1-2004

IMPACTS OF GREENHOUSE GAS AND PARTICULATE EMISSIONS FROM WOODFUEL PRODUCTION AND END-USE IN SUB-SAHARAN AFRICA

Robert Bailis
University of California

David Pennise
University of California

Majid Ezzati
Harvard University

Daniel M. Kammen
University of California

Evans Kituyi
Aga Khan University, evans.kituyi@aku.edu

Recommended Citation

Bailis, R., Pennise, D., Ezzati, M., Kammen, D. M., Kituyi, E. (2004). IMPACTS OF GREENHOUSE GAS AND PARTICULATE EMISSIONS FROM WOODFUEL PRODUCTION AND END-USE IN SUB-SAHARAN AFRICA. *Berkeley, CA: Renewable and Appropriate Energy Laboratory*.
Available at: https://ecommons.aku.edu/eastafrica_eai/42

IMPACTS OF GREENHOUSE GAS AND PARTICULATE EMISSIONS FROM WOODFUEL PRODUCTION AND END-USE IN SUB-SAHARAN AFRICA

Robert Bailis[1], David Pennise[2], Majid Ezzati[3], Daniel M. Kammen[1,4], Evans Kituyi[5]

[1] Energy and Resources Group, University of California, Berkeley, CA, USA
[2] School of Public Health, University of California, Berkeley, CA, USA
[3] Harvard School of Public Health, Harvard University, Cambridge, MA, USA
[4] Goldman School of Public Policy, University of California, Berkeley, CA, USA
[5] University of Nairobi & African Center for Technology Studies, Nairobi, Kenya

ABSTRACT: Household energy in sub-Saharan Africa is largely derived from woodfuels burned in simple stoves with poor combustion characteristics. These devices emit products of incomplete combustion [PICs] that both damage human health and negatively impact the atmospheric radiation budget. We use empirical studies and published emission factors to estimate the pollution associated with production, distribution and end-use of common household fuels and assess the impacts of these emissions on public health and the global environment. We find that each meal cooked with charcoal has 2-10 times the global warming effect of cooking the same meal with firewood and 5-16 times the effect of cooking the same meal with kerosene or LPG depending on the gases that are included in the analysis and the degree to which wood is allowed to regenerate. However, although charcoal is worse than other fuels with respect to GHG emissions, it can lead to reductions in concentrations of pollutants like particulate matter (PM). Concentrations of PM in households using charcoal were found to be 88 percent lower than households using open wood fires (charcoal: 465±387 μg/m^3; open wood fires: 3764±714 μg/m^3 (mean±95% CI)). Two years of health data collected from Kenyan families using wood and charcoal shows that charcoal users experienced 44-65 percent fewer cases of acute lower respiratory infection (ALRI) compared to wood users. Understanding the costs and benefits of household energy options is an important step in designing effective energy policies.
Keywords: charcoal, CDM, developing countries, GHG, LCA

1 INTRODUCTION

In many African countries, energy use is dominated by the residential sector. At the household level, energy is derived primarily from solid biomass fuels burned in simple stoves with poor combustion characteristics.

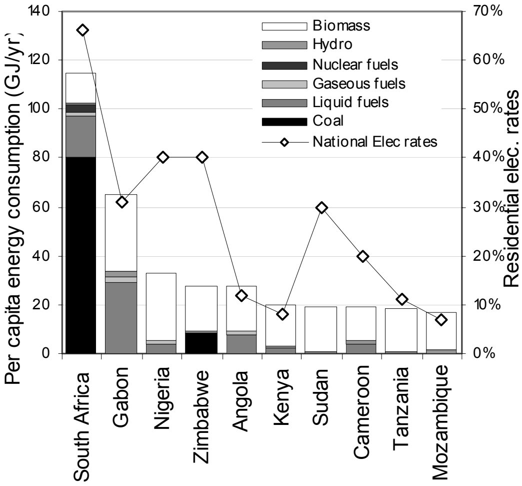

Figure 1: Per capita energy consumption and elec. rates for top-10 energy consuming countries in SSA in 2000.

Figure 1 shows per capita energy consumption by fuel and rates of household electrification in the top-10 energy consuming countries in the SSA region. It is evident from the figure that, with the exception of South Africa, biofuels dominate national energy supplies. Even in countries with significant fossil fuel resources like Gabon, Nigeria, and Angola, biomass constitutes the majority of national energy consumption. Moreover, it is clear that household electrification rates are quite low. The regional average (not shown on graph) is roughly 23 percent of households. However, electricity tends to be the most expensive option for cooking, so that even in countries where household access exceeds the regional average, biomass fuels still dominate energy supply. In addition, although the graph does not differentiate biomass fuels, biomass is typically used in different forms in SSA. The most common forms of biomass are unprocessed fuelwood and charcoal, with limited use of crop residues and dung. Regionally, roughly 20 percent of the wood energy harvest is processed into charcoal before final consumption, but in some countries the share of primary wood off take that is made into charcoal may be as high as 40 or 50 percent. Charcoal and fuelwood must be differentiated because they have very different emissions patterns. In addition, charcoal is a more commercialized fuel and the nature of charcoal markets typically lead to greater woodland exploitation than fuelwood. This impacts the net GHG emissions resulting from charcoal production and can result in local environmental degradation (we will not discuss this further here, but see, for example, [1, 2]). Heavy reliance on biomass can have significant negative impacts on indoor air quality and on the global climate. Indoor air pollution from residential combustion of solid fuels is one of the leading causes of death worldwide. Health impacts are largely the result of individual exposure to high smoke concentrations in households using solid fuels. This exposure is considered responsible for 1.5-2 million deaths per year, almost entirely in developing countries [3-5]. Figure 2 shows estimates of leading proximate causes of global mortality.

In addition, countries that are heavily reliant on woodfuels tend to have low GHG emissions relative to industrialized countries. However, the majority of their emissions tend to originate in the household sector, both as a result of land use activities and energy consumption. In this brief paper, we only consider energy consumption, though we acknowledge that in biomass-dependent societies, the two are strongly linked and the land-use component may dominate emissions. In the remainder of this paper, we develop the links between health damaging pollutants and GHG emission further. Based on three separate studies conducted in Kenya and India over the past several years, we compare different household energy technologies, and consider some ways to take advantage of the link between GHGs and indoor air pollution in order to reduce emissions of both.

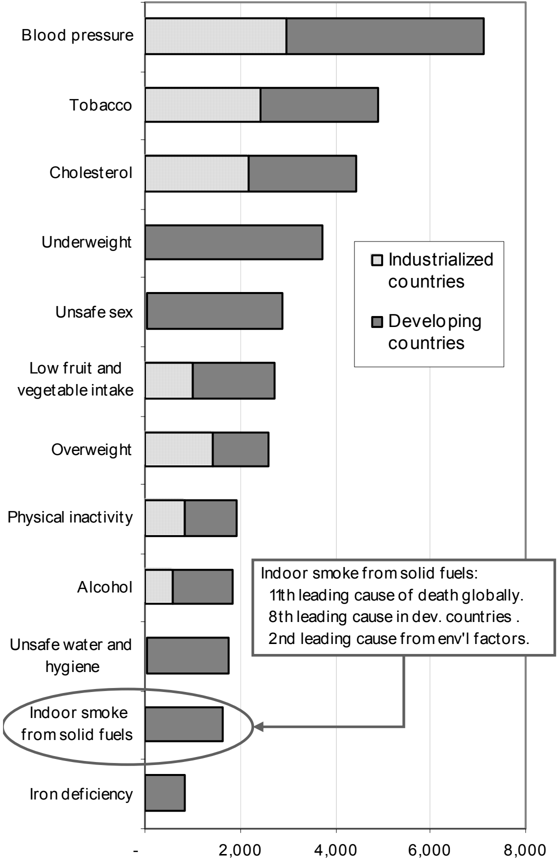

Figure 2: No. of global deaths (x 1000) for 12 leading risk factors in 2000 [3].

2 GHG ESTIMATIONS

The first study, which was performed in India, assessed emissions factors for major pollutants in 28 stove-fuel combinations in common use [6, 7]. The results of the study showed that most biofuels lead to higher global warming impacts than common fossil fuels because of poor combustion characteristics, which lead to high emissions of methane and other PICs. Figure 3 shows emissions of individual greenhouse gases and net global warming impacts (GWI) for a selection of the stoves and fuels tested in that study.

The emissions are converted into CO_2 equivalent units using 20-year Global Warming Potentials and account for the efficiency of the stove so that the emissions from each stove can be directly compared on the basis of "energy delivered". The top graph shows results for each pollutant and the two lower graphs show the aggregate effects of all pollutants. The middle graph shows gases falling under the Kyoto Protocol with and without CO_2 for wood and charcoal while the bottom graph shows all PICs with a measurable warming effect with and without CO_2 (see [7] for a discussion justifying the analysis of GHGs not included in the Kyoto Protocol). All graphs use the same vertical scale. Excluding CO_2 from the assessment is a simple way to simulate sustainable biomass harvesting practices and including CO_2 implies that the biomass is not replaced at all. In the context of wood and charcoal in sub-Saharan Africa, the actual situation is obviously lies somewhere in the middle, but there is no reliable data on a national or regional level so we limit our analysis to the two extreme cases.

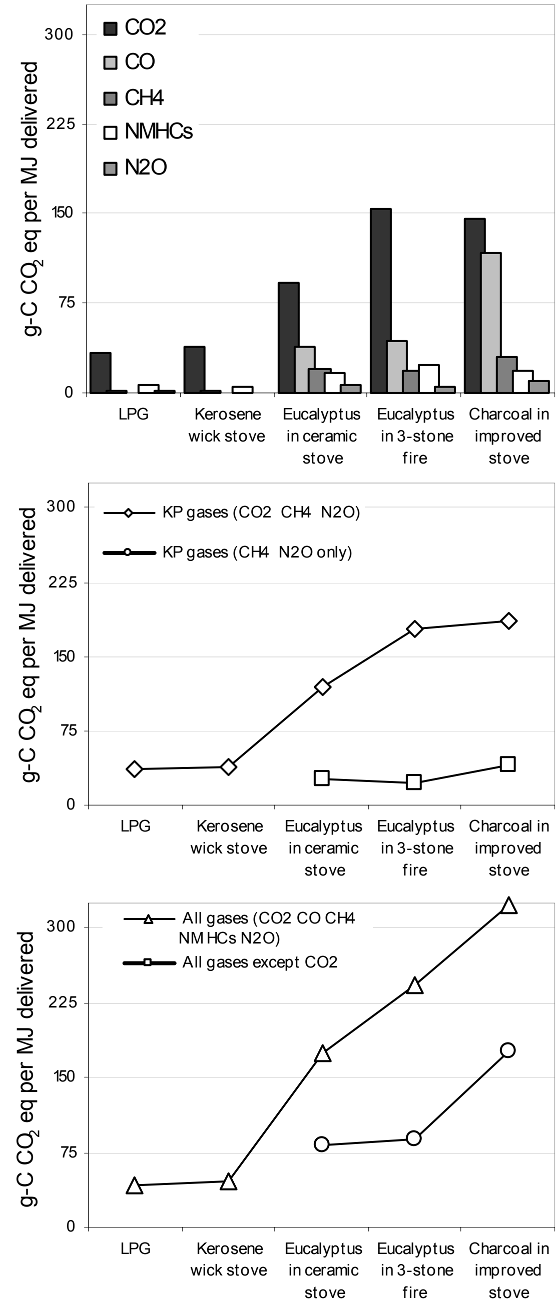

Figure 3: GHG emissions from common stove-fuel combinations as reported in [6].

A full comparison of the impact of household energy technologies requires more detailed analysis. Fossil fuels and charcoal are associated with substantial "upstream" emissions while unprocessed fuelwood is not. A more accurate impact assessment of long-lived pollutants that are dispersed globally should include "upstream" emissions including extraction, production, and distribution processes. The second study that we incorporate in this analysis measured the emissions from charcoal production in several developing countries, including typical earth-mound charcoal kilns in Kenya [8]. Charcoal production is an extremely GHG intensive activity because it is essentially wood pyrolisis with the gaseous products vented to the atmosphere. Figure 4 shows the results of four different empirical analyses of charcoal production from Africa. All pollutants are included, with the gases relevant for the Kyoto Protocol (CO_2 and CH_4) included in the lower two (solid) entries.

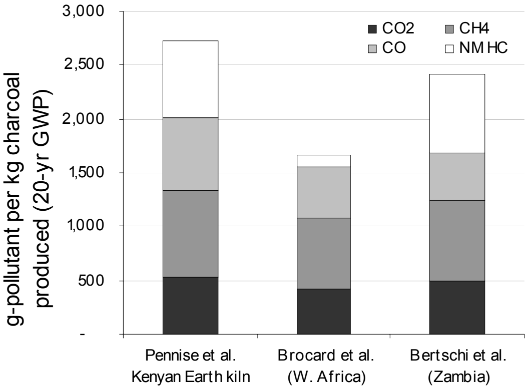

Figure 4: Emissions from charcoal production of each major pollutant showing pollutant mass per kg charcoal produced in C equivalent units weighted by 20-yr GWP (note: N_2O was reported for the Kenyan and W. African studies, but is negligible compared to other emissions).

We combine the results of this study with end-use emissions reported in the study described above to arrive at a full life-cycle GHG emissions estimate. To make the comprison, we estimate upstream emissions from fossil fuels like LPG or kerosene from Life-Cycle Assessment (LCA) models. We use one such program in our assessment [9]. We ackowledge that this model is based on emissions from the production of these fuels in the US economy, so that we only obtain an approximation of the emissions that are likely to occur in a developing country like Kenya. However, in the absence of better data, we opt to use this model for approximate emissions data.

We also include emissions from transportation of the fuels based on USEPA emissions factors for heavy-duty diesel trucks adjusted to reflect the age and condition of vehicles used to transport charcoal in Kenya [10]. Table I shows the result for one assessment: counting only gases that fall under the Kyoto Protocol (CO_2, CH_4, and N_2O), but assuming full biomass regeneration so that CO_2 is omitted from the assessment for wood and charcoal (assuming that regrowth of biomass removes it from the atmosphere). Our estimate shows that even in this ideal case, charcoal is associated with five to ten times the global warming impact of wood, and roughly five times worse than each fossil fuel. Table I shows a "best-case" scenario. If the woodfuels are not harvested sustainably or we consider the effects of gases that do not fall under Kyoto, but still have an impact on the atmospheric radiation budget [11], we find that charcoal has a still larger impact relative to other fuels. These results are shown in Table II.

Table I: g-C in CO_2 equivalents (20-yr GWP) released in each step of the fuel cycle per MJ-delivered to the pot for GHGs within the Kyoto Protocol (CO_2, CH_4, and N_2O).

	Production	Transport	End-use	Total
LPG	8.5	0.6	35.4	44.5
Kerosene wick stove	5.7	0.7	39.2	45.6
Eucalyptus in an open fire	0.0	1.1	22.6	23.8
Eucalyptus in a ceramic stove	0.0	0.7	26.7	27.4
Charcoal	174.1	1.6	39.6	215.3

Table II: Net life cycle GHG emissions for a range of GHG combinations expressed in terms of g-C (CO_2 equivalent units) per MJ delivered.

	Kyoto protocol gases		All gases	
	Ren biomass	Non-ren biomass	Ren biomass	Non-ren biomass
LPG	44.5	44.5	53.2	53.2
Kerosene wick stove	45.6	45.6	55.3	55.3
Eucalyptus in an open fire	23.8	178.2	28.9	244.6
Eucalyptus in a ceramic stove	27.4	119.0	34.7	174.8
Charcoal	215.3	470.6	485.6	867.5

With solid fuels in general, the same processes of incomplete combustion that release large amounts of GHG gases also release potentially harmful pollutants into the indoor environment. However, different fuels release these pollutants in different relative quantities, which means that the worst performer from the GHG point of view is not necessarily the worst gas in terms of health impacts.

This is especially true in the case of charcoal. Although it typically has poorer combustion efficencies than other solid fuels [6], the charcoal production process creates a fuel that burns with far less smoke than wood at the point of end-use, leading to lower emissions of PM. Of all of the common PICs released by solid fuel combustion, PM presents the greatest health threat.

3 HEALTH IMPACTS FROM HOUSEHOLD FUELS

This brings us to the third study that is incorporated in this analysis. This is an in-depth analysis of exposure to indoor air pollution in Kenyan households. 55 households were monitored for over 200 individual measurement-days [12, 13]. The study found that households using charcoal had significantly lower indoor concentrations of PM. Exposure to PM has a strong causal association with acute respiratory infection (ARI), one of the leading causes of illness and death in children under five worldwide [4, 5, 14]. Figure 5 shows the mean concentration of PM_{10} observed in these households (see supplemental data from [13]). The dashed line shows the USEPA's standard for exposure (24 hour average concentrations of PM_{10} should not exceed 150 $\mu g/m^3$).

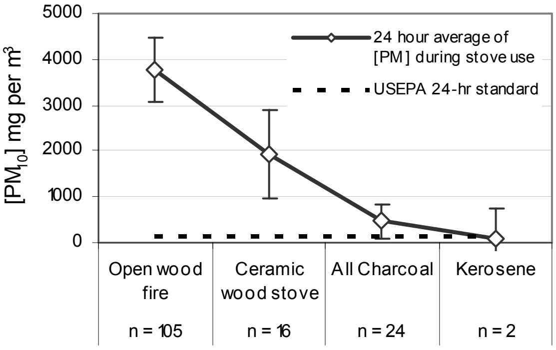

Figure 5: [PM_{10}] in 55 rural Kenyan homes using different cooking technologies (mean±95% CI).

This study also found a significant relationship between the incidence of respiratory illness and exposure to PM in the household. Table III shows the reduction in risk of contracting ALRI between groups of people using charcoal relative to groups using fuelwood (study groups were similar in demographic status). From Figure 5 it is clear that households using charcoal stoves typically have PM concentrations around 500 μg/m^3, while households using wood in an open fire have concentrations over 3000 μg/m^3. The risk of children under 5 contracting ALRI is 44% lower in households using charcoal rather than fuelwood. The reduction in risk for adult men (15-49) is very similar, while the reduction in risk for adult women is 65% [15].

Table III: Relative change in prevalence of ARI as a result of switching from wood to charcoal (from [15]).

		Open wood fire	**Charcoal stove**	**% difference in time spent with ARI**
Age	**Sex**	**% time spent with ARI (95% CI)**	**% time spent with ARI (95% CI)**	
0–4	F	0.05 (0.04–0.06)	0.03 (0.03–0.03)	44%
	M	0.06 (0.04–0.07)	0.03 (0.03–0.04)	44%
15–49	F	0.02 (0.02–0.02)	0.01 (0.00–0.01)	65%
	M	0.01 (0.01–0.01)	0.01 (0.00–0.01)	45%

4 DISCUSSION

This analysis shows that charcoal is associated with a very large GHG burden relative to other household energy options. For example, the total emissions from charcoal production and use in Kenya, one of the largest consumers of charcoal in SSA, are equivalent to emissions from transport and industry *even if all of the harvested wood is replaced*. However, charcoal is also associated with lower concentrations of indoor air pollution, which is a major cause if illness and death in developing countries. Charcoal has been associated with improved health in rural Kenyan households compaered to open wood burning [12, 15]. Although fuels such as LPG and kerosene burn with fewer emissions, these are not always viable options for fuel substitution among poor households because of cash constraints and lack of supply infrastructure. Similarly, clean-burning biofuels like bioethanol may be appropriate solutions in the long-term, but are not likely to satisfy household energy needs for poor rural consumers any time soon. Thus we raise the question of promoting charcoal as a near-term alternative to unprocessed fuelwood in areas where it is not already used. Of course, expanded charcoal utilization needs to be done in the context of a woodfuel sustainable supply. This presents a good opportunity for carbon finance mechanisms. The costs of carbon reductions through improved charcoal production techniques and sustainable woodland management for feedstock supply should be competitive with other forms of carbon emission reductions. In addition, this form of investment meshes very well with CDM goals of sustainable development. We will explore this further and provide estimations of the costs of both carbon offsets and expected health improvements in available through sustainable charcoal in forthcoming research.

4 REFERENCES

[1] Ribot, J.C., *Forest Policy and Charcoal Production in Senegal*. En. Pol., 1993. **21**(5): p. 559-585.
[2] Ellegård, A. and M. Nordström, *Charcoal Potential in Southern Africa: CHAPOSA*, in *Renewable Energy For Development*. 2003, Stockholm Environmental Institute (SEI): Stockholm. p. 4-6.
[3] WHO, *WHO Statistical Information System (WHOSIS)*. 2003.
[4] WHO, *World Health Report: Reducing Risks, Promoting Healthy Life*. 2002, WHO: Geneva.
[5] Bruce, N., R. Perez-Pedilla, and R. Albalak, *Indoor Air Pollution in Developing Countries: A Major Environmental and Public Health Challenge.* Bull. World Health Org., 2000. **78**(9): p. 1078-1092.
[6] Smith, K., et al., *Greenhouse Gases From Small-Scale Combustion Devices In Developing Countries Phase IIa: Household Stoves In India*. 2000, USEPA: Research Triangle Park, NC. p. 98.
[7] Smith, K., et al., *Greenhouse Implications of Household Stoves: An Analysis from India.* Ann. Rev. Energy Environmental., 2000. **25**: p. 741-763.
[8] Pennise, D., et al., *Emissions of Greenhouse Gases and Other Airborne Pollutants from Charcoal-Making in Kenya and Brazil.* Journal of Geophysical Research-Atmosphere, 2001. **106**: p. 24143-24155.
[9] Green Design Initiative, *Economic Input-Output Life Cycle Assessment method*. 2003, Carnegie Mellon University.
[10] USEPA, *Compilation of Air Pollutant Emission Factors*. 2000, USEPA.
[11] IPCC, *Climate Change 1995: Scientific-Technical Analyses of Impacts, Adaptations, and Mitigation of Climate Change*, ed. Watson, Zinyowera, and Moss. 1996, Cambridge, UK: Cambridge University Press.
[12] Ezzati, M. and D. Kammen, *Indoor Air Pollution from Biomass Combustion and Acute Respiratory Infections in Kenya: An Exposure Response Study.* The Lancet, 2001. **358**: p. 619-625.
[13] Ezzati, M., D. Kammen, and B. Mbinda, *Comparison of Emissions and Residential Exposure from Traditional and Improved Cookstoves in Kenya.* Env. Sci. Tech., 2000. **34**(4).
[14] Smith, K., et al., *Indoor Air Pollution in Developing Countries and Acute Respiratory Infections in Children.* Thorax, 2000. **55**: p. 518-532.
[15] Ezzati, M. and D. Kammen, *Evaluating Health Benefits of Transitions in Household Energy STechnology.* En. Pol., 2002. **30**(10): p. 815-826.