In-Home Assessment of Greenhouse Gas and Aerosol Emissions from Biomass Cookstoves in Developing Countries

Extended Abstract #34

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INTRODUCTION

Climate forcing emissions from residential cookstoves are not well characterized, even though nearly half the world's population still relies on solid fuels for their primary energy needs[1]. Emissions data from normal daily cooking are especially sparse, with the majority of data derived from water boiling tests (WBTs) conducted in a laboratory setting[2-5].

Of recent interest has been the potential for improved stoves to reduce black carbon (BC) emissions, as household biofuel use is thought to produce approximately one-fourth of total anthropogenic BC emissions[6]. Reducing particulate emissions with high BC content has been proposed to immediately slow global warming since the atmospheric life of black carbon is days to weeks, in contrast to other GHGs which can persist for decades or centuries[7, 8].

This study aims to begin filling these gaps by presenting emissions estimates of CO_2, CO, CH_4, total non-methane hydrocarbons (TNMHC), and particulate matter (characterized by black and organic fractions), from stoves in Uganda, Nepal, and India.

EXPERIMENTAL METHODS

Stoves and Study Sites

The study in Uganda funded by USAID and was conducted in Ruhiira, which is one of the 14 Millennium Village sites across Africa. The intervention stove was the rocket-style, wood burning StoveTec (Oregon, USA). The studies in Nepal and India were part of a field assessment and capacity building program funded by the USEPA and overseen by the Partnership for Clean Indoor Air. The Nepal intervention stove (Improved Biomass Cookstove [IBC]) was a built-in place chimney, wood-burning stove (Center for Rural Technology, Nepal), and in India the intervention stove was the Oorja, a mass manufactured, forced air gasifier stove (First Energy, Pune, India), which burned pellets composed of sugarcane residue.

Figure 1: From left to right: Traditional three-stove fire and StoveTec in Uganda; traditional chulha and Improved Biomass Cookstove in Nepal; and traditional chulha and Oorja in India.

Sampling and analysis

Sampling was conducted in homes during normal daily cooking events. Participants were asked to cook their regular meals and use their normal fuel and fire tending practices. No fuel was provided and all fuels were weighed before and after the cooking event. Emissions were collected in the plume above the stove and analyzed for carbon dioxide (CO_2), carbon monoxide (CO), methane (CH_4), total non-methane hydrocarbons (TNMHCs), and particulate matter ($PM_{4.0}$). $PM_{4.0}$ samples were analyzed for the relative compositions of elemental and organic carbon. Elemental carbon was assumed to be black carbon. Emission factors were determined using the carbon balance approach [9, 10].

Climate impacts in terms of CO_2-equivalent (CO_2e) were estimated using 100 year GWPs. The GWPs used for CO_2 and CH_4 (1 and 25, respectively) were those published in the IPCC's 2007 report [11], and the GWP for TNMHC (11) is from the IPCC's 1990 report [12] [a]. The IPCC reports a range of 100-year GWPs for CO from 1.0 to 3.0 with a mean of 1.9 [11], which was used here. The 100-year GWPs for BC (660) and OM (-30) are from the Bond Research Group [8, 13].

RESULTS

Modified combustion efficiency (MCE=[CO_2/CO_2+CO)] as carbon), fuel-based emission factors, and BC ratios are presented in Table 1. The intervention stoves in Uganda and Nepal had similar MCEs in comparison to their respective traditional stoves (93-94%). The StoveTec in Uganda and the IBC in Nepal also had similar or higher emission factors for CO and PM, indicating they did not burn fuel more cleanly than the traditional stoves they are meant to replace. The Oorja did perform better than the traditional chulha in India, with an MCE of ~96% and a PM emission factor 4.5 times lower.

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[a] GWPs for TNMHC are not presented in later IPCC assessments.

Table 1. Combustion efficiency, emission factors, and black carbon ratios.

Stove	N		MCE $\left(\frac{CO_2}{CO_2+CO}\right)$	Emission factors (gram/kg fuel)							BC/ TC	BC/ PM
				CO_2	CO	CH_4	TNMHC	PM	OC	BC		
Uganda traditional	20	mean	0.933	1557	72	4.5	2.4	9.6	5.5	0.6	0.11	0.07
		sd	0.013	36	13	3.4	2.2	3.6	2.5	0.4		
Uganda StoveTec	30	mean	0.931	1633	77	5.1	3.9	13.3	6.5	2.0	0.26	0.15
		sd	0.024	42	26	4.1	4.3	6.3	3.7	1.3		
Nepal traditional	15	mean	0.940	1578	64	4.1	14.1	5.2	3.3	0.7	0.15	0.14
		sd	0.023	41	25	3.0	3.2	2.4	2.0	0.3		
Nepal Improved Biomass	7	mean	0.934	1711	77	*	*	5.9	3.4	0.8	0.21	0.14
		sd	0.014	41	17	-	-	2.7	1.7	0.6		
India traditional	12	mean	0.930	1267	62	7.4	8.6	8.8	3.9	0.7	0.18	0.08
		sd	0.018	101	17	5.8	8.0	4.0	2.5	0.3		
India Oorja	18	mean	0.955	1661	50	3.4	8.2	1.9	0.7	0.1	0.22	0.06
		sd	0.026	33	30	1.4	3.3	0.7	0.4	0.1		

*Samples for analysis of CH_4 and TNMC's were not collected for the Nepal IBC.

The climate impacts were estimated by converting each emission factor to CO_2e and multiplying by the fuel consumption per person-meal. Figure 1 shows the CO_2e estimates, with the relative contributions from emissions species differentiated. All three intervention stoves produced less CO_2e per meal on average than their traditional counterparts, with the Oorja emitting 52% less CO_2e per meal. The lower CO_2e emission estimates for the StoveTec and Nepal IBC were primarily a result of lower fuel consumption per meal (42% and 30% less than their traditional counterparts, respectively), whereas the Oorja used less fuel and combusted the fuel more completely.

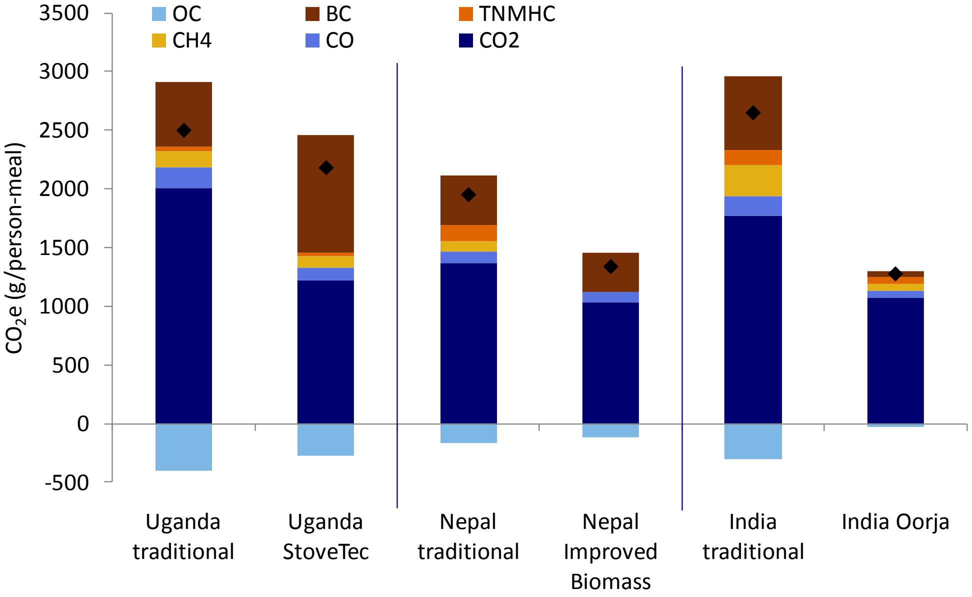

Figure 2. CO_2e emission factors per person-meal.

Products of incomplete combustion contributed substantially to the net CO_2e, accounting for 19-55% of the climate impact across stoves, even under the assumption that fuel is non-renewably harvested and thus CO_2 is included in the CO_2e estimates[b]. Among the products of incomplete combustion, black carbon generally had the largest contributions to net-CO_2e (up to 37%).

DISCUSSION

Implications for BC impacts

Figure 3 shows the stoves' PM emission factors with their respective fractions of BC composition. Only the Oorja had a lower PM emission factor and lower composition of BC compared to its traditional counterpart, whereas the StoveTec actually increased BC emissions by two fold per kg fuel. This trend was observed under laboratory conditions for a similar prototype rocket stove, for which the BC content of PM from the rocket stove (68%) was also approximately double that of a traditional three-stone fire (38%) [14]. These results highlight the need for more emissions assessments of stove technologies' impacts on BC emissions to help identify which are most promising for making meaningful BC reductions.

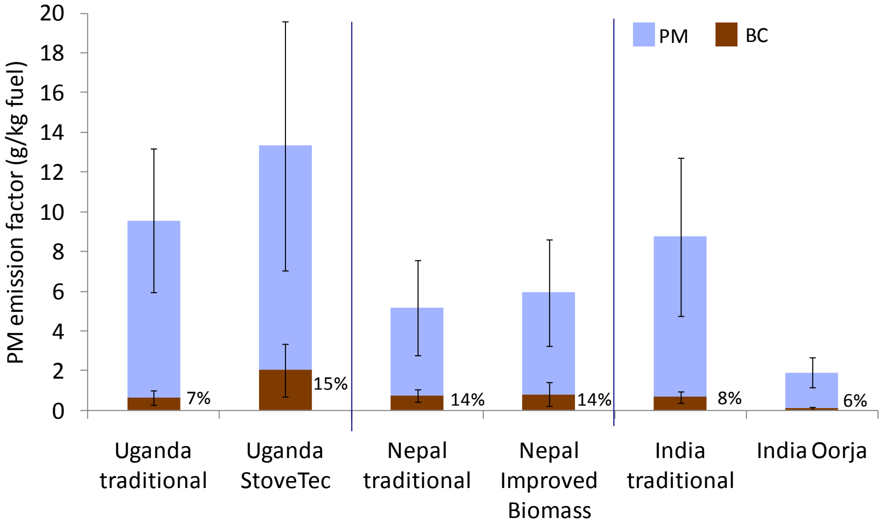

Figure 3. PM emission factors and relative compositions of BC, presented as percentages.

Importance of field testing

Figure 4 shows that the 93-94% modified combustion efficiencies measured in this study for the traditional open-fire stoves during normal daily cooking (highlighted in blue) are lower than the 96-97% reported during laboratory tests using WBTs reported from several studies [2-4, 9, 15, 16], which indicates approximately double the products of incomplete combustion were emitted per kg fuel used during normal use compared to the WBT. This discrepancy reinforces the need to study and report emission factors measured during normal daily cooking, as those derived from

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[b] This assumption is least likely for the Oorja as its pellet fuel is made from sugar cane residues, although there are additional CO_2 emissions associated with the production and distribution of pellets, which are not included here.

WBTs may produce errors in emission inventories used for climate models, as well as emission factors used for carbon offset calculations.

The reasons for these discrepancies likely arise from differences in fuel conditions and tending practices. Fuelwood is often more irregular, larger, and higher in moisture content in homes than that used for WBTs. Fires are also often left unattended while users conduct other tasks. Fuel loading is also generally higher during normal use than during WBTs, which can reduce combustion efficiency, especially for stoves designed to take smaller amounts of fuel.

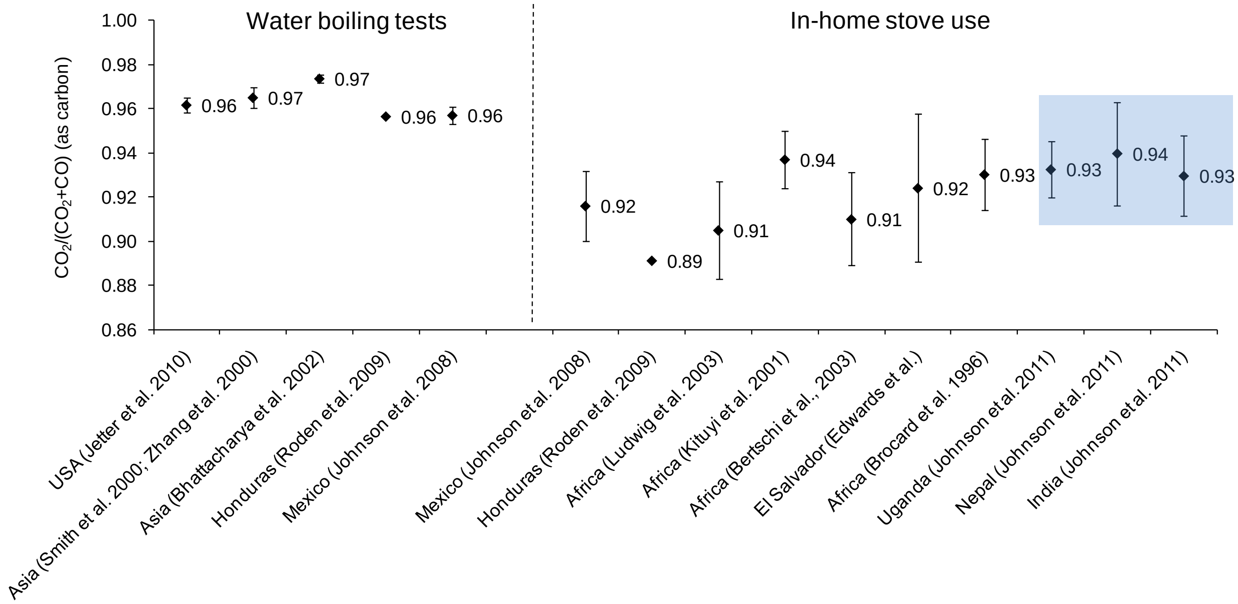

Figure 4. Modified combustion efficiencies ($CO_2/[CO_2+CO]$) for traditional open-fire stoves. Results from this study are highlighted in blue.

SUMMARY

The emissions estimates from this study indicate that both traditional and intervention stoves can emit large quantities of CO_2e as products of incomplete combustion, with black carbon contributing up to 37% of the net impact even when all CO_2 is included. The relative CO_2e contributions across stove types, however, vary substantially, highlighting the need to carefully evaluate stove emissions in the field to assess potential climate impacts. Assessment of a wider range of cooking solutions, including clean fuels (e.g. LPG, ethanol, biogas, kerosene, and plant oils), advanced stoves (e.g. forced air, gasifier, TLUD, and pyrolytic), rocket stoves, and others would provide a valuable database of emissions factors, as well as means to compare different stove technologies' performance under realistic conditions. Finally, efforts to better connect laboratory and field performance of stoves would greatly aid efforts in stove design, developing protocols for stove standards, and increasing the overall relevance of stove performance testing.

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A report on the USAID funded study can be found at: http://www.usaid.gov/our_work/economic_growth_and_trade/energy/publications/uganda_emissions_report.pdf.
A presentation on the field performance assessment of the USEPA funded project can be found at: http://www.pciaonline.org/files/PCIA_Aug11_Webinar_FieldTestResults_FINAL.pdf.

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