36%	57%	91%
N	9	9	9
95% CI	3.3	0.18	14
Min	8.8	0.15	10
Max	25	1.0	77
Median	13	0.44	17

Traditional Chulha Versus Eco Chulha with Wood

	CO_2	CO	$PM_{2.5}$
% Diff*	-21%	**-58%**	**-72%**
p-value	0.11	**<0.05**	**<0.05**

Traditional Chulha Versus Eco Chulha with Pellets

	CO_2	CO	$PM_{2.5}$
% Diff*	-4%	**-78%**	**-84%**
p-value	0.81	**<0.05**	**<0.05**

Traditional Chulha Versus Oorja

	CO_2	CO	$PM_{2.5}$
% Diff*	**-54%**	**-73%**	**-87%**
p-value	**<0.05**	**<0.05**	**<0.05**

* Statistically significant differences are bolded.

Table SM6. India: Emission factor statistics

	g/kg							g/SA meal							g/MJ						
Traditional Chulha																					
	CO_2	**CO**	**CH_4**	**TNMHC**	**$PM_{2.5}$**	**EC**	**OC**	**CO_2**	**CO**	**CH_4**	**TNMHC**	**$PM_{2.5}$**	**EC**	**OC**	**CO_2**	**CO**	**CH_4**	**TNMHC**	**$PM_{2.5}$**	**EC**	**OC**
Mean	1539	90	7.4	11	9.2	0.78	4.3	512	30	2.8	3.6	3.3	0.23	1.5	83	4.9	0.40	0.57	0.50	0.042	0.232
SD	139	31	4.1	6.7	3.3	0.29	1.2	275	19	2.6	3.7	2.4	0.13	1.0	4.5	1.6	0.24	0.36	0.18	0.016	0.065
CoV	9%	34%	56%	63%	36%	37%	28%	54%	62%	93%	104%	72%	57%	65%	5%	33%	59%	64%	36%	37%	28%
N	22	22	20	18	22	17	17	21	21	19	17	21	16	16	22	22	20	18	22	17	17
95% CI	58	13	1.8	3.1	1.4	0.14	0.56	118	8.0	1.2	1.8	1.0	0.064	0.47	1.9	0.66	0.10	0.17	0.076	0.0074	0.031
Min	1232	52	2.6	1.3	4.0	0.21	2.7	185	9.4	0.43	0.58	0.67	0.065	0.47	75	3.0	0.14	0.068	0.21	0.013	0.14
Max	1708	171	19	27	16	1.4	6.1	1242	77	10	17	8.2	0.57	3.2	89	9.0	1.1	1.4	0.82	0.076	0.35
Median	1597	84	6.6	8.5	8.4	0.72	4.35	451	26	1.7	2.6	2.3	0.19	1.1	84	4.5	0.36	0.45	0.48	0.039	0.23
Eco Chulha - Wood																					
	CO_2	**CO**	**CH_4**	**TNMHC**	**$PM_{2.5}$**	**EC**	**OC**	**CO_2**	**CO**	**CH_4**	**TNMHC**	**$PM_{2.5}$**	**EC**	**OC**	**CO_2**	**CO**	**CH_4**	**TNMHC**	**$PM_{2.5}$**	**EC**	**OC**
Mean	1791	58	2.5	19	3.8	0.24	1.7	225	7.3	0.34	2.7	0.45	0.033	0.22	86	2.8	0.12	0.89	0.18	0.011	0.078
SD	54	21	1.2	13	3.5	0.13	2.4	90	3.8	0.31	2.8	0.43	0.021	0.33	3.5	0.98	0.053	0.57	0.16	0.0058	0.11
CoV	3%	37%	48%	69%	91%	54%	146%	40%	52%	91%	107%	96%	64%	152%	4%	35%	45%	64%	86%	50%	140%
N	16	16	11	11	16	10	10	16	16	11	11	16	10	10	16	16	11	11	16	10	10
95% CI	27	10	0.71	7.7	1.7	0.080	1.5	44	1.9	0.18	1.7	0.21	0.013	0.20	1.7	0.48	0.031	0.34	0.076	0.0036	0.068
Min	1702	24	1.1	3.7	0.59	0.11	0.034	110	1.7	0.13	0.43	0.068	0.0091	0.0092	79	1.2	0.057	0.19	0.029	0.0054	0.0016
Max	1934	96	4.6	46	14	0.58	8.4	487	14	1.2	11	1.87	0.076	1.1	91	4.3	0.21	2.1	0.64	0.026	0.38
Median	1780	61	2.2	15	3.0	0.22	0.96	217	6.3	0.25	1.9	0.34	0.028	0.11	87	3.0	0.10	0.69	0.14	0.010	0.048
Eco Chulha - Pellets																					
	CO_2	**CO**	**CH_4**	**TNMHC**	**$PM_{2.5}$**	**EC**	**OC**	**CO_2**	**CO**	**CH_4**	**TNMHC**	**$PM_{2.5}$**	**EC**	**OC**	**CO_2**	**CO**	**CH_4**	**TNMHC**	**$PM_{2.5}$**	**EC**	**OC**
Mean	1683	23	1.7	6.2	1.7	0.34	0.61	339	4.3	0.34	1.3	0.32	0.062	0.12	97	1.3	0.10	0.36	0.10	0.019	0.035
SD	38	13	0.55	5.9	1.1	0.20	0.50	107	2.1	0.18	1.6	0.23	0.037	0.10	1.7	0.72	0.032	0.35	0.066	0.011	0.029
CoV	2%	57%	32%	95%	67%	58%	83%	32%	49%	53%	120%	71%	60%	88%	2%	56%	33%	96%	68%	57%	84%
N	8	8	6	6	8	6	6	8	8	6	6	8	6	6	8	8	6	6	8	6	6
95% CI	26	8.9	0.44	4.7	0.79	0.16	0.40	74	1.5	0.14	1.3	0.16	0.030	0.083	1.2	0.50	0.026	0.28	0.046	0.0088	0.023
Min	1637	6.9	0.97	1.2	0.11	0.069	0.12	182	1.2	0.17	0.30	0.032	0.02	0.01	94	0.39	0.057	0.067	0.0064	0.0040	0.0071
Max	1746	45	2.3	17	3.3	0.59	1.3	497	6.4	0.60	4.3	0.72	0.11	0.29	99	2.5	0.14	1.0	0.19	0.033	0.077
Median	1679	21	1.7	3.7	1.6	0.36	0.49	328	5.2	0.28	0.55	0.32	0.060	0.090	97	1.2	0.10	0.21	0.10	0.020	0.028
Oorja																					
	CO_2	**CO**	**CH_4**	**TNMHC**	**$PM_{2.5}$**	**EC**	**OC**	**CO_2**	**CO**	**CH_4**	**TNMHC**	**$PM_{2.5}$**	**EC**	**OC**	**CO_2**	**CO**	**CH_4**	**TNMHC**	**$PM_{2.5}$**	**EC**	**OC**
Mean	1562	54	3.4	9.2	2.3	0.12	1.1	370	11	0.87	2.1	0.72	0.033	0.35	91	3.2	0.20	0.54	0.14	0.0071	0.064
SD	33	24	1.4	1.4	1.0	0.061	0.59	236	8.5	0.76	1.5	0.84	0.030	0.42	3.7	1.3	0.082	0.08	0.057	0.0036	0.035
CoV	2%	43%	42%	15%	42%	50%	55%	64%	76%	87%	69%	118%	90%	119%	4%	42%	41%	14%	42%	51%	54%
N	9	9	9	8	9	9	9	7	7	7	7	7	7	7	9	9	9	8	9	9	9
95% CI	21	15	0.92	0.94	0.65	0.040	0.39	175	6.3	0.56	1.1	0.62	0.022	0.31	2.4	0.87	0.053	0.054	0.037	0.0024	0.023
Min	1517	21	1.9	6.6	1.6	0.050	0.37	145	3.3	0.17	0.85	0.17	0.0076	0.070	86	1.3	0.11	0.40	0.090	0.0030	0.021
Max	1617	93	5.9	11	4.7	0.26	2.4	844	27	2.5	5.2	2.6	0.080	1.3	98	5.3	0.33	0.67	0.27	0.016	0.14
Median	1565	50	3.2	9.4	1.8	0.11	1.1	305	12	0.75	1.6	0.41	0.023	0.17	91	2.9	0.19	0.54	0.11	0.0068	0.059
Traditional Chulha Versus Eco Chulha with Wood																					
% Diff*	16%	-36%	-66%	78%	-58%	-69%	**-61%**	-56%	-76%	-88%	-26%	-86%	-86%	**-85%**	4%	-43%	-71%	56%	-64%	-73%	**-66%**
p-value	**<0.05**	**<0.05**	**<0.05**	**<0.05**	**<0.05**	**<0.05**	**<0.05**	**<0.05**	**<0.05**	**<0.05**	0.89	**<0.05**	**<0.05**	**<0.05**	**<0.05**	**<0.05**	**<0.05**	0.077	**<0.05**	**<0.05**	**<0.05**
Traditional Chulha Versus Eco Chulha with Pellets																					
% Diff*	**9%**	**-75%**	**-77%**	-42%	**-81%**	**-56%**	**-86%**	-27%	**-80%**	**-84%**	-79%	**-86%**	**-69%**	**-91%**	16%	-73%	-75%	-37%	-80%	-54%	-85%
p-value	**<0.05**	**<0.05**	**<0.05**	0.17	**<0.05**	**<0.05**	**<0.05**	0.10	**<0.05**	**<0.05**	0.17	**<0.05**	**<0.05**	**<0.05**	**<0.05**	**<0.05**	**<0.05**	0.22	**<0.05**	**<0.05**	**<0.05**
Traditional Chulha Versus Oorja																					
% Diff*	2%	**-40%**	**-54%**	-13%	**-74%**	**-84%**	**-74%**	-28%	**-72%**	-79%	-44%	**-78%**	**-85%**	**-76%**	10%	-35%	-51%	-5%	**-73%**	-141%	-118%
p-value	0.63	**<0.05**	**<0.05**	0.58	**<0.05**	**<0.05**	**<0.05**	0.23	**<0.05**	0.07	0.33	**<0.05**	**<0.05**	**<0.05**	**<0.05**	**<0.05**	**<0.05**	0.82	**<0.05**	**<0.05**	**<0.05**

* Statistically significant differences are bolded.

Table SM7. Uganda: Combustion efficiency and fuel consumption statistics.

Three Stone Fire

	MCE	Power (kW)	Fuel Consumption				Standard Adults
			Per Event (g)	Per Event (MJ)	Per SA-Meal (g)	Per SA-Meal (MJ)	
Mean	90.2%	7.5	695	13	420	7.6	2.6
SD	3.3%	2.4	398	7.2	241	4.4	0.93
CoV	4%	32%	57%	57%	57%	57%	36%
N	23	23	23	23	23	23	23
95% CI	1%	1.0	162	2.9	99	1.8	0.38
Min	80.4%	2.8	221	4.1	165	3.0	0.80
Max	95.2%	13	1786	32	1023	19	4.3
Median	91.0%	7.9	593	11	364	6.8	2.6

Traditional Charcoal

	MCE	Power (kW)	Fuel Consumption				Standard Adults
			Per Event (g)	Per Event (MJ)	Per SA-Meal (g)	Per SA-Meal (MJ)	
Mean	83.7%	2.2	285	8.0	139	3.5	3.6
SD	4.6%	0.66	123	3.6	72	2.2	2.2
CoV	6%	31%	43%	45%	51%	62%	62%
N	15	15	15	15	12	12	12
95% CI	2.3%	0.33	62	1.8	41	1.2	1.3
Min	76.2%	1.2	120	3.4	25	0.70	1.8
Max	93.1%	3.2	506	14	233	6.6	8.2
Median	83.2%	2.2	255	7.2	136	3.1	2.6

HomeStove

	MCE	Power (kW)	Fuel Consumption				Standard Adults
			Per Event (g)	Per Event (MJ)	Per SA-meal (g)	Per SA-Meal (MJ)	
Mean	95.5%	3.0	278	5.0	182	3.3	3.7
SD	2.8%	0.93	96	1.7	131	2.4	1.4
CoV	3%	31%	35%	35%	72%	72%	36%
N	16	16	16	16	16	16	16
95% CI	1.4%	0.46	47	0.86	64	1.2	0.66
Min	89.2%	1.7	137	2.5	56	1.0	1.3
Max	98.5%	4.6	408	7.4	556	10	6.1
Median	95.9%	2.7	291	5.3	129	2.3	3.4

LPG

	MCE	Power (kW)	Fuel Consumption				Standard Adults
			Per Event (g)	Per Event (MJ)	Per SA-Meal (g)	Per SA-Meal (MJ)	
Mean	98.7%	2.6	203	9.1	-	-	-
SD	2%	1.1	95	4.2	-	-	-
CoV	2%	0.41	47%	47%	-	-	-
N	12	12	12	12	-	-	-
95% CI	1%	0.62	54	2.4	-	-	-
Min	94.2%	1.3	80	3.6	-	-	-
Max	99.9%	5.0	430	19	-	-	-
Median	99.2%	2.1	190	8.5	-	-	-
	Traditional Charcoal Versus LPG						
% Diff*	**18%**	22%	-29%	14%	**-**	**-**	-
p-value	**<0.05**	0.17	0.07	0.46	**-**	**-**	-
	Three Stone Fire Versus HomeStove						
% Diff*	**6%**	**-61%**	**-60%**	**-60%**	**-57%**	**-57%**	**45%**
p-value	**<0.05**	**<0.05**	**<0.05**	**<0.05**	**<0.05**	**<0.05**	**<0.05**

* Statistically significant differences are bolded.

Table SM8. Uganda: Emission factor statistics

Three Stone Fire

	g/kg							g/SA meal							g/MJ						
	CO_2	CO	CH_4	TNMHC	$PM_{2.5}$	EC	OC	CO_2	CO	CH_4	TNMHC	$PM_{2.5}$	EC	OC	CO_2	CO	CH_4	TNMHC	$PM_{2.5}$	EC	OC
Mean	1638	113	-	-	12	-	-	686	46	-	-	5.1	-	-	90	6.2	-	-	0.65	-	-
SD	74	38	-	-	7.9	-	-	392	27	-	-	5.1	-	-	3.8	2.1	-	-	0.44	-	-
CoV	5%	33%	-	-	67%	-	-	57%	59%	-	-	100%	-	-	4%	34%	-	-	68%	-	-
N	23	23	-	-	23	-	-	23	23	-	-	23	-	-	23	23	-	-	23	-	-
95% CI	30	15	-	-	3.2	-	-	160	11	-	-	2.1	-	-	1.5	0.86	-	-	0.18	-	-
Min	1451	56	-	-	4.4	-	-	271	16	-	-	1.0	-	-	81	3.1	-	-	0.24	-	-
Max	1737	225	-	-	30	-	-	1692	102	-	-	22	-	-	96	12	-	-	1.7	-	-
Median	1655	104	-	-	8.1	-	-	589	35	-	-	3.9	-	-	91	5.7	-	-	0.44	-	-

Traditional Charcoal

	g/kg							g/SA meal							g/MJ						
	CO_2	CO	CH_4	TNMHC	$PM_{2.5}$	EC	OC	CO_2	CO	CH_4	TNMHC	$PM_{2.5}$	EC	OC	CO_2	CO	CH_4	TNMHC	$PM_{2.5}$	EC	OC
Mean	2533	313	11	16	7.4	0.52	3.2	354	40	1.5	2.6	1.1	0.087	0.34	172	20	0.39	0.61	0.28	0.019	0.12
SD	206	93	3.6	5.7	9.2	0.50	3.7	175	23	0.85	1.3	2.2	0.094	0.32	94	8.6	0.14	0.22	0.38	0.019	0.13
CoV	8%	30%	34%	34%	124%	97%	113%	50%	58%	55%	51%	198%	108%	94%	55%	44%	35%	36%	136%	98%	113%
N	15	15	10	10	15	8	8	12	12	8	8	12	6	6	15	15	10	10	15	8	8
95% CI	104	47	2.2	3.5	4.6	0.35	2.5	99	13	0.59	0.91	1.3	0.075	0.26	48	4.4	0.09	0.14	0.19	0.013	0.092
Min	2085	137	6.1	9.4	0.35	0.053	0.59	61	9	0.45	0.51	0.050	0.0075	0.076	85	12	0.22	0.33	0.01	0.0019	0.021
Max	2878	480	18	25	35	1.7	10	631	88	2.8	4.4	8.0	0.26	0.89	360	43	0.67	0.94	1.48	0.062	0.38
Median	2545	332	11	17	3.6	0.46	1.4	358	38	1.5	2.8	0.47	0.063	0.18	124	17	0.38	0.60	0.13	0.017	0.053

HomeStove

	g/kg							g/SA meal							g/MJ						
	CO_2	CO	CH_4	TNMHC	$PM_{2.5}$	EC	OC	CO_2	CO	CH_4	TNMHC	$PM_{2.5}$	EC	OC	CO_2	CO	CH_4	TNMHC	$PM_{2.5}$	EC	OC
Mean	1741	52	-	-	5.7	-	-	317	9.1	-	-	1.2	-	-	96	2.9	-	-	0.31	-	-
SD	57	33	-	-	4.6	-	-	232	7.4	-	-	1.4	-	-	3.2	1.8	-	-	0.25	-	-
CoV	3%	63%	-	-	81%	-	-	73%	81%	-	-	118%	-	-	3%	62%	-	-	81%	-	-
N	16	16	-	-	16	-	-	16	16	-	-	16	-	-	16	16	-	-	16	-	-
95% CI	28	16	-	-	2.3	-	-	114	3.6	-	-	0.67	-	-	1.6	0.88	-	-	0.12	-	-
Min	1627	17	-	-	0.94	-	-	100	1.8	-	-	0.16	-	-	90	0.93	-	-	0.052	-	-
Max	1805	125	-	-	19	-	-	993	23	-	-	5	-	-	100	6.9	-	-	1.1	-	-
Median	1751	48	-	-	4.8	-	-	219	6.2	-	-	0.50	-	-	97	2.7	-	-	0.26	-	-

LPG

	g/kg							g/SA meal[ǂ]							g/MJ						
	CO_2	CO	CH_4	TNMHC	$PM_{2.5}$[**]	EC	OC	CO_2	CO	CH_4	TNMHC	$PM_{2.5}$	EC	OC	CO_2	CO	CH_4	TNMHC	$PM_{2.5}$[**]	EC	OC
Mean	2919	24	2.0	15	0.47	-	-	-	-	-	-	-	-	-	65	0.54	0.045	0.34	0.011	-	-
SD	87	30	2.8	16	0.23	-	-	-	-	-	-	-	-	-	1.9	0.67	0.062	0.35	0.0051	-	-
CoV	3%	125%	137%	101%	48%	-	-	-	-	-	-	-	-	-	3%	125%	137%	101%	48%	-	-
N	12	12	12	12	12	-	-	-	-	-	-	-	-	-	12	12	12	12	12	-	-
95% CI	49	17	1.57	8.8	0.13	-	-	-	-	-	-	-	-	-	1.1	0.38	0.035	0.20	0.0029	-	-
Min	2720	2.1	0.0	0.0	0.25	-	-	-	-	-	-	-	-	-	61	0.047	0.0	0.0	0.0057	-	-
Max	2996	107	6.24	40	0.96	-	-	-	-	-	-	-	-	-	67	2.4	0.14	0.90	0.021	-	-
Median	2960	14	0.00	8.8	0.40	-	-	-	-	-	-	-	-	-	66	0.32	0.0	0.20	0.0089	-	-
Three Stone Fire versus HomeStove																					
% Diff[*]	**6.3%**	**-54%**	**-**	**-**	**-52%**	**-**	**-**	**-54%**	**-80%**	**-**	-	**-77%**	**-**	**-**	**7.2%**	**-53%**	**-**	-	**-52%**	**-**	**-**
p-value	**<0.05**	**<0.05**			**<0.05**			**<0.05**	**<0.05**			**<0.05**			**<0.05**	**<0.05**			**<0.05**		
Traditional Charcoal versus LPG																					
% Diff[*]	**15%**	**-92%**	**-81%**	-7%	**-94%**	**-**	**-**	-	**-**	**-**	-	**-**	**-**	**-**	**-62%**	**-97%**	**-88%**	-43%	**-96%**	-	-
p-value	**<0.05**	**<0.05**	**<0.05**	0.83	**<0.05**	**-**	**-**	-	**-**	**-**	-	**-**	**-**	**-**	**<0.05**	**<0.05**	**<0.05**	0.054	**<0.05**	-	-

[ǂ] Standard adult data not available for LPG samples

[*] Statistically significant differences are bolded.

[**] Statistics based sample calculations using the LOD for $PM_{2.5}$ of 0.13mg/m^3 for 9 samples which were below the LOD.

Table SM9. Uganda: Emission rate statistics.

	CO_2 g/min	CO g/min	$PM_{2.5}$ mg/min
Three Stone Fire			
Mean	41	2.7	278
SD	14	0.88	206
CoV	33%	33%	74%
N	23	23	23
95% CI	5.6	0.36	84
Min	13	1.1	107
Max	74	4.5	957
Median	43	2.6	206
Traditional Charcoal			
	CO_2 g/min	**CO g/min**	**$PM_{2.5}$ mg/min**
Mean	12	1.5	32
SD	4.2	0.54	33
CoV	34%	37%	105%
N	15	15	15
95% CI	2.1	0.27	17
Min	6.2	0.74	1.4
Max	20	2.4	105
Median	12	1.4	15
HomeStove			
	CO_2 g/min	**CO g/min**	**$PM_{2.5}$ mg/min**
Mean	17	0.53	62
SD	5.2	0.44	70
CoV	30%	82%	114%
N	16	16	16
95% CI	2.6	0.22	34
Min	10	0.15	8.5
Max	27	1.6	292
Median	16	0.35	34
LPG			
	CO_2 g/min	**CO g/min**	**$PM_{2.5}$ mg/min**
Mean	10	0.070	1.5
SD	4.4	0.056	0.56
CoV	42%	81%	37%
N	12	12	12
95% CI	2.5	0.032	0.32
Min	4.6	0.0052	0.65
Max	20	0.18	2.3
Median	8.3	0.072	1.6
Three Stone Fire versus HomeStove			
% Diff*	**-58%**	**-80%**	**-78%**
p-value	**<0.05**	**<0.05**	**<0.05**
Traditional Charcoal versus LPG			
% Diff*	-15%	**-95%**	**-95%**
p-value	0.26	**<0.05**	**<0.05**

* Statistically significant differences are bolded.

Table SM10. Kenya: Combustion efficiency and fuel consumption statistics.

KCJ

	MCE	Power (kW)	Fuel Consumption Per Event (g)	Fuel Consumption Per Event (MJ)	Fuel Consumption Per SA-Meal (g)	Fuel Consumption Per SA-Meal (MJ)	Standard Adults
Mean	83.6%	3.2	275	7.5	166	4.6	2.3
SD	2.2%	1.2	109	3.0	108	3.2	0.89
CoV	2.7%	36%	40%	40%	65%	70%	38%
N	23	23	23	23	23	23	23
95% CI	0.9%	0.47	44	1.2	44	1.3	0.36
Min	79.5%	1.5	87	2.5	45	1.3	0.80
Max	88.4%	5.6	525	16	538	16	4.6
Median	83.4%	2.8	267	7.0	139	3.7	2.1

Jikokoa

	MCE	Power (kW)	Fuel Consumption Per Event (g)	Fuel Consumption Per Event (MJ)	Fuel Consumption Per SA-Meal (g)	Fuel Consumption Per SA-Meal (MJ)	Standard Adults
Mean	88.2%	1.6	193	5.4	92	2.6	3.1
SD	3.4%	0.60	73	2.1	64	1.8	1.9
CoV	3.9%	37%	38%	38%	70%	70%	59%
N	33	33	33	33	33	33	33
95% CI	1.2%	0.20	25	0.70	22	0.61	0.63
Min	79.8%	0.62	101	2.8	24	0.67	0.50
Max	94.0%	3.6	405	11	315	8.8	8.9
Median	88.9%	1.6	169	4.7	84	2.3	2.6
% Diff*	**5%**	**-49%**	**-30%**	**-29%**	**-45%**	**-44%**	36%
p-value	**<0.05**	**<0.05**	**<0.05**	**<0.05**	**<0.05**	**<0.05**	0.051

*Statistically significant differences are bolded.

Table SM11. Kenya: Emission rate statistics

KCJ

	Emission Rates CO_2 g/min	Emission Rates CO g/min	Emission Rates $PM_{2.5}$ mg/min
Mean	17	2.1	60
SD	6.4	0.62	50
CoV	37%	30%	82%
N	23	23	23
95% CI	2.6	0.25	20
Min	7.7	1.0	10
Max	30	3.3	174
Median	15	2.1	40

Jikokoa

	Emission Rates CO_2 g/min	Emission Rates CO g/min	Emission Rates $PM_{2.5}$ mg/min
Mean	9.5	0.82	25
SD	3.6	0.38	23
CoV	38%	47%	89%
N	33	33	32
95% CI	1.2	0.13	7.8
Min	3.7	0.28	3.4
Max	22	1.7	105
Median	9.2	0.75	16
% Diff*	**-44%**	**-61%**	**-58%**
p-value	**<0.05**	**<0.05**	**<0.05**

Table SM12. Kenya: Emission factor statistics

KCJ

	g/kg			g/SA meal			g/MJ		
	CO_2	CO	$PM_{2.5}$	CO_2	CO	$PM_{2.5}$	CO_2	CO	$PM_{2.5}$
Mean	2488	309	8.3	414	50	1.5	90	11	0.31
SD	167	44	5.9	283	28	1.7	2.7	1.6	0.23
CoV	7%	14%	70%	69%	55%	111%	3%	14%	74%
N	23	23	23	23	23	23	23	23	23
95% CI	68	18	2.4	116	11	0.67	1.1	0.7	0.092
Min	2178	223	1.9	122	12	0.11	86	7.4	0.065
Max	2734	388	21	1431	120	6.0	95	14	0.83
Median	2495	300	6.3	338	44	0.81	90	11	0.24

Jikokoa

	g/kg			g/SA meal			g/MJ		
	CO_2	CO	$PM_{2.5}$	CO_2	CO	$PM_{2.5}$	CO_2	CO	$PM_{2.5}$
Mean	2740	234	7.4	252	21	0.64	98	8.4	0.27
SD	110	68	5.7	178	16	0.58	3.8	2.4	0.20
CoV	4%	29%	77%	70%	74%	92%	4%	29%	77%
N	33	33	32	33	33	32	33	33	32
95% CI	38	23	2.0	61	5.4	0.20	1.3	0.82	0.07
Min	2498	119	1.0	69	4.1	0.040	89	4.2	0.03
Max	2963	404	23	888	73	2.5	105	14.4	0.84
Median	2760	217	5.9	241	18	0.43	99	7.9	0.21
% Diff*	**10%**	**-24%**	-11%	**-39%**	**-57%**	**-57%**	**9%**	**-25%**	-14%
p-value	**<0.05**	**<0.05**	0.55	**<0.05**	**<0.05**	**<0.05**	**<0.05**	**<0.05**	0.47

*Statistically significant differences are bolded.

Table SM13. South Vietnam: Combustion efficiency and fuel consumption statistics.

South Vietnam Traditional Wood

	MCE	Power (kW)	Fuel Consumption Per Event (g)	Fuel Consumption Per Event (MJ)	Fuel Consumption Per SA-Meal (g)	Fuel Consumption Per SA-Meal (MJ)	Standard Adults
Mean	91.5%	4.4	771	12	356	5.4	3.2
SD	1.4%	1.8	358	5.6	385	6.3	1.5
CoV	1.6%	42%	46%	49%	108%	117%	47%
N	19	19	19	19	19	19	19
95% CI	0.6%	0.83	161	2.5	173	2.8	0.68
Min	88.4%	0.93	191	2.8	59	0.91	0.80
Max	94.5%	8.8	1588	23	1734	29	5.6
Median	91.5%	4.5	730	10	238	3.6	3.2

High Efficiency Stove (HES) - Wood

	MCE	Power (kW)	Fuel Consumption Per Event (g)	Fuel Consumption Per Event (MJ)	Fuel Consumption Per SA-Meal (g)	Fuel Consumption Per SA-Meal (MJ)	Standard Adults
Mean	88.9%	3.0	449	6.9	407	6.5	2.0
SD	4.4%	1.5	77	1.9	273	4.6	1.3
CoV	4.9%	48%	17%	27%	67%	70%	66%
N	4	4	4	4	4	4	4
95% CI	4.3%	1.4	75	1.8	268	4.5	1.3
Min	83.0%	1.0	354	4.3	93	1.1	0.80
Max	93.6%	4.4	532	8.7	666	11	3.8
Median	89.6%	3.3	454	7.3	435	7.0	1.6

High Efficiency Stove (HES)- Charcoal

	MCE	Power (kW)	Fuel Consumption Per Event (g)	Fuel Consumption Per Event (MJ)	Fuel Consumption Per SA-Meal (g)	Fuel Consumption Per SA-Meal (MJ)	Standard Adults
Mean	84.8%	3.2	411	8.7	157	3.3	3.3
SD	3.1%	1.0	118	1.8	78	1.7	1.4
CoV	3.7%	31%	29%	21%	50%	51%	42%
N	12	12	12	12	12	12	12
95% CI	1.8%	0.56	67	1.0	44	1.0	0.78
Min	78.3%	1.8	264	6.4	57	1.5	1.3
Max	89.3%	5.1	600	11	302	6.7	6.6
Median	85.4%	3.1	406	8.9	157	3.1	3.3
SV Traditional Wood versus HES Wood							
% Diff*	**-3%**	-31%	-42%	-40%	14%	20%	-39%
p-value	**<0.05**	0.18	0.10	0.13	0.81	0.75	0.14
SV Traditional Wood versus HES Charcoal							
% Diff*	**-7%**	**-27%**	**-47%**	-25%	-56%	-38%	3%
p-value	**<0.05**	**0.05**	**<0.05**	0.095	0.088	0.28	0.86

*Statistically significant differences are bolded.

Table SM14. South Vietnam: Emission rate statistics

South Vietnam Traditional Wood

	Emission Rates CO_2 g/min	Emission Rates CO g/min	Emission Rates $PM_{2.5}$ mg/min
Mean	29	1.7	162
SD	13	0.67	81
CoV	46%	39%	50%
N	19	19	19
95% CI	6.1	0.30	36
Min	6.6	0.24	12
Max	69	3.0	319
Median	29	1.9	160

High Efficiency Stove (HES) - Wood

	Emission Rates CO_2 g/min	Emission Rates CO g/min	Emission Rates $PM_{2.5}$ mg/min
Mean	19	1.3	109
SD	8.4	0.27	50
CoV	45%	21%	46%
N	4	4	4
95% CI	8.3	0.26	49
Min	7.5	1.0	38
Max	27	1.6	151
Median	20	1.3	124

High Efficiency Stove (HES) - Charcoal

	Emission Rates CO_2 g/min	Emission Rates CO g/min	Emission Rates $PM_{2.5}$ mg/min
Mean	19	2.2	63
SD	6.8	0.88	47
CoV	35%	40%	76%
N	12	12	12
95% CI	3.8	0.50	27
Min	8.3	1.4	22
Max	32	4.4	134
Median	18	2.0	36
SV Traditional Wood versus HES Wood			
% Diff*	-36%	-25%	-33%
p-value	0.15	0.24	0.23
SV Traditional Wood versus HES Charcoal			
% Diff*	**-34%**	29%	**-61%**
p-value	**<0.05**	0.091	**<0.05**

*Statistically significant differences are bolded.

Table SM15. South Vietnam: Emission factor statistics

South Vietnam Traditional Wood

	g/kg			g/SA meal			g/MJ		
	CO_2	CO	$PM_{2.5}$	CO_2	CO	$PM_{2.5}$	CO_2	CO	$PM_{2.5}$
Mean	1658	98	9.7	593	34	3.2	111	6.6	0.65
SD	41	16	3.8	643	35	3.1	8.6	1.1	0.25
CoV	2%	16%	40%	108%	105%	98%	8%	17%	39%
N	19	19	19	19	19	19	19	19	19
95% CI	18	7.1	1.7	289	16	1.4	3.9	0.49	0.11
Min	1584	65	0.78	93	5.7	0.12	98	4.4	0.055
Max	1765	132	17	2876	165	15	132	8.6	1.1
Median	1658	98	9.7	414	25	3.0	111	6.6	0.63

High Efficiency Stove (HES) - Wood

	g/kg			g/SA meal			g/MJ		
	CO_2	CO	$PM_{2.5}$	CO_2	CO	$PM_{2.5}$	CO_2	CO	$PM_{2.5}$
Mean	1615	128	9.5	670	43	3.7	107	8.9	0.63
SD	70	52	3.0	465	23	2.2	12.2	5.1	0.16
CoV	4%	41%	31%	69%	54%	60%	11%	58%	26%
N	4	4	4	4	4	4	4	4	4
95% CI	68	51	2.9	455	22	2.2	12.0	5.0	0.16
Min	1530	74	7.0	142	19	0.72	98	4.5	0.43
Max	1699	200	14	1131	72	6.0	125	16	0.83
Median	1615	119	8.8	704	41	4.1	103	7.4	0.63

High Efficiency Stove (HES) - Charcoal

	g/kg			g/SA meal			g/MJ		
	CO_2	CO	$PM_{2.5}$	CO_2	CO	$PM_{2.5}$	CO_2	CO	$PM_{2.5}$
Mean	2139	244	6.8	336	39	1.1	101	11	0.32
SD	110	47	4.6	170	22	1.0	15	1.9	0.22
CoV	5%	19%	67%	51%	58%	87%	15%	17%	68%
N	12	12	12	12	12	12	12	12	12
95% CI	62	27	2.6	96	13	0.55	8.4	1.1	0.12
Min	1947	173	2.1	127	13	0.18	79	8.6	0.11
Max	2269	349	16	640	81	3.4	129	14	0.71
Median	2162	239	5.1	340	35	0.91	102	12	0.23
SV Traditional Wood versus HES Wood									
% Diff*	-3%	**31%**	-2%	13%	28%	17%	-4%	36%	-3%
p-value	0.10	**<0.05**	0.93	0.82	0.62	0.75	0.45	0.06	0.87
SV Traditional Wood versus HES Charcoal									
% Diff*	**29%**	**150%**	**-30%**	-43%	15%	**-65%**	**-10%**	**73%**	**-51%**
p-value	**<0.05**	**<0.05**	**<0.05**	0.19	0.65	**<0.05**	**<0.05**	**<0.05**	**<0.05**

*Statistically significant differences are bolded.

Table SM16. North Vietnam: Combustion efficiency and fuel consumption statistics.

North Vietnam Traditional Wood

	MCE	Power (kW)	Fuel Consumption Per Event (g)	Fuel Consumption Per Event (MJ)	Fuel Consumption Per SA-Meal (g)	Fuel Consumption Per SA-Meal (MJ)	Standard Adults
Mean	91.3%	6.5	971	14	335	5.0	3.9
SD	2.9%	2.0	513	8.4	251	4.0	1.6
CoV	3.1%	31%	53%	58%	75%	80%	41%
N	16	16	16	16	16	16	16
95% CI	1.4%	1.0	251	4.1	123	2.0	0.79
Min	84.6%	3.3	350	4.4	112	1.5	1.6
Max	95.4%	9.8	2540	39	930	15	6.6
Median	90.7%	6.2	749	11	241	3.5	4.0

Rice Husk Gasifier – Low PM

	MCE	Power (kW)	Fuel Consumption Per Event (g)	Fuel Consumption Per Event (MJ)	Fuel Consumption Per SA-Meal (g)	Fuel Consumption Per SA-Meal (MJ)	Standard Adults
Mean	95.2%	4.7	958	14	337	4.8	3.3
SD	1.7%	1.7	446	6.3	159	2.3	1.2
CoV	1.7%	35%	47%	46%	47%	47%	36%
N	8	8	8	8	8	8	8
95% CI	1.1%	1.1	309	4.4	110	1.6	0.82
Min	93.1%	1.7	464	6.6	205	2.9	1.3
Max	97.0%	7.8	1988	28	710	10	5.1
Median	95.2%	4.7	843	12	299	4.3	3.2

Rice Husk Gasifier – High PM

	MCE	Power (kW)	Fuel Consumption Per Event (g)	Fuel Consumption Per Event (MJ)	Fuel Consumption Per SA-Meal (g)	Fuel Consumption Per SA-Meal (MJ)	Standard Adults
Mean	94.4%	4.9	869	12	378	5.4	3.0
SD	1.6%	1.7	223	3.1	201	2.8	0.50
CoV	1.7%	34%	26%	25%	53%	52%	16%
N	7	7	7	7	7	7	7
95% CI	1.2%	1.2	165	2.3	149	2.1	0.37
Min	92.1%	3.3	549	7.8	196	2.8	2.6
Max	96.9%	8.3	1102	16	776	11	3.9
Median	94.8%	4.3	897	13	291	4.1	2.8
NV Traditional Wood versus RHG – Low PM							
% Diff*	**4%**	**-27%**	-1%	-6%	1%	-4%	-16%
p-value	**<0.05**	**<0.05**	0.95	0.58	0.98	0.89	0.34
NV Traditional Wood versus RHG – High PM							
% Diff*	**3%**	-25%	-11%	-14%	13%	8%	-22%
p-value	**<0.05**	0.078	0.62	0.54	0.69	0.82	0.17

*Statistically significant differences are bolded.

Table SM17. North Vietnam: Emission rate statistics

North Vietnam Traditional Wood

	Emission Rates CO_2 g/min	Emission Rates CO g/min	Emission Rates $PM_{2.5}$ mg/min
Mean	43	2.5	373
SD	13	0.9	367
CoV	30%	36%	98%
N	16	16	16
95% CI	6.5	0.44	180
Min	26	1.0	123
Max	71	4.2	1570
Median	44	2.5	269

Rice Husk Gasifier – Low PM

	Emission Rates CO_2 g/min	Emission Rates CO g/min	Emission Rates $PM_{2.5}$ mg/min
Mean	28	0.95	81
SD	9.6	0.56	80
CoV	34%	60%	98%
N	8	8	8
95% CI	6.6	0.39	55
Min	10.5	0.26	2.9
Max	46	2.0	197
Median	29	0.81	52

Rice Husk Gasifier – High PM

	Emission Rates CO_2 g/min	Emission Rates CO g/min	Emission Rates $PM_{2.5}$ mg/min
Mean	27	1.0	852
SD	9.5	0.44	377
CoV	35%	42%	44%
N	7	7	7
95% CI	7.0	0.33	279
Min	17	0.44	348
Max	46	1.8	1495
Median	25	0.95	862
NV Traditional Wood versus RHG – Low PM			
% Diff*	**-35%**	**-63%**	**-78%**
p-value	**<0.05**	**<0.05**	**<0.05**
NV Traditional Wood versus RHG – High PM			
% Diff*	**-37%**	**-59%**	**129%**
p-value	**<0.05**	**<0.05**	**<0.05**

*Statistically significant differences are bolded.

Table SM18. North Vietnam: Emission factor statistics

North Vietnam Traditional Wood

	g/kg			g/SA meal			g/MJ		
	CO_2	CO	$PM_{2.5}$	CO_2	CO	$PM_{2.5}$	CO_2	CO	$PM_{2.5}$
Mean	1634	98	14	550	34	3.8	113	6.8	1.02
SD	73	32	14	415	28	2.6	12	2.3	1.08
CoV	4%	32%	94%	76%	81%	69%	11%	34%	106%
N	16	16	16	16	16	16	16	16	16
95% CI	36	15	6.6	203	14	1.3	5.8	1.1	0.53
Min	1466	51	5.8	183	6	0.72	98	3.2	0.36
Max	1731	169	60	1515	101	11	131	11	4.8
Median	1647	105	9.4	394	28	3.3	109	6.8	0.66

Rice Husk Gasifier – Low PM

	g/kg			g/SA meal			g/MJ		
	CO_2	CO	$PM_{2.5}$	CO_2	CO	$PM_{2.5}$	CO_2	CO	$PM_{2.5}$
Mean	1420	46	3.7	478	16	1.3	100	3.2	0.26
SD	29	16	3.3	217	12	1.4	1.8	1.1	0.23
CoV	2%	34%	91%	45%	73%	109%	2%	34%	91%
N	8	8	8	8	8	8	8	8	8
95% CI	20	11	2.3	150	8.0	0.99	1.3	0.76	0.16
Min	1376	28	0.15	289	8.5	0.048	97	2.0	0.010
Max	1453	65	9.8	980	44	3.9	102	4.5	0.68
Median	1430	46	2.8	429	12	0.70	100	3.2	0.20

Rice Husk Gasifier – High PM

	g/kg			g/SA meal			g/MJ		
	CO_2	CO	$PM_{2.5}$	CO_2	CO	$PM_{2.5}$	CO_2	CO	$PM_{2.5}$
Mean	1335	51	44	504	19	15	93	3.6	3.1
SD	73	16	23	266	11	5.8	3.8	1.0	1.6
CoV	5%	31%	53%	53%	57%	39%	4%	29%	51%
N	7	7	7	7	7	7	7	7	7
95% CI	54	12	17	197	7.9	4.3	2.8	0.77	1.2
Min	1225	26	21	240	7.7	5.9	86	1.9	1.5
Max	1463	74	86	1028	41	23	97	4.9	5.7
Median	1325	47	37	388	16	16	93	3.3	2.6
NV Traditional Wood versus RHG – Low PM									
% Diff*	**-13%**	**-54%**	**-75%**	-13%	-54%	**-65%**	**-12%**	**-53%**	-75%
p-value	**<0.05**	**<0.05**	**<0.05**	0.65	0.09	**<0.05**	**<0.05**	**<0.05**	0.063
NV Traditional Wood versus RHG – High PM									
% Diff*	**-18%**	**-48%**	**209%**	-8%	-45%	**288%**	**-18%**	**-48%**	**201%**
p-value	**<0.05**	**<0.05**	**<0.05**	0.79	0.18	**<0.05**	**<0.05**	**<0.05**	**<0.05**

*Statistically significant differences are bolded.

Appendix B: Fuel Analysis

Results of fuel analysis are shown in Table for wood pellets from India, rice husks from Northern Vietnam, and charcoal from Benin, Southern Vietnam, and Kenya. Fuel testing was carried out by Colorado State University in Fort Collins.

Table SM19. Fuel Analysis results for tested fuels.

	Pellets (India)	Rice Husk (N. Vietnam)	Charcoal (Benin)	Charcoal (S. Vietnam)	Charcoal (Kenya)
Ash (%)	1.8	18 ± 1.8	4.9 ± 1.1	6.2 ± 4.1	3.7 ± 2.4
Total Carbon (%)	46	41 ± 0.5	68 ± 5.4	71 ± 4.6	87 ± 3.8
Total Nitrogen (%)	0.04	0.45 ± 0.04	0.35 ± 0.13	0.67 ± 0.38	-
LHV (MJ/kg)	17.8	15.8 ± 1.4	30.8 ± 1.6	30.5 ± 2.1	29 ± 3.5

Notes: Percent mass is presented on a dry basis. Low heating value (LHV), used to convert mass to energy equivalents, were estimated by subtracting 1.32 MJ for wood, and 0.76 MJ/kg for charcoal, as assumed by Jetter et a.[8]. ± represents the standard deviation of tested samples. Pellets from India were batch analyzed so variability in fuel metrics is not available.

Table SM20. Default fuel characteristics for non-tested fuels (moisture content was measured for wood).

	Wood	Kerosene	Paper	Plastic	Palm	Dung	Charcoal
Carbon (%)	50 ± -	84 ± -	50 ± -	85 ± -	50 ± -	50 ± -	87± 3.8
HHV (kJ/kg)	19 ± -	40 ± -	19 ± -	40 ± -	13± -	12 ± -	28 ± 3.5
Moisture (%)	-	0	5 ± -	0	10 ± -	10 ± -	2.3 ± 0.95

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