In-field charcoal stove emission factors and indoor air pollution in Nairobi, Kenya

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Introduction

- Kenya's household energy sources resemble those of Sub-Saharan Africa and the rest of the developing world
  - Kerosene: 5.9 million homes (of ~6.2 million total)
  - Charcoal: 2.8 million homes
  - Fuelwood: 4.0 million homes

  (HEDON 2008)
- There is much potential to reduce greenhouse gas emissions and exposure to health damaging pollutants by promoting a switch to improved stoves and cleaner burning fuels

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Purpose

- Determine in-field emission factors of health-damaging pollutants and greenhouse gases for charcoal stoves (in households in Nairobi)
  - carbon dioxide (CO_2)
  - methane (CH_4)
  - total non-methane hydrocarbons (TNMHC)
  - carbon monoxide (CO)
  - particulate matter (PM)
  - sulfur dioxide (SO_2)

  → Compare to IPCC default emission factors and other published data
- Simultaneously measure indoor air pollution levels
  - CO, $PM_{2.5}$, SO_2, HCHO (formaldehyde)
  - Compare to WHO and US EPA guidelines to clarify health risks

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Methods: Overview & Design

- 4 households
  - 3 controlled cooking tests (ugali)
  - 1 typical evening meal
- Approach isolates impact of stove by minimizing other household factors
- New jiko (improved) charcoal stove, charcoal, and pot (for CCT) given to each household
  - lit for at least 3 hours before testing to volatize residual water and other volatile compounds in the stove

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Methods: Emissions Sampling

- Emissions collected directly above stove with 3-pronged aluminum sampling probe
- 3-sided aluminum curtain placed around stove to minimize impacts from air currents
- Sample split into two lines:
  - Emission sample collection bag
  - Real-time CO-CO_2 monitor, followed by SO_2 monitor
- Another sample was collected to correct emissions for background concentrations
- Aliquots of emissions and background samples transferred to metal-coated multilayer Tedlar (MMT) bags
  - GC analysis of CO_2, CO, CH_4, and TNMHC (UC Irvine)
- Teflon filters inserted in-line to determine PM emissions
- These sampling methods were validated relative to controlled flow hoods

  (Johnson, Edwards, et al., ES&T, in press)

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Methods: CO_2-equivalent Emissions

- How do we use in-field measurements to estimate carbon emissions?
- $$CO_2e = \sum GWP_i \times GHG_i$$
  - GWP_i is the 100 year global warming potential of each gas (relative to CO_2)
  - GHG_i is the quantity of each greenhouse gas emitted
  - To determine net emissions (i.e. carbon credits), must multiply by non-renewability fraction of the biomass (X_{nrb})

- Methodologies and allowable set of greenhouse gases:
  - CO_2e (Gold Standard/Kyoto/CDM): CO_2 (1), CH_4 (21) *(IPCC/Solomon 2007)*
  - CO_2e (full list): CO_2 (1), CH_4 (21), CO (3), TNMHC (10) (*IPCC 1990)*
    - Black carbon analyses pending

- Emissions from charcoal making are not included here

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Methods: Indoor Air Measurements

- Simultaneous with emissions measurements
- Instruments installed 1.0 meter from the center of the stove and 1.5 m above the ground
- $PM_{2.5}$: Pump and filter method and real-time measurements (TSI DustTrak 8520)
- Real-time SO_2: RKI SC-01 (RKI Instruments, USA)
- Real-time CO: Draeger PAC III (Draeger, Germany)
- HCHO (formaldehyde): collected with Waters Sep Pak aldehyde cartridges (Waters Corp., USA); analyzed by HPLC by Berkeley Analytical Associates (Berkeley, CA, USA)
- Statistical analyses performed on SAS version 9.1 using general linear models (Proc GLM) with repeated measures, when appropriate, to account for repeated tests within the same households

Results: Emissions

	unit	CCT	Meal	IPCC
# HHs	---	12	4	---
NCE	%	81.2 ± 2.9	75.6 ± 3.4	---
CO_2	g/kg	2543 ± 113	2394 ± 103	3304*
CH_4	g/kg	14.3 ± 5.6	15.0 ± 3.8	10**
CO	g/kg	273.2 ± 54.5	350.5 ± 68.5	(134)***
TNMHC	g/kg	29.9 ± 13.6	53.4 ± 10.2	(7)***
PM	g/kg	14.07 ± 5.31	15.89 ± 7.69	---
SO_2	g/kg	0.06 ± 0.04	0.05 ± 0.05	---

NCE=nominal combustion efficiency
* IPCC: Stationary combustion of charcoal in residential category (emission inventory expert panel)
** IPCC: Charcoal stoves, residential source (experimental studies on traditional and improved stoves: Bhattacharya et al., 2002; Smith et al. 1992, 1993, 2000)
*** Bertschi et al., 2003 (charcoal stoves)

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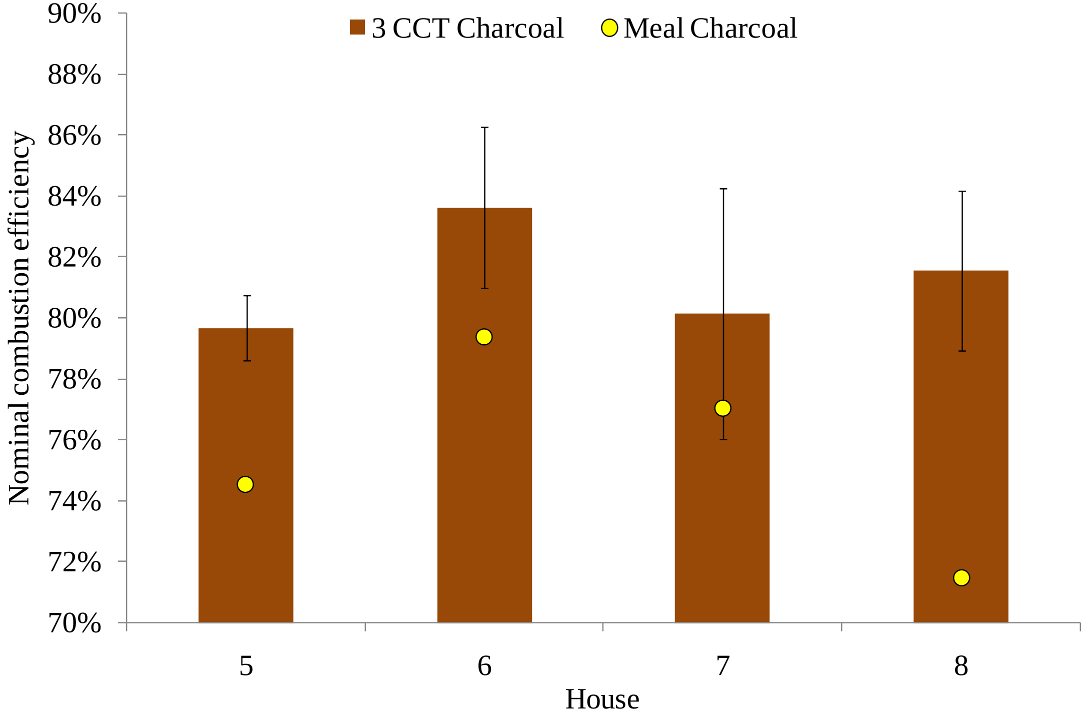
Results: Emissions (CCT vs. Meal)



Comparison	N	NCE (p value)	PM (p value)	SO_2 (p value)
CCT vs. Meal	8	**<u>0.035</u>**	0.606	0.884

- CCT and meal emissions compared using paired sample Student's t-tests of significance

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Results: CO_2e Emissions

- Assuming non-renewable harvesting of charcoal

Test	N	CO_2e (full) (kg/kg)	CO_2e (Kyoto) (kg/kg)
CCT	12	3.96 ± 0.41	2.84 ± 0.36
Meal	4	4.29 ± 0.36	2.71 ± 0.27
IPCC	---	4.0	3.5

Discussion

- Current methodologies for carbon credit estimation exclude some significant greenhouse gases in charcoal-burning (biomass) households
- Emission factors not systemically different from IPCC default values for residential charcoal (CO_2 EF lower, CH_4 EF higher)

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Results: Indoor Air Pollution

	Unit	CCT	Meal	All Day	Guideline
# of HHs	---	12	4	4	-----
$PM_{2.5}$	μg/m^3	385 ± 96	294 ± 271	156 ± 30	75* (24-hour,Interim Target 1)
SO_2	ppm	0.02 ± 0.05	0.02 ± 0.02	0.00 ± 0.00	0.19* (10-minute)
CO	ppm	85 ± 35	96 ± 25	36 ± 13	90* (15-minute)
HCHO	μg/m^3	64 ± 20	NA	NA	130** (15-minute)

* WHO Guideline

** US NIOSH Guideline

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Discussion

- Particulate matter continues to be the most significant health threat, even for charcoal stoves.
- Monitoring studies of improved, affordable charcoal and biomass stoves are ongoing; further field results coming in the next year.

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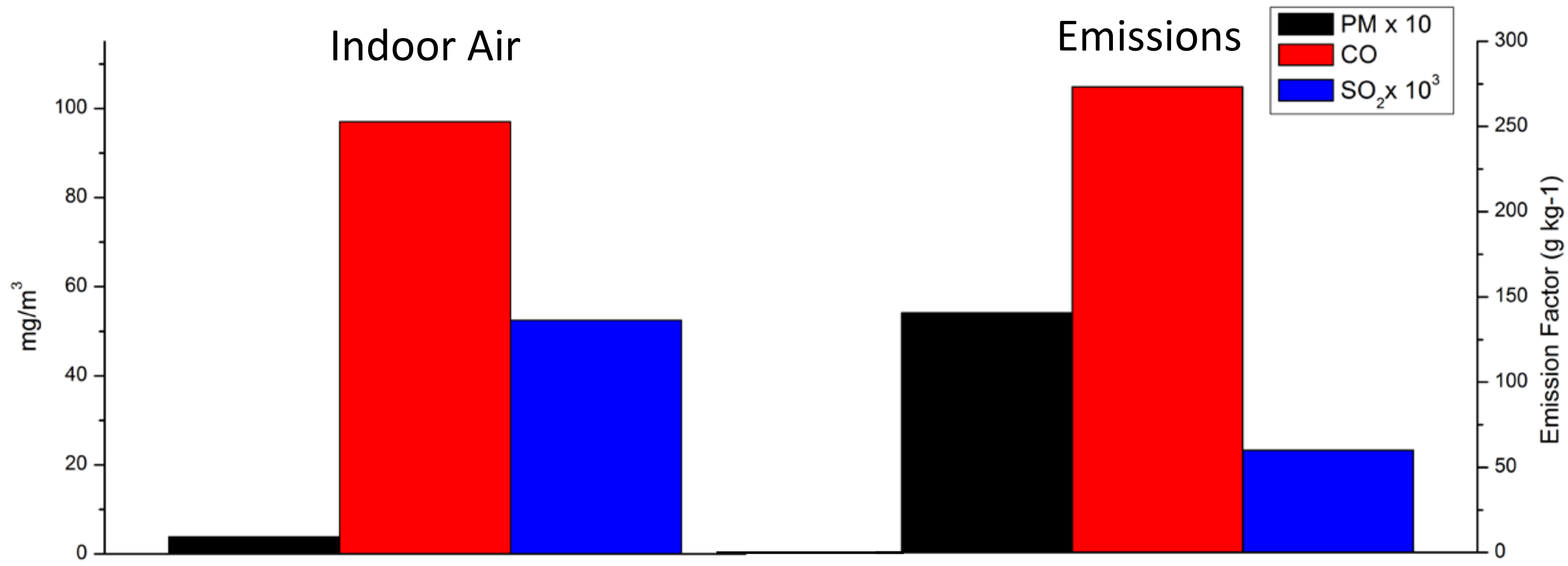
Results: Comparison Between Emissions and Indoor Air Pollution



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Discussion

- Points to value of monitoring both controlled cooking tests and typical, uncontrolled meals in households
- Useful for modeling relationship between emissions and indoor air concentrations (and guideline setting)

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