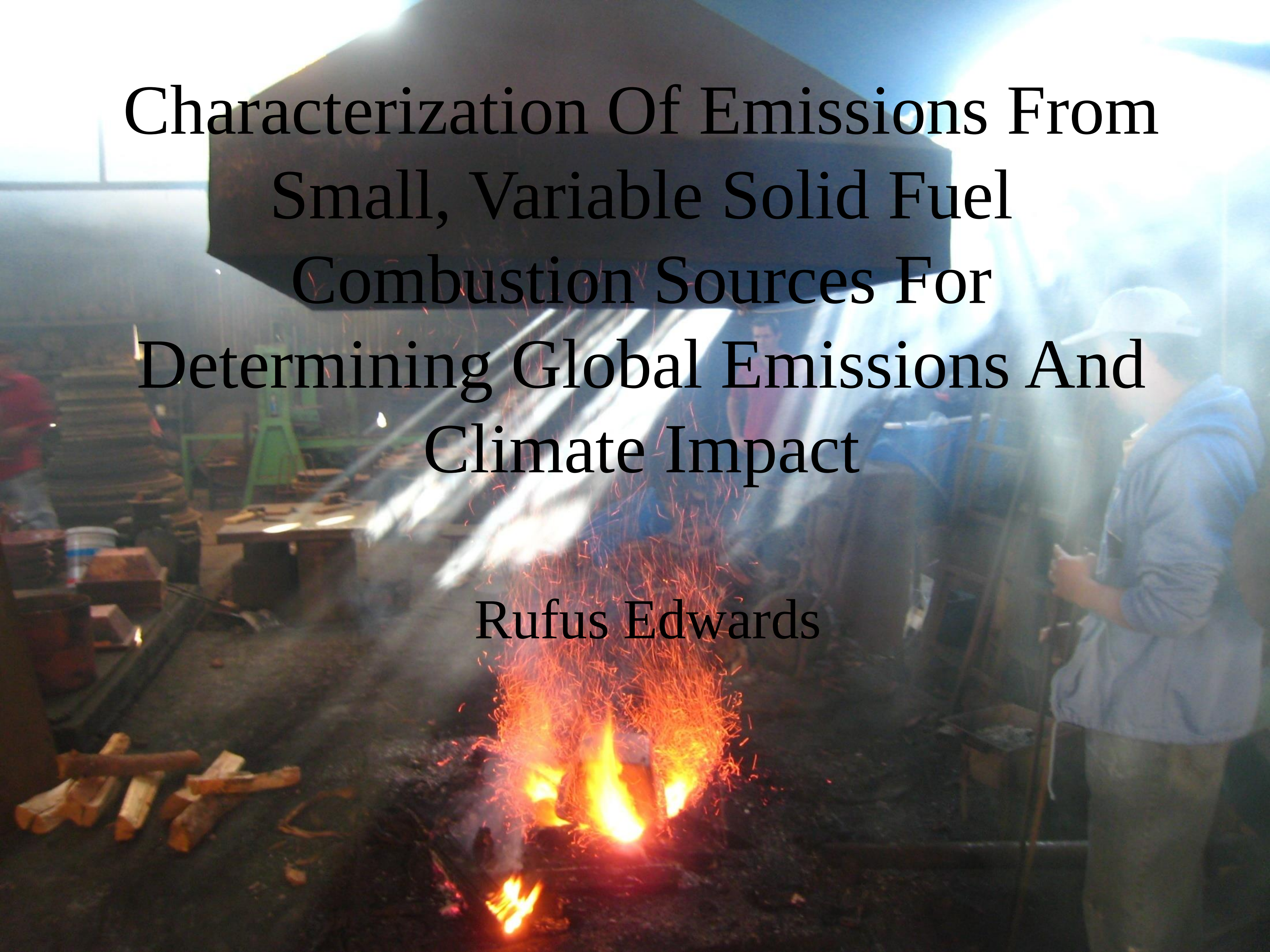
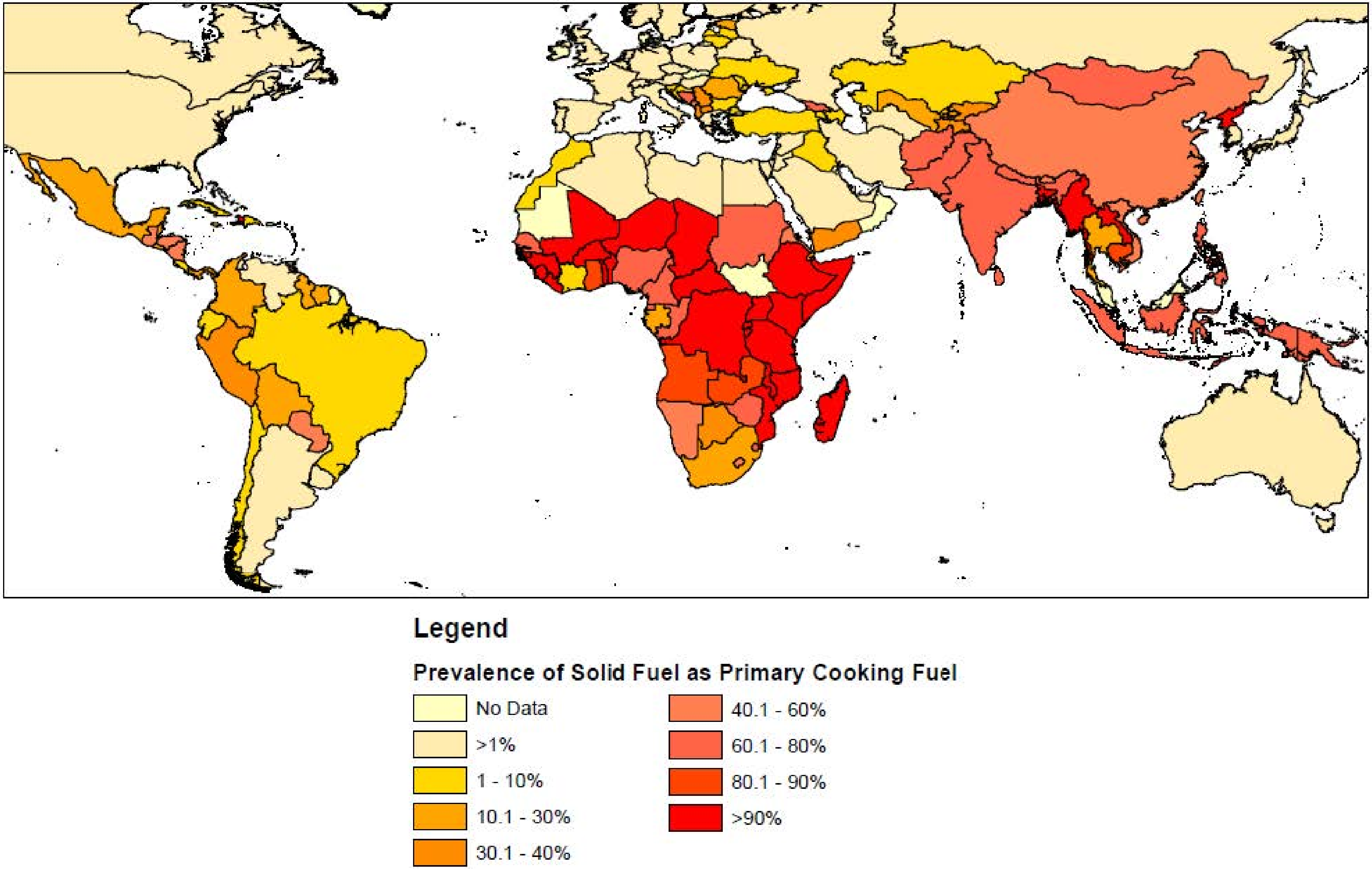


Characterization Of Emissions From Small, Variable Solid Fuel Combustion Sources For Determining Global Emissions And Climate Impact

Rufus Edwards

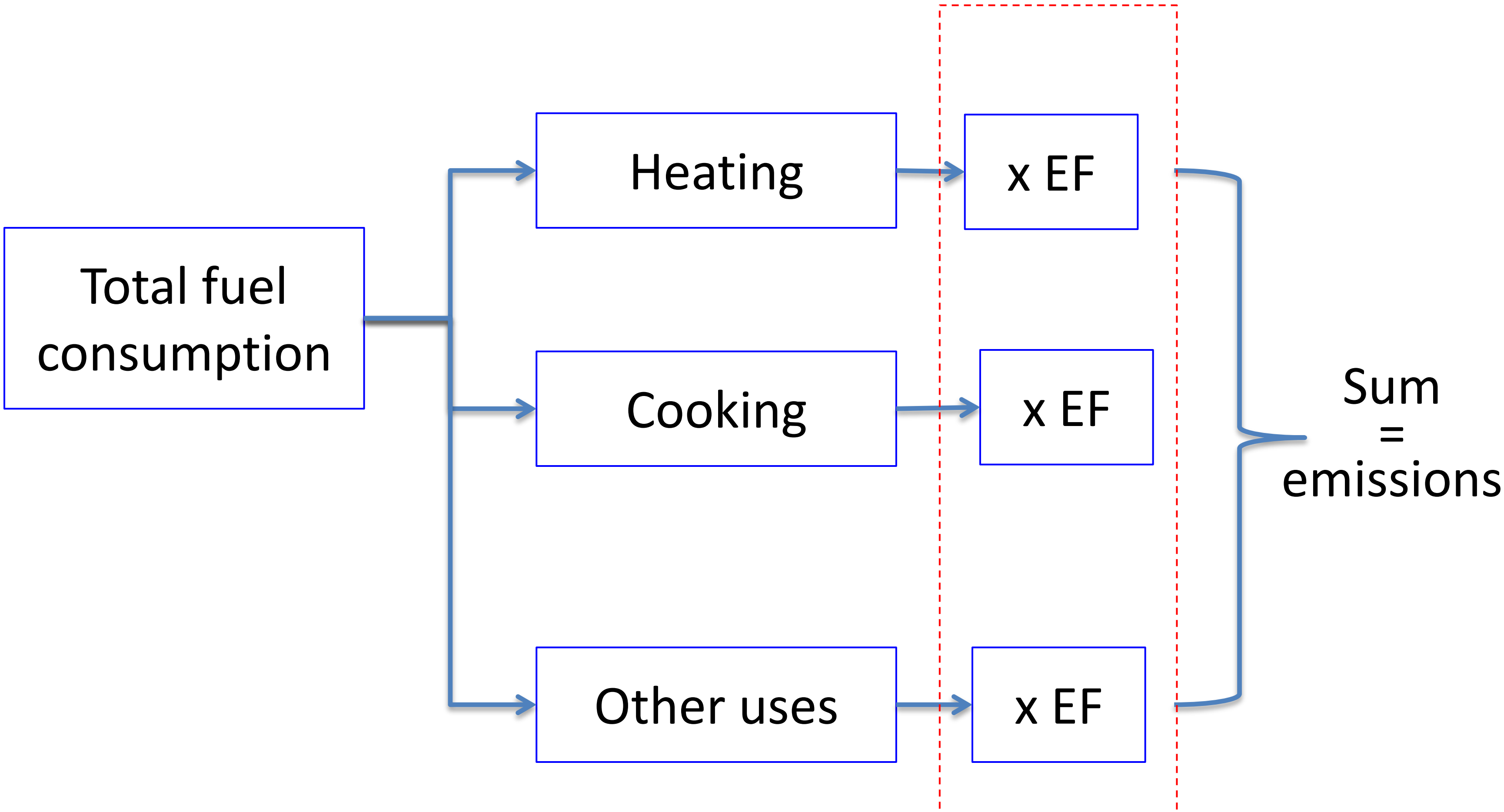
Use of solid fuel as primary cooking fuel



available data for ~82% of the world's population, of which approximately 51% (3.1 billion individuals) cook primarily with solid fuels.

Emission inventory procedure

and all we need to improve



Fuel use based on surveys & extrapolations; no formal records. Not well constrained

Division done loosely, or not done at all.

Few field measurements

Where were we when this project started?

- Focus on urban areas
- Systematic under representation of atmospheric PM concentrations by bottom up models
- SPEW (AR5)
- Used in-field EF for BC and OC from one study.
- GAINS
- Used highest PM emission, from heating stove in New Zealand, multiplied by BC fraction.
- EDGAR
- Took emission factors from SPEW. Not clear how technologies are chosen and EFs are translated.

Previous state of emissions factors

In field emission factors for household stoves during daily cooking activities.

Fuel		Stove classification		Emission factors (g/kg fuel) CO_2	CO	CH_4	TNMOC	PM	BC	NCE
Biomass-	Wood	Traditional Unvented	Local	1509	87.2	5.0	10.0	7.4	0.7	93.4
				(1672-1267) 6	(145-25.66) 12	(7.4-2.8) 5	(14.85-2.4) 4	(11.7-5) 11	(0.7-0.6) 3	(94-93) 19
		Improved Unvented	Local	1711	74.5			3.3	1.4	93.4
				(1711) 1	(77-72) 2			(5.9-1.2) 6	(2.145-0.8) 5	(93.4) 6
			Natural	1672	74.5	5.1	3.9	4.8	1.5	93.3
				(1711-1633) 2	(88.6-47) 10	1.0	1.0	(13.3-1.2) 14	(2.145-0.8) 6	(93.4-93.1) 14
			Forced	1661	50.0	3.4	8.2	1.9	0.1	95.5
				1	1	1	1	1	1	1
		Improved Vented	Local	1628	40.9	2.5		5.6		93.4
				(1764-1452) 4	(65.33-16.33) 5	(4.4-0.93) 4		1.0		1
	Charcoal	Improved Unvented	Local	2469	311.9	14.7	41.7	15.0		78.4
				(2543-2394) 2	(350.5-273.2) 2	(15.0-14.3) 2	(53.4-29.9) 2	(15.9-14.1) 2		(81.2-75.6) 5
Liquid-	Kerosene	Improved Unvented	Local		11.0				90	
					1				1	
Gas-	LPG/NG	Improved Unvented	gas burner	2848	9.4	0.032				
				(3440-1390) 4	(19.1-0.3) 3	(0.044-0.012) 3				

Number after parentheses indicates number of stoves

We only had emissions factors for a handful of stoves in Central America, and only for using wood fuels

WHO Indoor Air Quality Guidelines: Household fuel Combustion.
Chapter 4: Emissions of Health-Damaging Pollutants from Household Stoves


11/27/2011 14:49
11/27/2011 14:25

Field sites

Northern India; International Clinical Epidemiology Network (INCLEN) SOMAARTH demographic surveillance site. Palwal District - 51 villages - 200,000+ people 77% use biomass - 94% gather fuel. Almost all outdoor cooking using dung, crop residues, and wood, Phillips forced draft advanced combustion stove

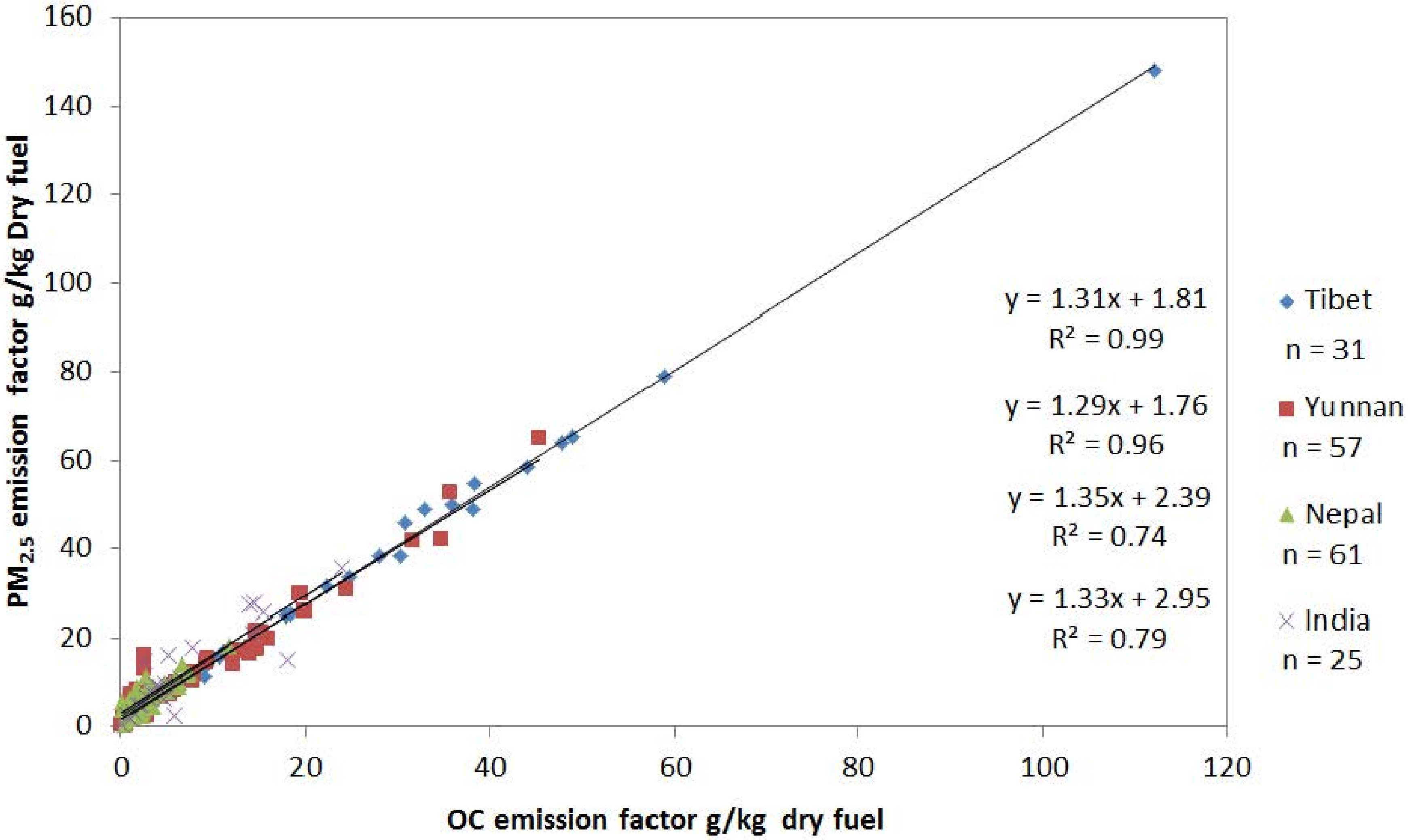
China-Tibet; Nam CO high altitude research station; Linzhi. local nomadic populations and communities that primarily use yak dung and wood as fuel. Fuel types measured represent ~ 95% of household energy consumption.

Nepal; Center for Rural Techology Nepal - Midhills and plains regions. Fuel use is predominantly wood 74%, dung 8%, and kerosene 3.5 %. Fuel types measured represent ~85% of household energy consumption.

China -Yunnan; Chinese CDC and NCI group working on cancer, coal smoke and gene environment interactions. Fuel types measured represent ~89% of household energy consumption

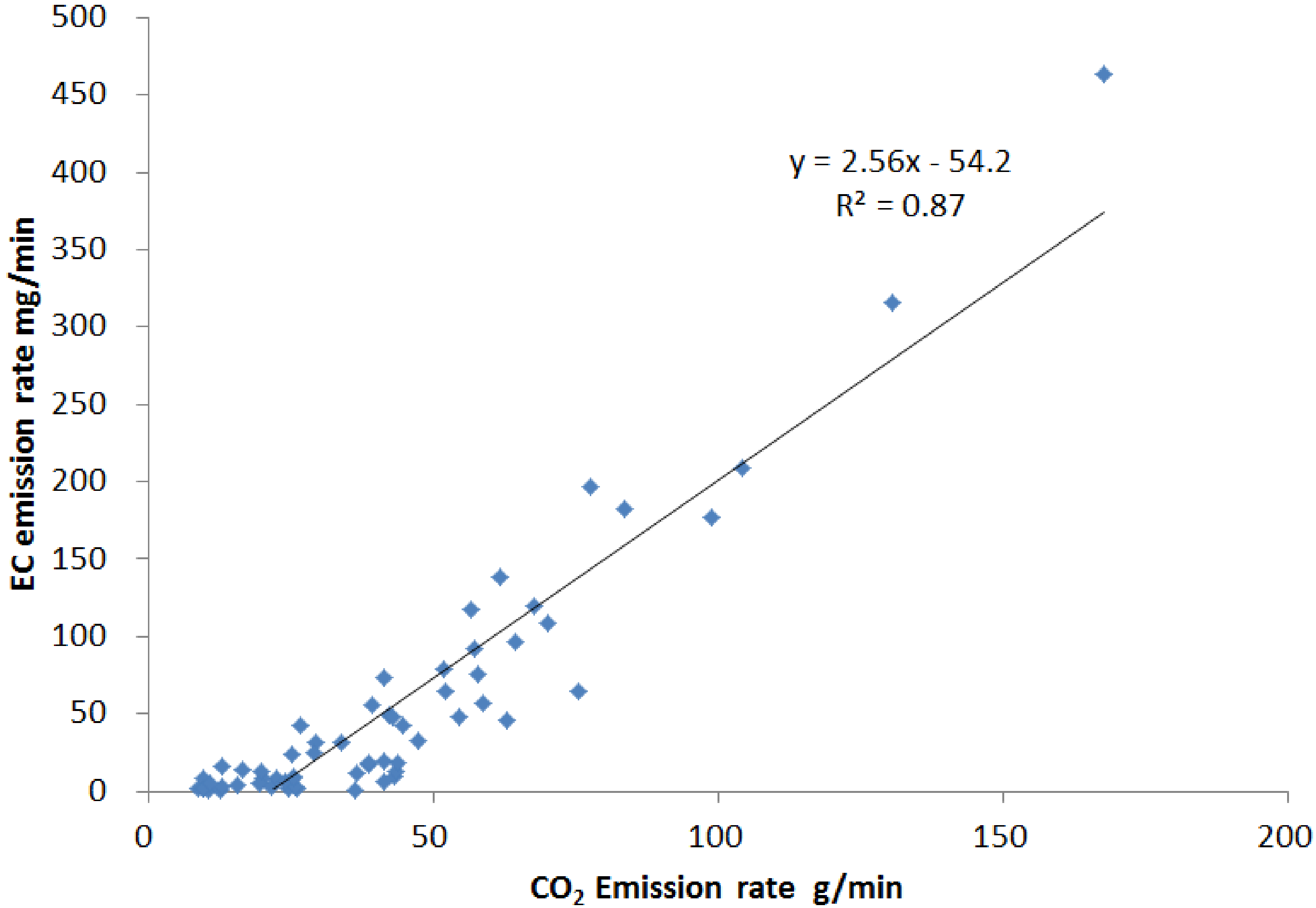
Major findings

OC correlates well with $PM_{2.5}$ mass across all sites

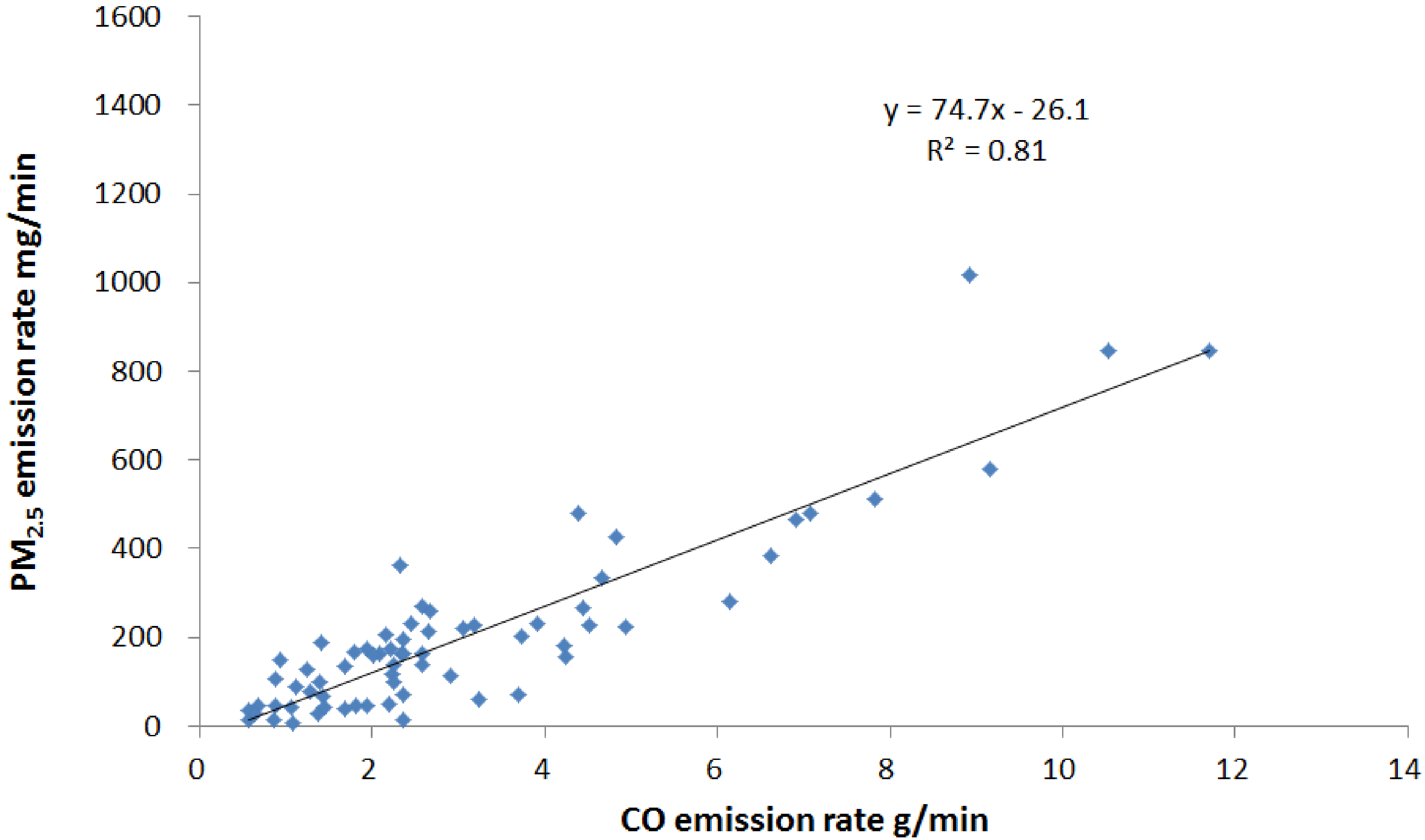


174 measurements representing wide range of fuel types, stove types, flues, altitudes etc

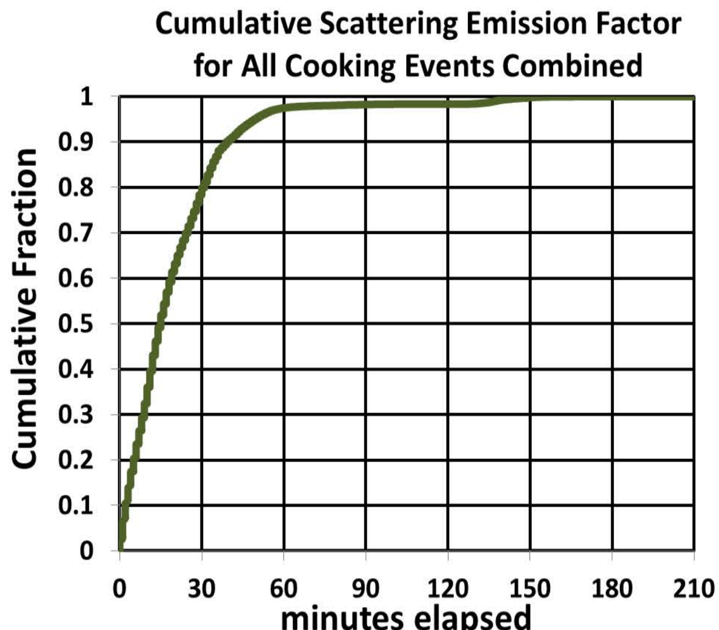
EC correlates well with CO_2 Emissions rate in Nepal

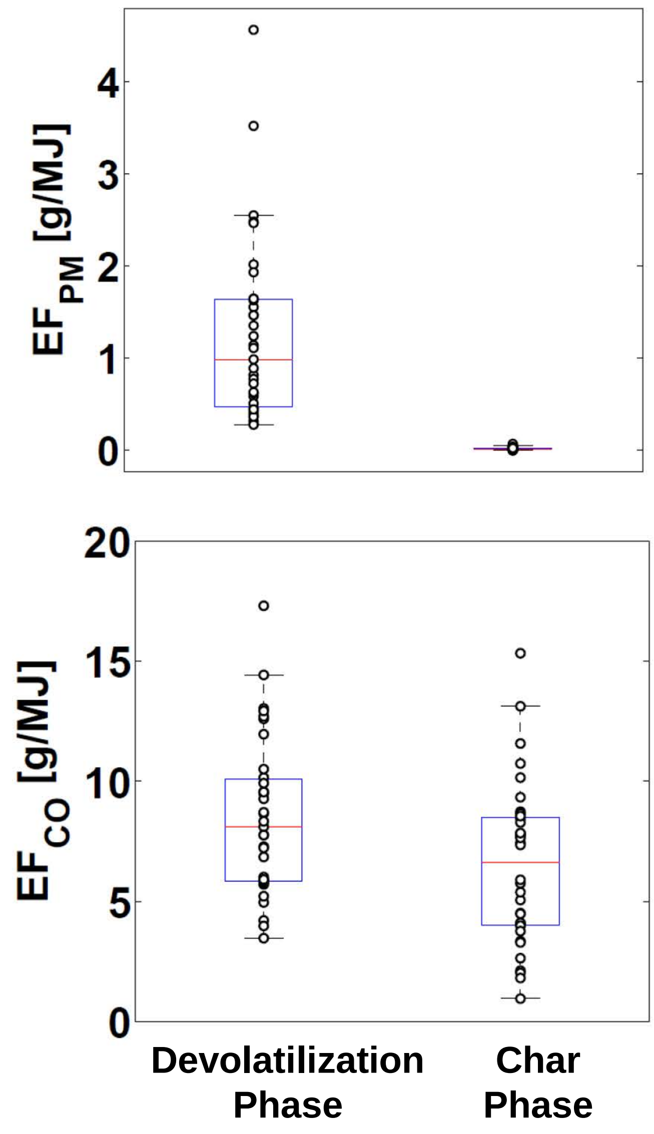


$PM_{2.5}$ emissions rates correlate well with CO emission rates in Nepal



Yunnan Coal stoves





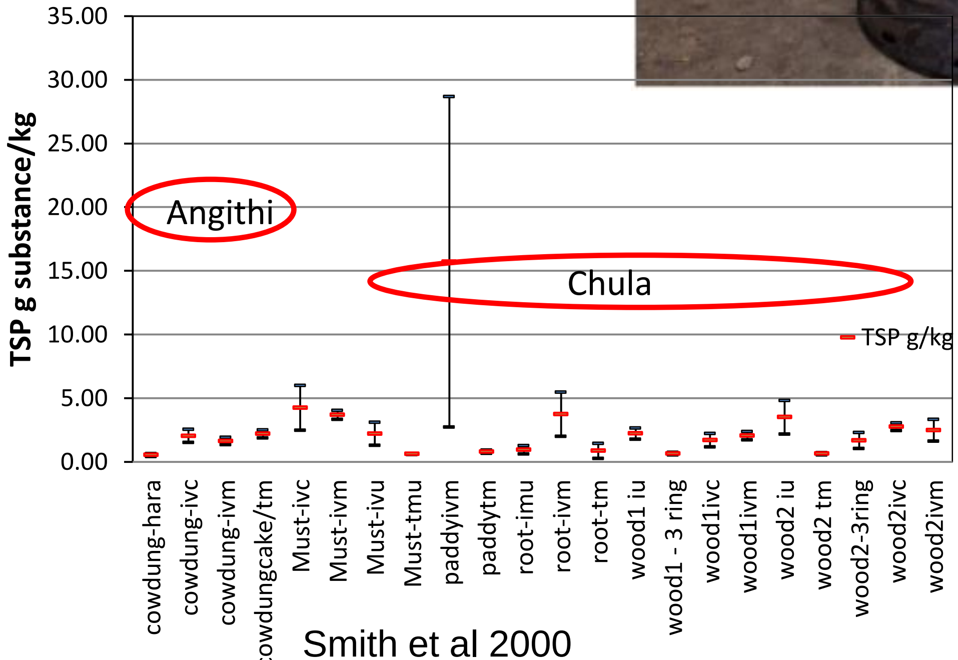
Dependent variable	n	R^2	Std. Error	Significance	Independent variables	Unstandardized Coefficients B	Std. Error	Sig.
EC emission g/kg dry fuel	35	0.67	1.41	0.000	(Constant)	-1.51	0.48	0.003
					OC emission g/kgfuel	-0.83	0.17	0.000
					PM emission g/kgfuel	0.78	0.13	0.000
					flue	1.56	0.49	0.003

India emissions

	n	MCE	CO_2	CO	$PM_{2.5}$	EC	OC
			g substance/ kg dry fuel				
Fixed Chula w/o Chimney	12	0.94 (±0.02)	1050 (±326)	67.3 (±19.3)	14.6 (±10.7)	0.5 (±0.7)	7.5 (±7.4)
Phillips	12	0.96 (±0.02)	1366 (±297)	51.2 (±25.9)	7.0 (±4.7)	0.4 (±0.5)	3.2 (±2.1)
Haro/Angithi	5	0.91 (±0.02)	694 (±167)	66.8 (±14.8)	35.7 (±39.9)	1.2 (±2.4)	22.5 (±22.5)
Haro/Angithi *	4	0.91 (±0.02)	620 (±16)	61.8 (±11.2)	18.1 (±7.9)	0.2 (±0.1)	12.7 (±6.0)

*large outlier removed

Somewhat higher than previous in field tests – a lot higher than Lab based measurements that formed most of our inventories



Smith et al 2000

Comparison to fireplaces in the US

Table 1
Database Summary of Particulate Emission Factors for Masonry and Factory-Built Fireplaces

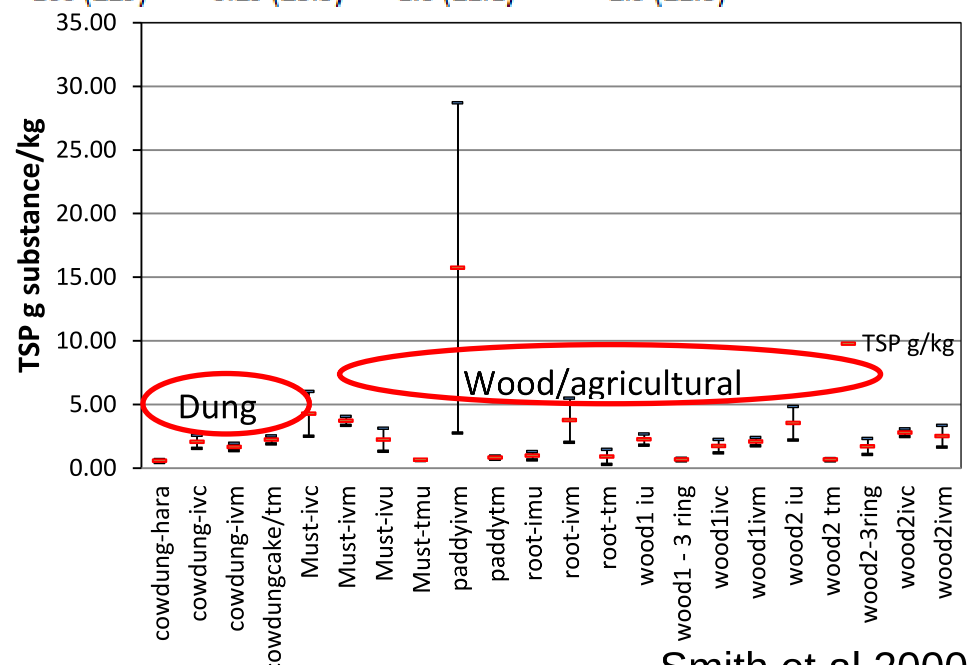
Parameter	5G g/kg		5H g/kg		Count
	Mean	Median	Mean	Median	n
All masonry and factory-built (zero clearance)	8.4	6.4	9.5	7.5	360
All cordwood	11.7	11.3	13.0	12.6	167
All dimensional lumber	5.6	4.3	6.5	5.2	193
All with closed doors	4.8	3.5	5.6	4.4	104
All with open doors	9.9	8.4	11.1	9.8	256
All masonry fireplaces	9.6	7.2	10.6	8.7	90
All factory-built fireplaces	8.0	6.1	9.2	7.2	270
Cordwood, factory-built, open doors	12.4	11.9	13.9	13.5	92
Dimensional lumber, factory-built, open doors	7.1	5.6	8.2	6.5	92
AP-42 calculated from referenced tests*	15.2	14.5	16.4	15.9	54
AP-42	16.2	-	17.3	-	-

Notes: Three outlier runs were removed from the database, average moisture for all runs was 20% and average burn rate for all runs was 4.8 kg/hr.
*OMNI was unable to duplicate the exact AP-42 values from the tests cited.

From: Broderick, D. R., Houck, J. E. and Crouch, J. (2005). Development of Fireplace Baseline Particulate Emission Factor Database. OMNI and HBPA report

Nepal emissions

		Mean mission factors g/kg dry fuel					
	N	MCE	CO_2	CO	$PM_{2.5}$	EC	OC
dung	8	0.93 (±0.02)	1273 (±541)	86 (±39)	5.9 (±2.5)	0.6 (±0.3)	2.7 (±2.1)
dung; ag res	3	0.92 (±0.01)	1234 (±67)	114 (±14)	3.9 (±3.3)	0.8 (±0.9)	1.4 (±1.0)
wood	16	0.94 (±0.02)	1606 (±99)	107 (±29)	4.4 (±2.5)	0.6 (±0.6)	2.2 (±1.8)
wood; dung	13	0.92 (±0.01)	1056 (±228)	91 (±25)	6.08 (±4.5)	0.5 (±0.4)	2.7 (±2.6)
mix	6	0.94 (±0.02)	1673 (±43)	102 (±28)	7.8 (±3.4)	1.1 (±0.7)	2.8 (±2.2)
agricultural residue	25	0.94 (±0.02)	1553 (±101)	103 (±28)	7.7 (±3.4)	2.5 (±0.8)	3.8 (±2.5)
Total	71	0.93 (±0.02)	1439 (±303)	100 (±29)	6.29 (±3.5)	1.3 (±1.1)	2.9 (±2.3)

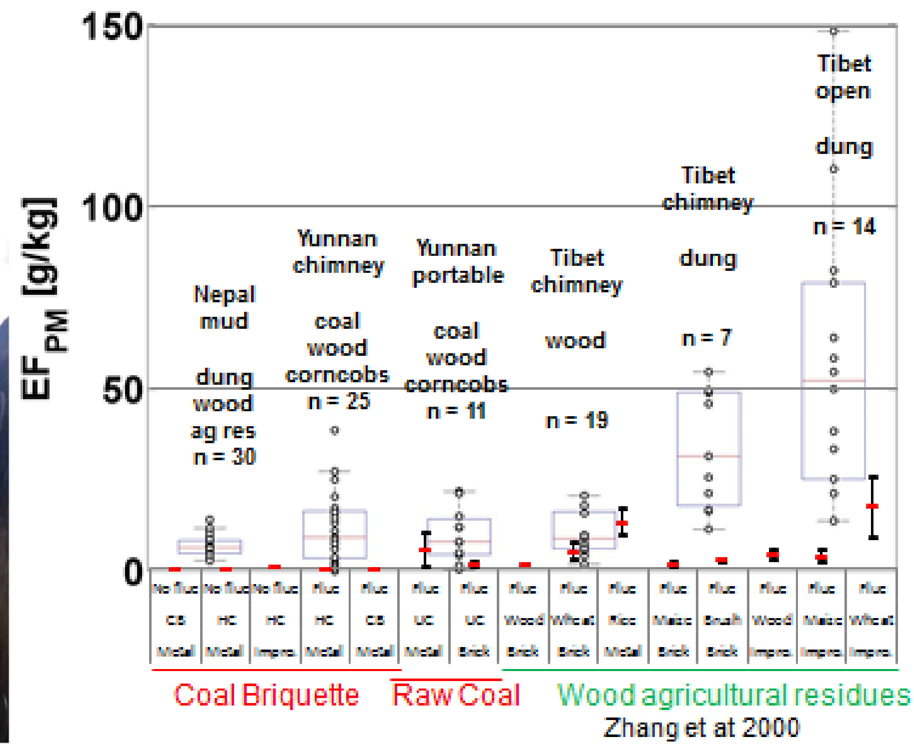


Smith et al 2000

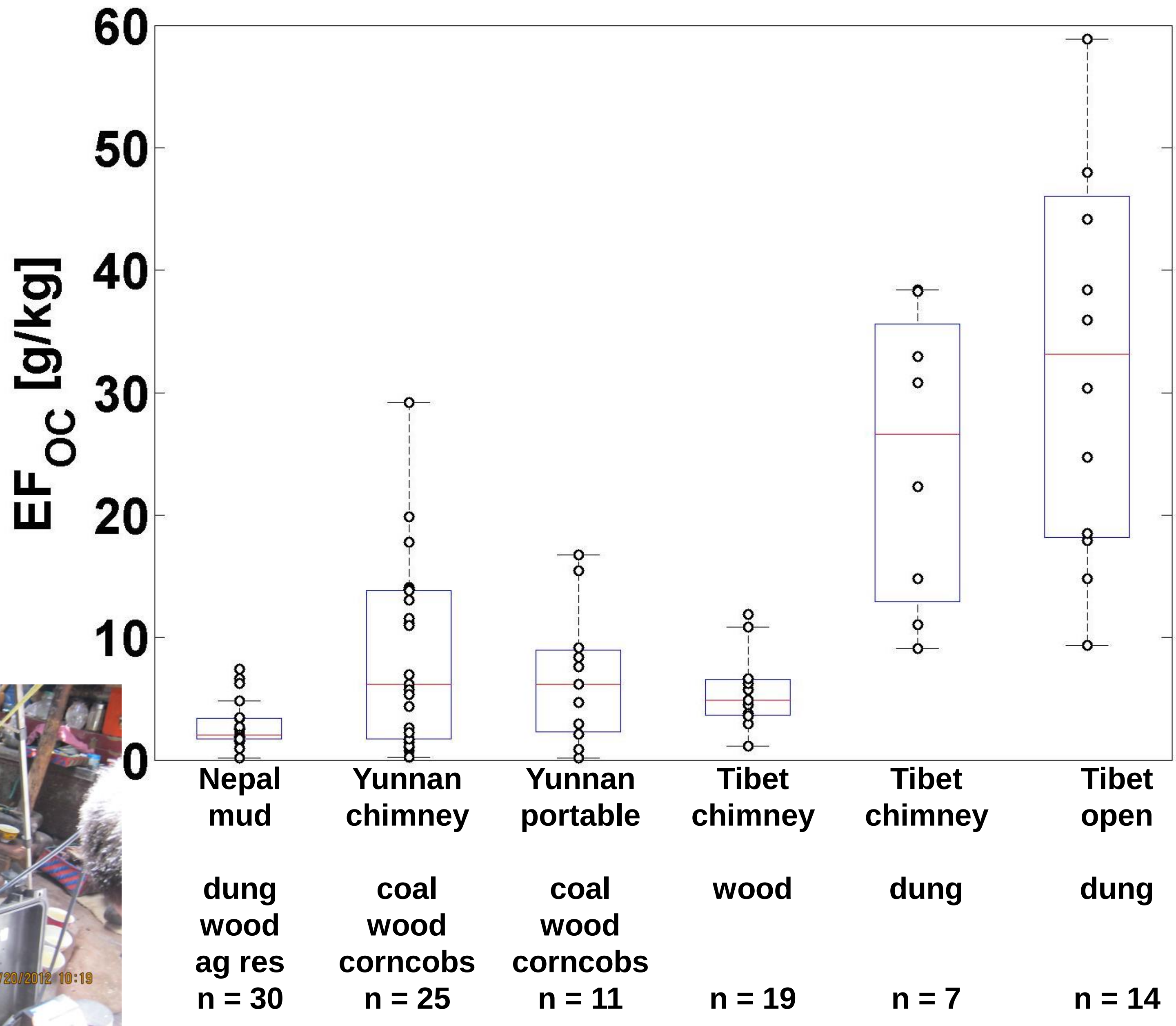
Yunnan Emissions

	n	MCE	g substance/ kg fuel				
			CO_2	CO	$PM_{2.5}$	EC	OC
Coal	23	0.90 (±0.03)	1689 (±330)	134.8 (±47.8)	12.8 (±11.6)	2.2 (±3.0)	8.0 (±8.9)
Mixed fuels	35	0.90 (±0.03)	1580 (±399)	133.1 (±50.3)	11.3 (±14.8)	0.6 (±0.5)	7.6 (±11.0)
Cobs	1	0.89	1508	121.7	10.0	0.4	6.0
Wood	2	0.94 (±0.03)	1664 (±39)	90.8 (±13.2)	3.9 (±0.8)	0.7 (±0.5)	1.5 (±1.0)

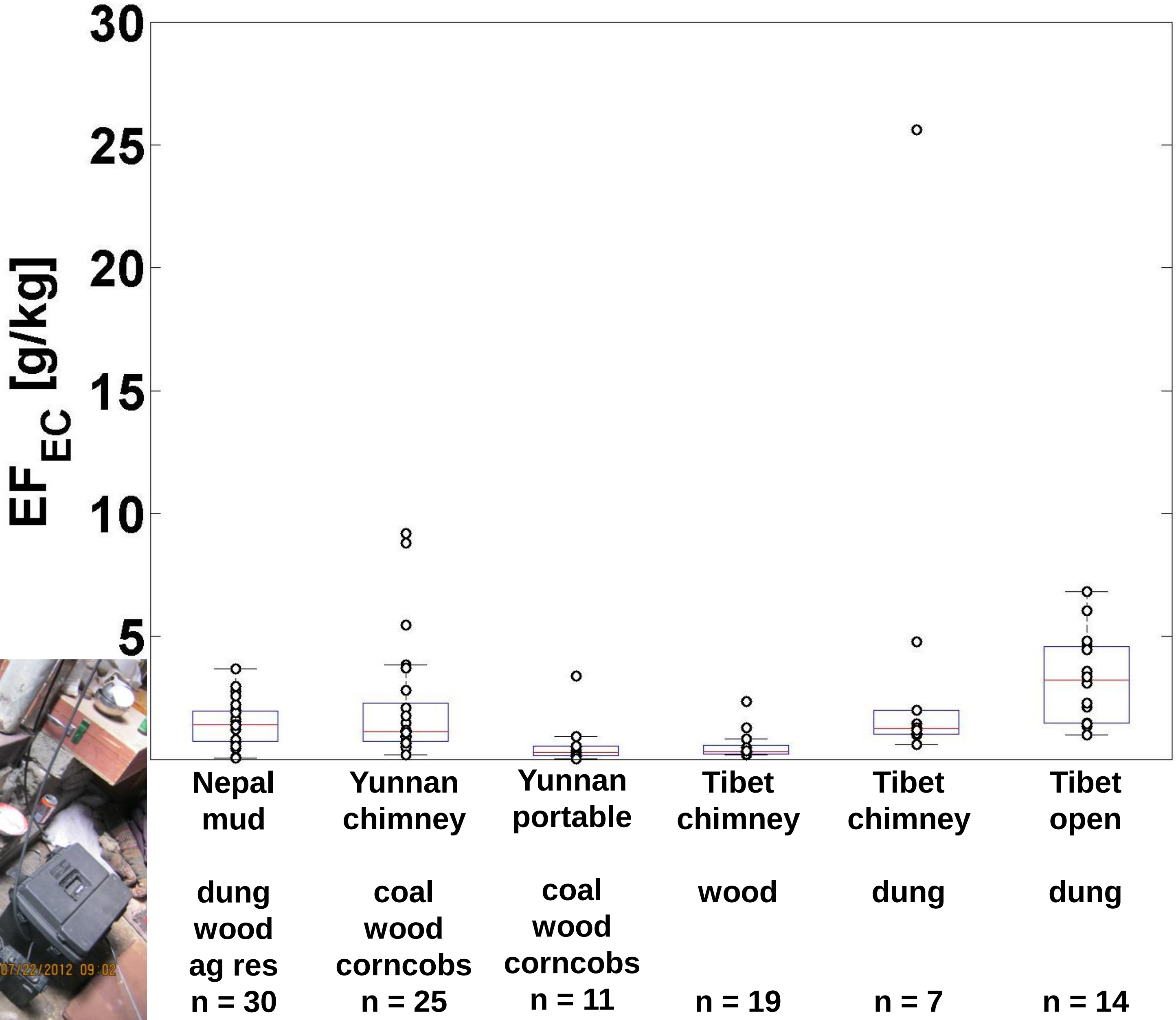
Again substantially higher than previous lab based emission factors



OC Emission Factor



EC Emission Factor



WHO air quality guidelines for indoor air quality: unprocessed coal combustion

Recommendation 3: Household use of coal

Recommendation	Strength of recommendation
Unprocessed[3] coal should not be used as a household fuel.	Strong

Remarks

1. This recommendation is made for the following three reasons, over and above the documented health risks from products of incomplete combustion of solid fuels.
    i. Indoor emissions from household combustion of coal have been determined by the International Agency for Research on Cancer (IARC) to be carcinogenic to humans (Group 1).
    ii. Coal – in those parts of the world where coal is most extensively used as a household fuel and the evidence base is strongest – contains toxic elements (including fluorine, arsenic, lead, selenium and mercury) which are not destroyed by combustion and lead to multiple adverse health effects.
    iii. There are technical constraints on burning coal cleanly in households.

Small scale industries

- Economic and social significance well recognized
- In Africa and Asia small-scale non-farming enterprises provide 20%–45% of full-time employment and 30%–50% of rural household income (Haggblade and Liedholm 1991).
- Latin America has an estimated 50 million micro and small-scale enterprises responsible for 20 to 40% of GDP (Scott A 2000), employing 120 million people (Berger and Guillamon 1996).
- Emissions are practically uncharacterized. We don't know a) how many there are, b) their emissions, or c) what fraction of fuel use they constitute.
- Relatively low combustion temperatures and inefficient technology.
- lack pollution control equipment, labour intensive, often located in poor residential neighbourhoods
- Contribute substantially to regional concentrations of climate altering pollutant species and adverse health impacts

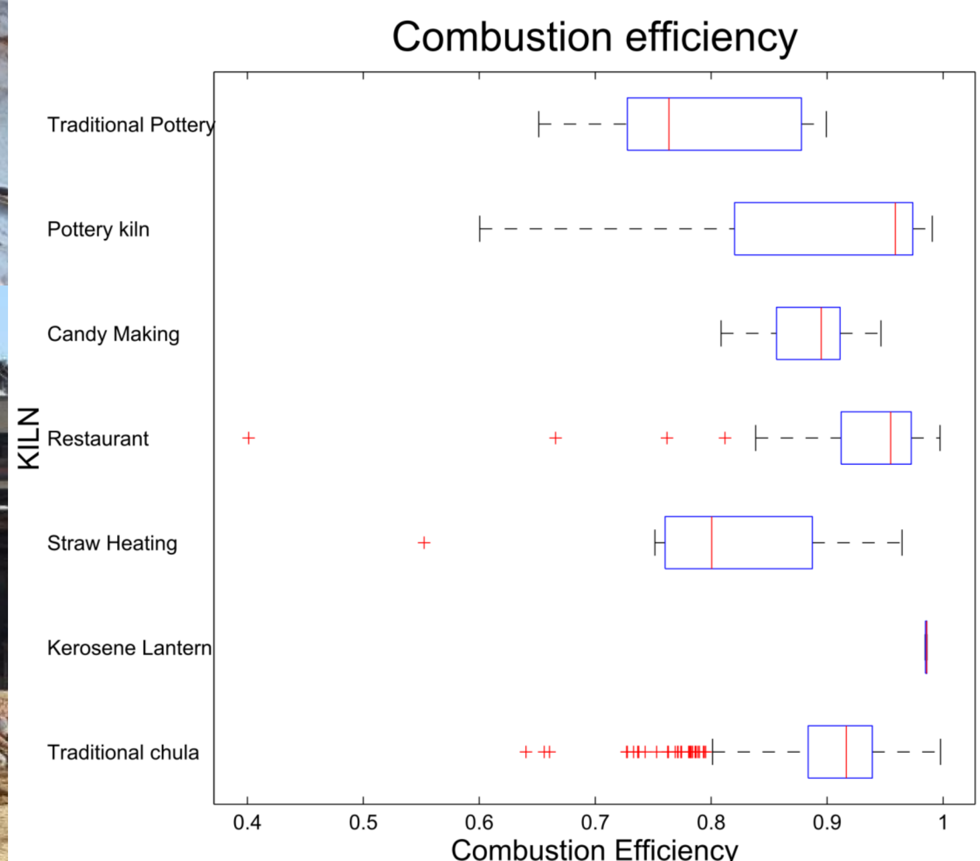


Emission factors

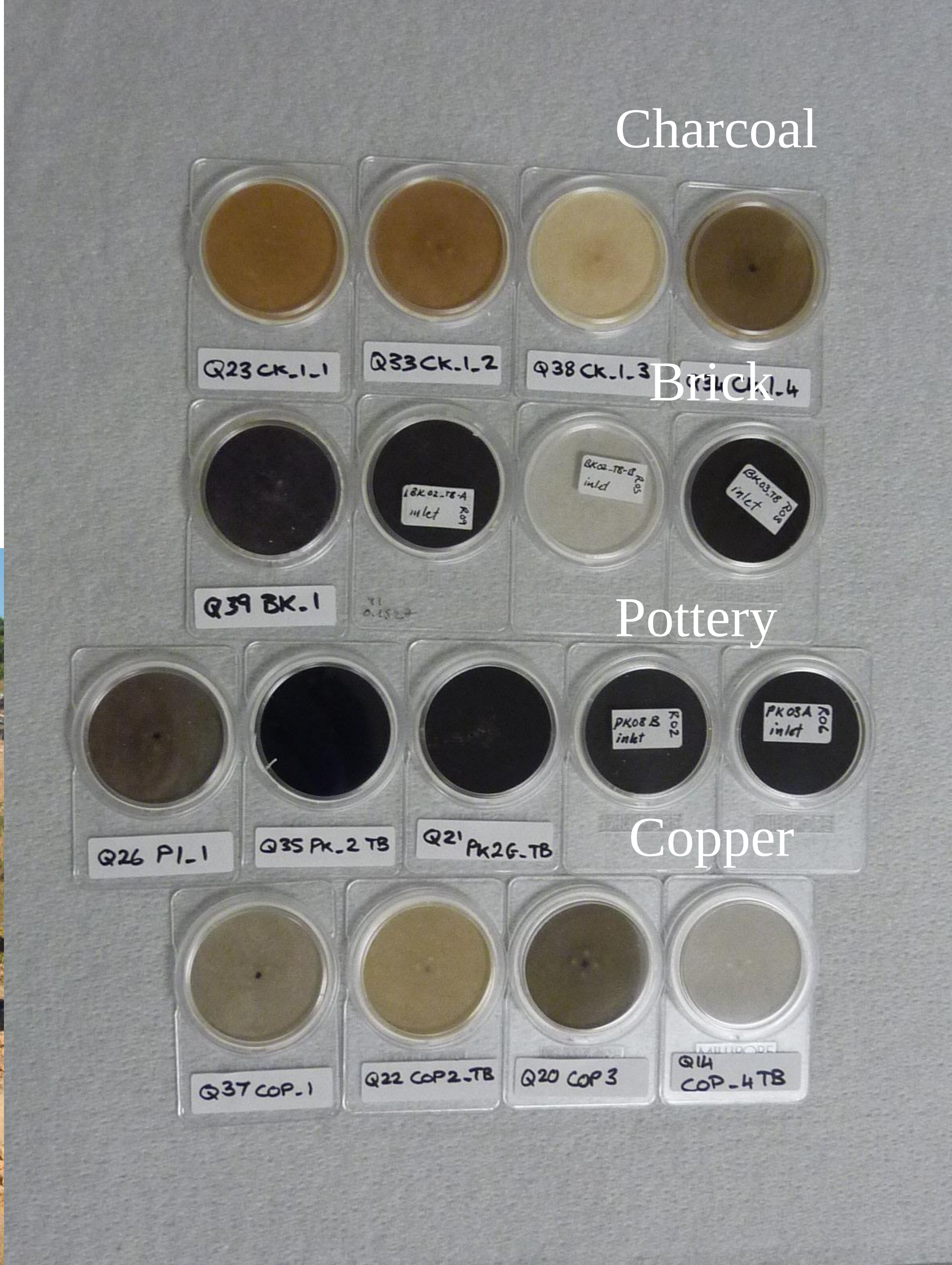
	n	MCE	g substance/ kg dry fuel				
			CO_2	CO	$PM_{2.5}$	EC	OC
Mexico Brick Kilns	2	0.89 (±0.00)	1456 (±6)	187.1 (±6.0)	3.2 (±0.0)	1.1 (±0.6)	2.6 (±0.8)
Mexico Charcoal	8	0.75 (±0.12)	1622 (±259)	547.8 (±262.7)	5.7 (±5.0)	0.1 (±0.1)	4.9 (±5.8)
Mexico Copper	4	0.95 (±0.05)	1554 (±79)	80.6 (±79.3)	10.5 (±3.9)	0.5 (±0.3)	6.0 (±2.9)
Mexico Pottery Glazing	4	0.94 (±0.02)	1534 (±37)	98.8 (±35.3)	11.9 (±12.6)	10.7 (±10.5)	4.2 (±4.5)
Nepal Hotels	2	0.91 (±0.03)	1495 (±36)	140.5 (±41.5)	9.8 (±4.2)	1.8 (±1.6)	3.8 (±0.7)
Nepal Candy	1	0.93	1514	131.9	1	0.1	1.0
Nepal Ceramics	1	0.92	1543	103.5	0.8	0.8	0.3
India Dhaba	2	0.93 (±0.00)	2030 (±10)	155.6 (±9.9)	1.7 (±0.4)	0.1	0.9 (±0.1)
India Candy	1	0.94	1237	81.2	14.6	4.6	4.3
India Pottery	1	0.82	968	216.8	22.0	0.3	13.5

	n	g substance/ kg fuel			
		CO	PM	EC	OC
Haystack	1	198.5	39.0	1.9	30.1
Candy Making	1	129.9	4.1	0.4	2.4
Improved Pottery	2	101.2 (±99.2)	1.9 (±1.2)	1.5 (±0.8)	0.3 (±0.2)
Traditional Pottery	4	246.5 (±99.9)	6.7 (±5.4)	0.04 (±0.05)	5.7 (±4.9)
Restaurant	2	66.2 (± 17.0)	7.2 (±0.5)	3.6 (±1.1)	2.9 (±0.02)

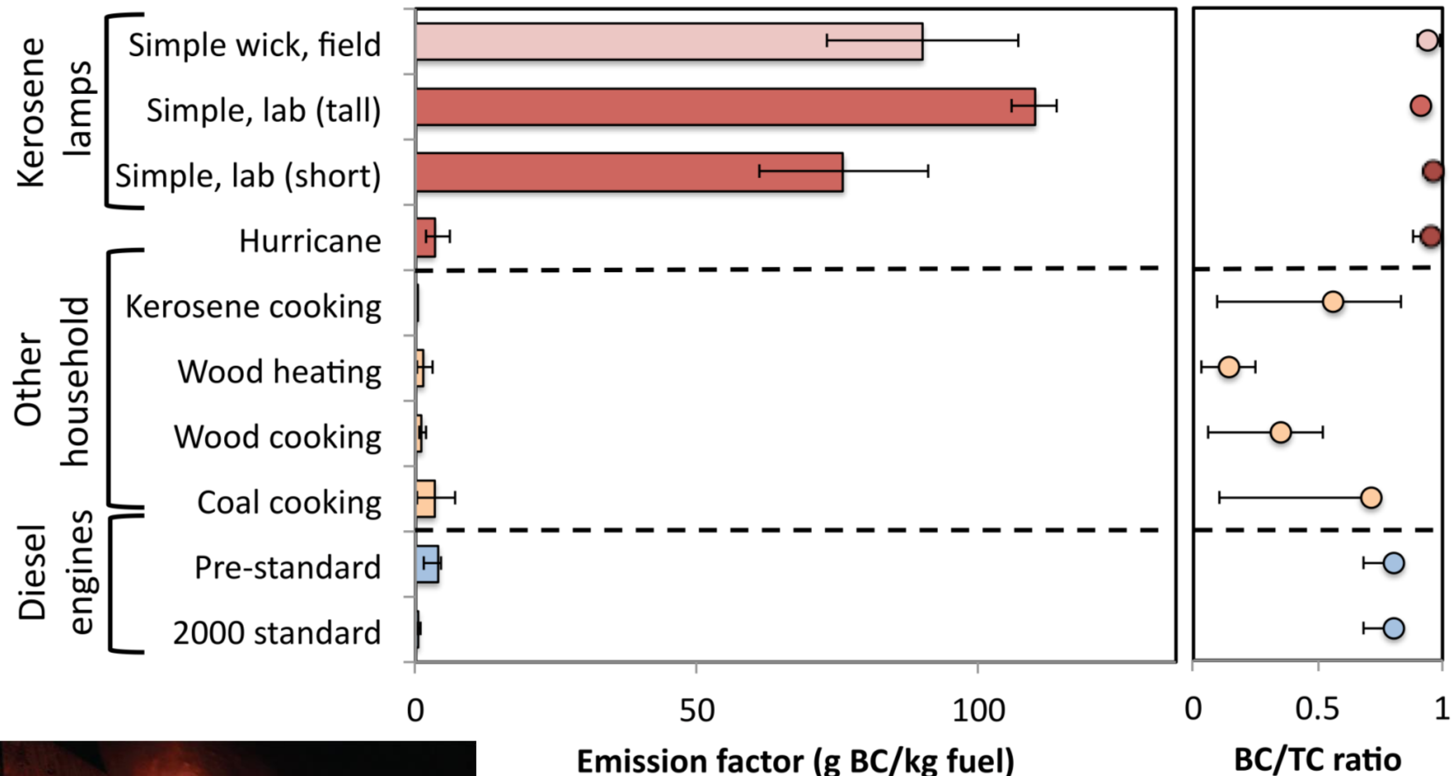
They are not the same as household stoves



	EC/OC
Brick	0.44
Charcoal	0.01
Copper	0.08
Pottery	2.51



Surprise sector: kerosene lamps

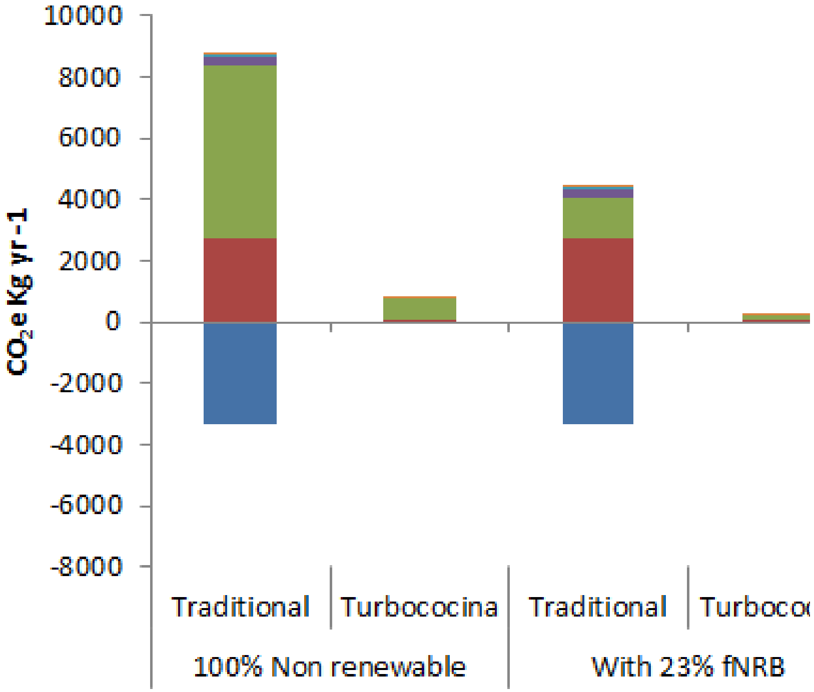


Emission factors larger than anything else – pure BC

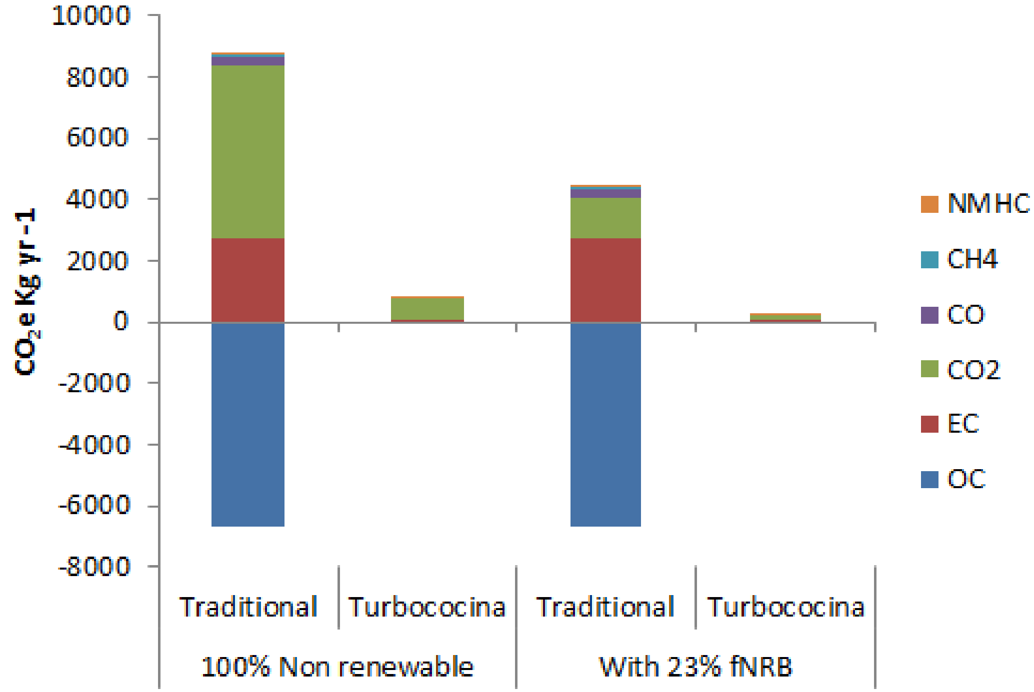
Photos: Ajay Pillarisetti, Evan Mills

Advanced combustion stoves

Emissions



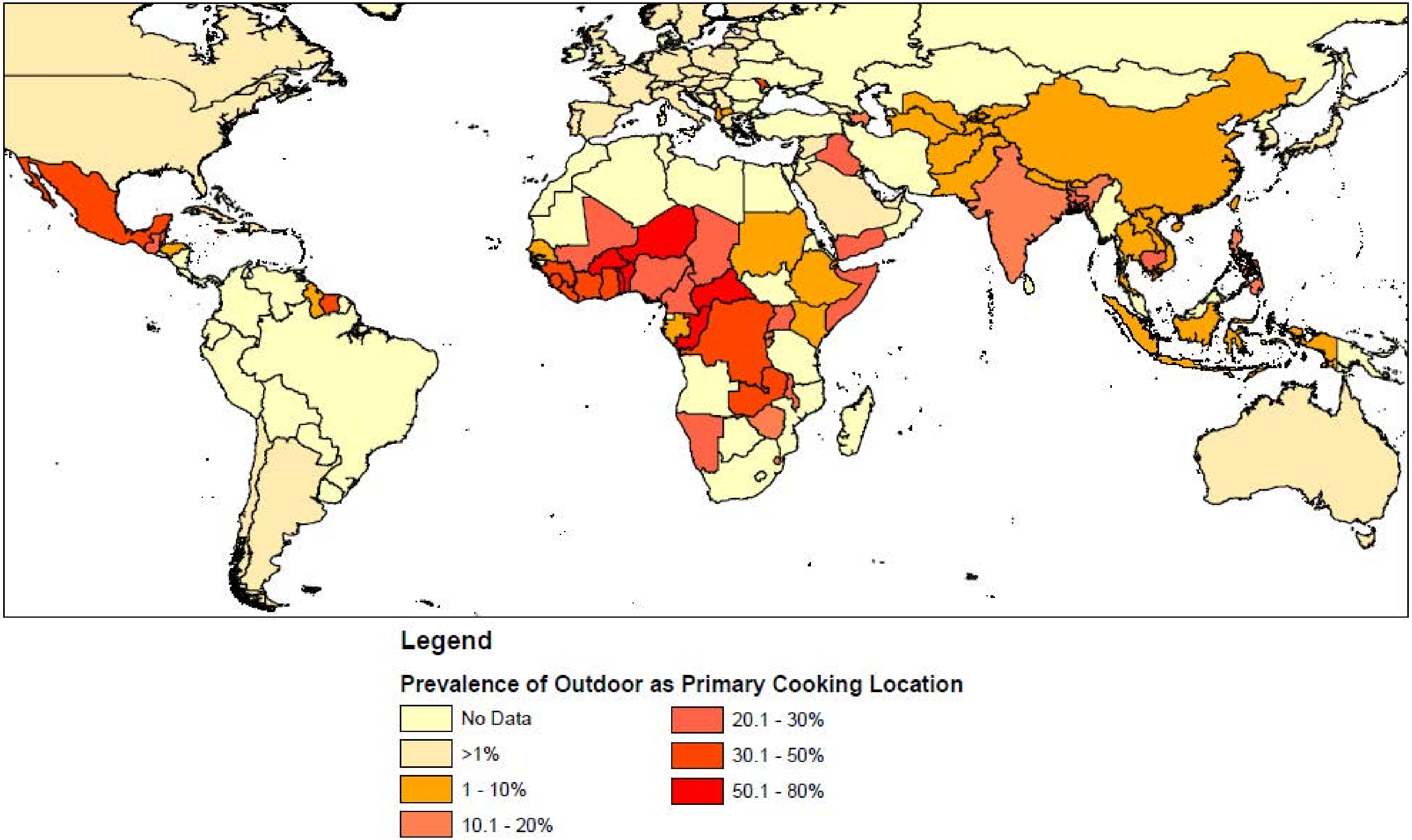
Condensation of OC in atmosphere



	PM g/kg	EC g/kg	OC g/kg	EC/OC
TRADITIONAL	15.9	0.9	7.9	0.11
TURBOCOCINA	2.9	0.5	1.3	0.41
	81%	41%	84%	

However adoption and stove stacking also important

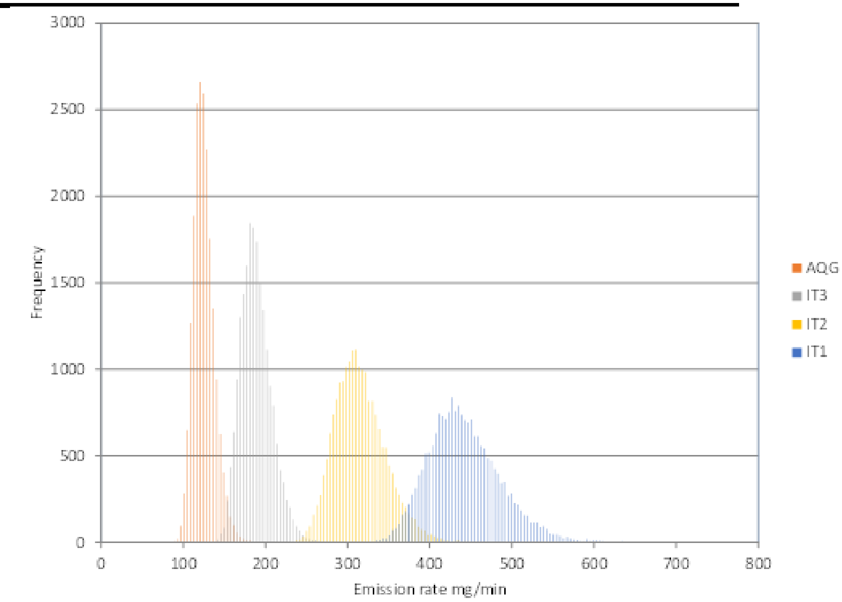
Outdoor cooking as a primary cooking location



Data represents ~66% of the world's population, of which approximately 12.7% (586 million individuals) cook primarily outdoors.

Emissions rates from outdoor cooking to increase exposures equivalent to WHO AQG and interim targets

Exposure concentration	stove/cook height (m)	Emission rate(mg/min) Mean	St Dev	5%	10%	25%	50%	75%	90%	95%
AQG	0.3,1	126	13	108	111	117	125	134	142	148
IT3	0.3,1	189	19	161	166	176	187	200	213	222
IT2	0.3,1	315	31	269	278	293	312	334	355	371
IT1	0.3,1	441	44	377	389	411	437	468	499	520
AQG	0.9,1.5	99	10	84	87	92	98	105	112	116
IT3	0.9,1.6	148	15	126	130	138	146	157	167	174
IT2	0.9,1.7	247	24	211	218	229	244	261	279	291
IT1	0.9,1.8	345	34	296	305	321	342	366	390	406

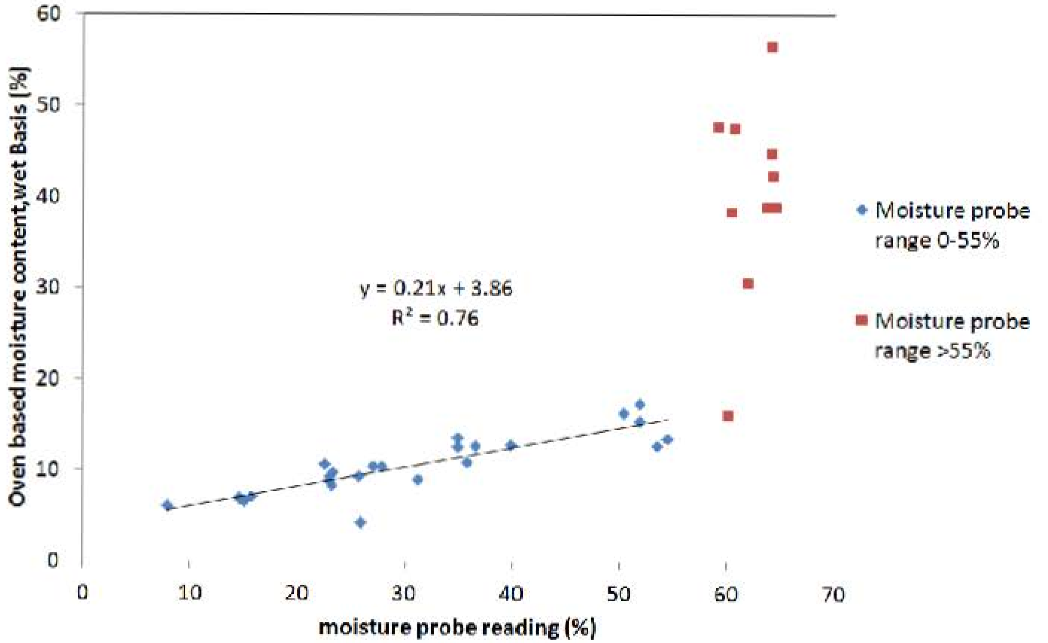


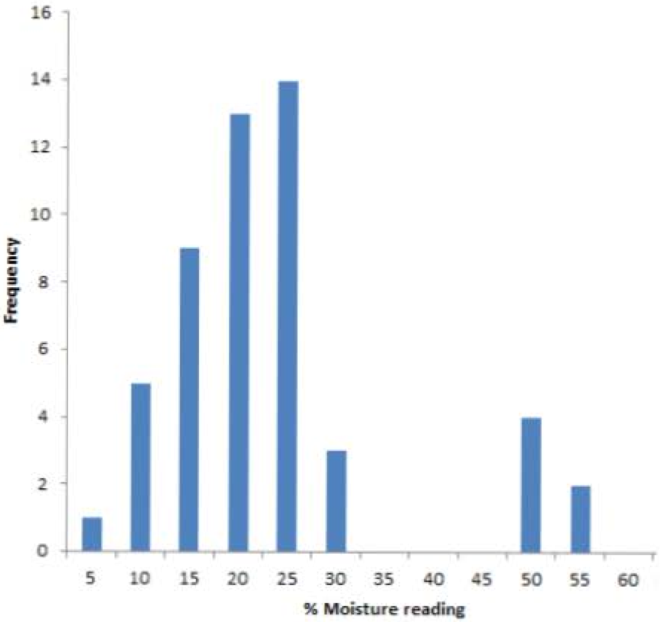
Impact of outdoor cooking on neighborhood pollution levels

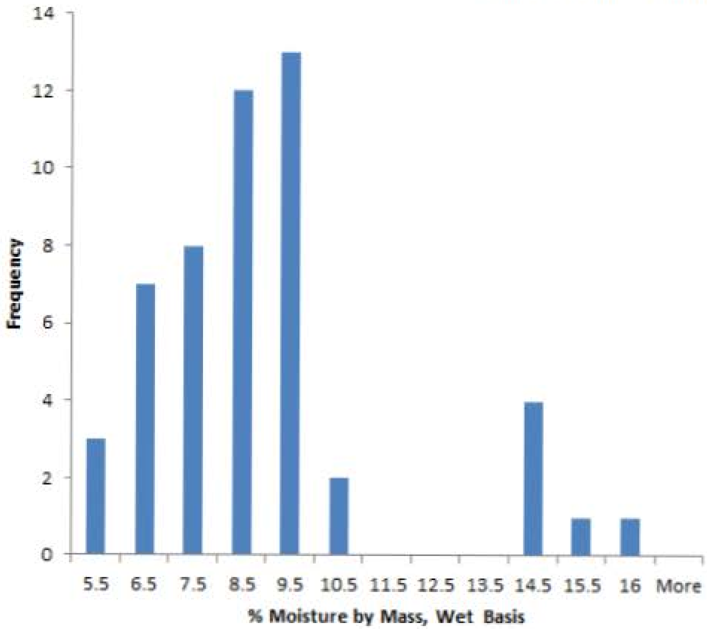
A function of emission intensity and housing density

						Distance to reach 1 ug/m^3 (m)		
Stove Type	Fuel	n	Time (min)	MCE	$PM_{2.5}$ (mg/min)	u=0.5 (m/s)	u=1.0 (m/s)	u=1.5 (m/s)
Angithi/Haro	Dung	7	143 (± 50)	85.1% (± 4.9%)	620 (± 431)	725	439	214
Chula	Dung + wood	16	168 (± 22)	91.2% (± 1.5%)	94 (± 56)	144	68	32
Philips	Dung + wood	6	238 (± 133)	93.1% (± 1.6%)	31 (± 30)	56	22	10
Philips	Wood only	7	211 (± 74)	94.9% (± 2.6%)	7.8 (± 6.6)	23	6	3

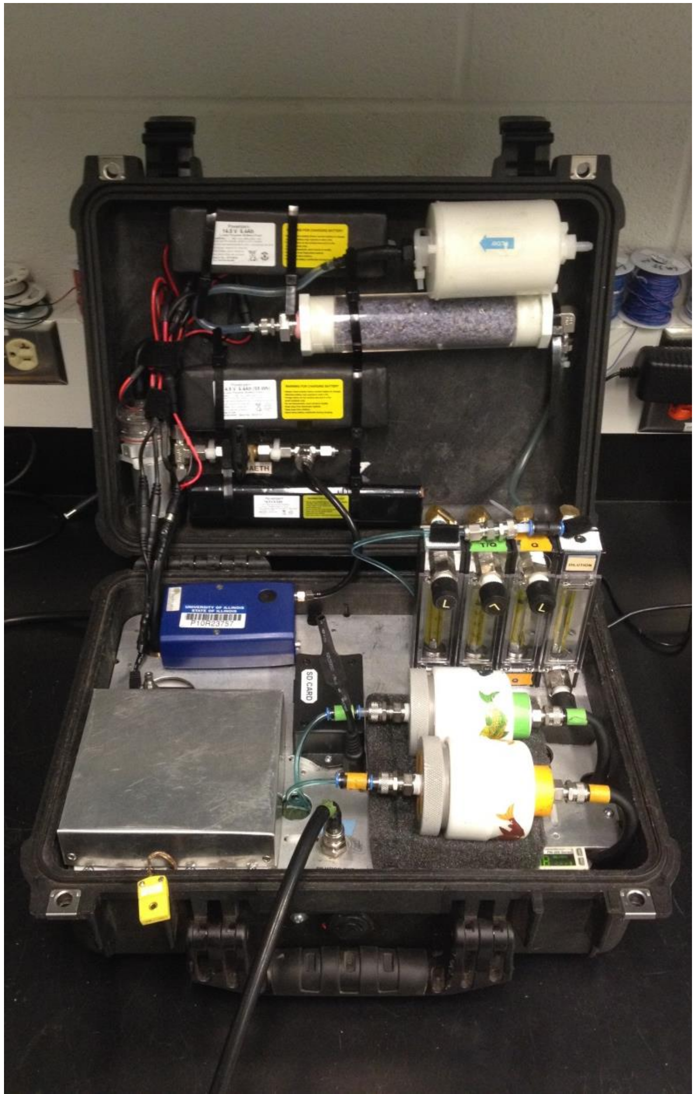
Dung moisture







Equipment Development



- Dilution sampler
- Hand carried by one person

  Sensor box: 12 kg
  Sample probe kit: 5 kg
  Accessory kit: 5 kg
  22 kg

- 12 hour run time
- Teflon and quartz filters
- SD card logger
- Wireless transmitter
- Real-time sensors
  - CO
  - CO2
  - PM scattering
  - PM absorption (MicroAeth)
  - Temperature
  - Relative Humidity
  - Filter flow rates
  - Background CO
  - Background CO2

Thank you

Thanks to all the field site collaborators :
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