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LETTER

Outdoor cooking prevalence in developing countries and its implication for clean cooking policies

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Abstract

More than 3 billion people use wood fuels for their daily cooking needs, with detrimental health implications related to smoke emissions. Best practice global initiatives emphasize the dissemination of clean cooking stoves, but these are often expensive and suffer from interrupted supply chains that do not reach rural areas. This emphasis neglects that many households in the developing world cook outdoors. Our calculations suggest that for such households, the use of less expensive biomass cooking stoves can substantially reduce smoke exposure. The cost-effectiveness of clean cooking policies can thus be improved by taking cooking location and ventilation into account.

1. Introduction

In recent years, the promotion of clean cookstoves to reduce smoke exposure has received much attention in both academic and policy discussions. Indeed, much is at stake: more than 3 billion people in developing countries rely on firewood and charcoal for their daily cooking purposes. According to the World Health Organisation (WHO), the emitted smoke from cooking kills 4.3 million people every year—more deaths than are caused by malaria, tuberculosis and HIV combined—making it one of the most lethal environmental health risks (WHO 2014a, Martin et al 2011).

Under the auspices of the United Nations initiative Sustainable Energy for All (SE4All) and spearheaded by the Global Alliance for Clean Cookstoves (GACC), the international development community is currently embarking on a massive effort to spur universal adoption of clean cookstoves and fuels (GACC 2011, SE4All 2015). Achieving universal adoption is a laudable outcome, but one that faces substantial organizational and financial constraints. This raises the question of whether policies should concentrate on technologies and fuels that qualify as absolutely clean from a public health perspective, such as electricity, LPG, or advanced gasifier biomass stoves, or whether intermediate technologies such as simple improved biomass stoves should also be promoted under certain conditions (Simon et al 2014). Notwithstanding their considerably higher costs and often fragmented supply chains, a recent WHO report advocates the usage of primarily LPG and electricity or advanced gasifier biomass stoves. The justification is that these stoves have proven themselves in applied settings to substantially reduce fuel consumption and to improve health outcomes for cooks and accompanying children (WHO 2016).

In the present paper, we argue for an alternative prioritization that takes into account how smoke exposure is impacted by the interaction of cookstove technologies and cooking behaviors (Jeuland et al 2015). In this regard, where people cook—whether indoors or outdoors—has important implications for the particulate matter area concentration levels, ventilation, and thus smoke exposure (see Bensch and Peters 2015, DasGupta et al 2006, Yu 2011), but has nonetheless been widely neglected in debates about clean stove distribution. Impact potentials of stoves are higher if meals are prepared indoors. Conversely, if meals are prepared outdoors, natural ventilation reduces concentration levels considerably, with an associated reduction...
in the beneficial impact of the clean cookstove.Scarce public resources should consequently concentrate on distributing the most advanced cookstoves among households where indoor cooking prevails and hence exposure is highest. In areas where outdoor cooking dominates, much simpler—and cheaper—improved biomass stoves are potentially more cost effective in reducing the adverse effects of biomass cooking. Donors should of course continue to invest in and promote the distribution of clean cookstoves. But given that this process depends on LPG supply chains and the electricity grid, it is likely to take decades before all regions are covered. Hence, the targeted distribution of improved biomass cookstoves, coupled with the promotion of outdoor cooking and awareness raising campaigns to encourage better ventilation practices, can act as ‘bridging interventions’ while supply side bottlenecks are removed.

We develop this argument in two steps. Drawing on data from the Demographic and Health Surveys (DHS), we first document cooking behavior by country, which reveals a sizeable incidence of outdoor cooking. Next, we calculate hypothetical concentration level reductions for different stove types and ventilation scenarios and then categorize the stoves into different internationally recognized emissions categories, or tiers, that are used by SE4All to define which stove type qualifies as clean. Our exercise demonstrates that this multi-tier categorization heavily depends on where the cooking is done and the ventilation in the kitchen. Based on the documented heterogeneity in cooking patterns, we suggest that the dissemination of cheaper improved biomass stoves should be given serious consideration as a cost-effective instrument to bring down exposure levels among households that cook outdoors.

2. Policy and literature background

2.1. Health effects of household air pollution and cooking ventilation

The literature on health effects from air pollution distinguishes between emissions, concentration, and exposure. While emissions refer to the number and size of emitted particles by the cookstove, particulate matter concentration level refers to the concentration of the particulate matter in some area unit like a room. Exposure levels refer to the particulate matter that people are directly exposed to and thus inhale.

Exposure to particulate matter induced by biomass cooking affects health in various ways, and may lead to acute respiratory infections, stunted growth in children, pneumonia, chronic bronchitis in women, chronic obstructive pulmonary disease (COPD), cataracts and other visual impairments, cardiovascular diseases, lung cancer, tuberculosis and perinatal diseases (Po et al 2011, Ezzati and Kamen 2002, Amegah et al 2014, Dherani et al 2008, McCracken et al 2012, Hosgood et al 2010, Bruce et al 2013, Smith et al 2014). The WHO’s Global Burden of Disease/Comparative Risk Assessment Project estimates that the exposure to household air pollution from cooking with solid fuels caused 4.3 million premature deaths in 2012 (WHO 2014b).6

A small number of studies drawn from field surveys examine the particulate matter (PM) concentration level around the cooking location once the location is outdoors. The suggested range of the effect is broad. Balakrishnan et al (2002) find a reduction of particulate matter concentration between 40%–44% in India, while Rosa et al (2014) find a reduction of 57% in Rwanda. The highest estimate of which we are aware is from Albalat et al (1999), who find a 77% reduction in Bolivia. Research by van Vliet et al (2013) also finds that outdoor cooking concentrations are lower than indoor concentrations in Ghana, but they do not find a significant difference in exposure between outdoor- and indoor cooking households. Note that all these studies rely on cross-sectional comparison between non-randomized groups of outdoor and indoor cooking households, and thus the observed differences might to some degree be driven by unobservables.7

Evidence on the relationship between outdoor cooking and health is likewise scant. Rehfuess et al (2009) and Buchner and Rehfuess (2015) conduct cross country studies among 16 African countries and 9 Sub-Saharan countries, respectively, finding a lower incidence of acute lower respiratory infections among children that results from improved ventilation and cooking outdoors. Langbein (2017) analyzes the role of cooking location on the incidence of respiratory diseases among children in Africa, Asia, and Latin America. He estimates that outdoor cooking reduces the incidence by upwards of 11%. Bensch and Peters (2015) observe a surprising improvement in self-reported health indicators for an ICS whose design is not expected to generate health effects. They suggest that a reduction in smoke exposure due to a shorter cooking duration and increased outside cooking might explain this result.

2.2. Policy background

The different levels of cleanliness of stoves are accounted for in SE4All’s Global Tracking Framework (GTF), which uses a four-tier system to categorize ICS and track the progress towards universal access

5 See Grabow et al (2013) for results in a laboratory environment and Rosa et al (2014) for results in a field environment.

6 Note that unlike the health outcomes associated with household air pollution, the estimated burden is based on the following five diseases only: Acute respiratory infections in children, COPD; ischemic heart disease, stroke, and lung cancer in adults.

7 Since parts of our analysis in this paper is based on this literature, table 1 in the online supplementary material provides a summary of these four studies.
to modern energy. These four tiers, defined according to measurements that are done under standardized indoor conditions, are also used as a reference by WHO, GACC, and other actors in the clean cooking policy scene. The GTF evaluates cookstoves in the four categories of efficiency, safety, indoor emissions, and total emissions for a high- and low-power scenario, with the latter categories and their respective tiers shown in table 1.

While all stakeholders are dedicated to eradicating energy poverty and to providing households with improved cookstoves, the understanding of what exactly constitutes an improved cookstove differs between the different actors. Many non-governmental organizations and most African governments focus on affordable simple technologies. Although these stoves, which fall under Tiers 1, 2, and 3, are not designed to completely eliminate smoke emissions, they generate co-benefits related to deforestation, climate, time and monetary savings (see for example Bensch et al. 2013, Bensch et al. 2015, Beyene et al. 2015, Jagger and Perez-Heydrich et al. 2016, Jeuland and Pattanayak et al. 2012, Köhlin et al. 2015, Martin et al. 2011, Pattanayak et al. 2016). WHO and GACC, by contrast, clearly concentrate on the adverse health effects of woodfuel cooking and thus only consider an improved cook stove (ICS) as improved if it is classified as Tier 4. The rationale behind this is the non-linear particulate exposure-response relation found in epidemiological research, which suggests that large reductions in smoke exposure are required in order to ensure positive health effects (see for example Ezzati and Kammen 2002, Pope et al. 2011, or Burnett et al. 2014). In this regard, even the concentration levels reached outdoors are not considered as clean by the WHO.

Based on the emerging evidence of positive health impacts from outdoor cooking, the present paper takes a different tact. Our argument assumes that improved ventilation—with outdoor cooking being the extreme case—can have a considerable effect on particulate matter concentration levels and thus, on exposure. Hence, the cooking location should be taken into account when decisions are taken on whether to consider a certain stove as clean and, consequently, whether to consider it for promotion. The benefit from promoting outdoor cooking as a bridging intervention is magnified by the widespread practice of stove stacking, whereby multiple stove types are used simultaneously. Research has shown that even after the introduction of clean cookstoves, people continue to use traditional techniques (Jeuland et al. 2015, Simons et al. 2017). Although some may move the most polluting actions for periodic uses outside, those who remain indoors will be exposed to dangerous levels of smoke.

3. Data

We use data from the latest waves of the nationally representative DHS. The data have been regularly collected in around 90 low-and middle-income countries since 1984. For our purpose, we only included low and lower middle income countries in Africa, Latin America and South-East Asia as defined by the World Bank, thereby excluding Brazil and the Maldives. Due to data regulations, not all countries that fit this classification could be included in the analysis.8

Information on the cooking location is only available for those countries where the latest available wave (wave 6) or the second latest available wave (wave 5) of the standard DHS questionnaire was conducted.9 If information in two waves were available for one country, we used the latest wave. This leaves us with a sample of 40 countries and 650,723 household observations for the years 2006 to 2014. Most of the included countries are situated in Africa (30), followed by Asia (6) and Latin America (4).10

The DHS questionnaires contain questions regarding cooking behavior, including stove usage, cooking fuels, and cooking location. We restrict our interest to the question on the cooking location, which asks households whether they usually cook in the house, in a separate building, or outside.11 It was not possible to give multiple answers, as may be relevant, for example, if a household changes cooking location according to the season.

We divide the sample between rural and urban areas, since we expect different outdoor cooking patterns for these two groups. All results are furthermore

8 This excludes Cambodia, Eritrea, Equatorial Guinea, Samoa, Sri Lanka, Vietnam and Yemen.
9 This excludes Botswana, Cape Verde, Central African Republic, Colombia, Guatemala, Guyana, Laos, Mauritania, Paraguay, Sao Tomé and Principe, South Africa, Swaziland and Tanzania.
10 See table A1 in the appendix for a list of included countries and respective number of observations.
11 Solid fuel use can indeed be expected to be most harmful when used inside and in particular in the main building. Tables 2 and 3 in the online supplementary material shows the fuel use patterns for those households that cook in the main building.

### Table 1. Emissions and indoor emissions tiers of performance levels.

|                           | Tier 0 | Tier 1 | Tier 2 | Tier 3 | Tier 4 |
|---------------------------|--------|--------|--------|--------|--------|
| Indoor emission PM$_{2.5}$ (mg min$^{-1}$) | $> 40$ | $\leq 40$ | $\leq 17$ | $\leq 8$ | $\leq 2$ |
| Emissions in high power scenario PM$_{2.5}$ (mg MJ$^{-1}$) | $> 979$ | $\leq 979$ | $\leq 386$ | $\leq 168$ | $\leq 41$ |
| Emissions in low power scenario PM$_{2.5}$ (mg min$^{-1}$) | $> 8$ | $\leq 8$ | $\leq 4$ | $\leq 2$ | $\leq 1$ |

Source: International Organization for Standardization (2012).
weighted to ensure nationally representative results, with the weights provided by the DHS.

4. Outdoor cooking prevalence

As seen from figures 1 and 2, outside cooking is prevalent in both the urban and rural areas of many developing countries, reaching a high of nearly 80% in rural Niger. Notwithstanding substantial heterogeneity, a few patterns in the data are evident. Out of the 20 countries with the highest outdoor cooking rates, 18 are located in Africa. Further differentiating within the African continent shows that West African countries have the highest share of outdoor cooking. Among the ten countries with the highest outdoor cooking rates, seven are in West Africa. At the other end of the spectrum, the four countries with the lowest outdoor cooking rates are spread across South America, the Caribbean, South East Asia, and Asia, with Pakistan registering the lowest rate of about 1%.

Large differences between urban and rural outside cooking patterns are seen in some countries. We take a closer look at only those countries with more than 15 percentage points difference in rural and urban...
outdoor cooking patterns. This yields two different types of countries, all based in Africa: those in which more households cook outside in rural areas than in urban areas (Benin, Gabon, Lesotho and Namibia) and those in which more households cook less outside in rural areas than in urban areas (Burundi, Republic of the Congo, Democratic Republic of the Congo, Guinea, Liberia, Madagascar, Malawi and Uganda). For all other countries, no major difference between household cooking patterns in rural and urban areas is observed.

5. Implications for air pollution—a stylized numerical comparison

The variation in cooking location has considerable implications for the emission-concentration-exposure nexus of cooking induced smoke. In this section, we provide a back-of-the-envelope calculation of particulate matter levels for different stove types according to whether the stove is used indoors or outdoors. The aim is to show that the effective cleanliness of a stove is profoundly impacted by this distinction. We use as cleanliness categories the tiers as defined in the SE4All Global Tracking Framework (see table 1). Our analysis includes stoves from tiers zero to three. Tier four stoves are mostly those that run on electricity and LPG, so virtually free of smoke emissions and thus not relevant to this analysis. All stoves included in our analysis have in common that they are non-traditional, portable, household biomass stoves without a chimney and not used for commercial purposes. 12

12 See table A2 in the appendix for a list of the cookstoves, their categories, fuel and retail price.
We focus on the high power scenario results, since emissions tend to be higher during this phase. Results for the low power scenario are presented in supplementary table 3 available at stacks.iop.org/ERL/12/115008/mmedia. The two scenarios are complementary: while the high power scenario simulates the actual high power use of the cookstove, such as quickly boiling water, the low power scenario simulates the long simmering of legumes or pulses (GACC 2014). The scenarios are nonetheless just a proxy indicator for actual field use, as they do not capture behavioral confounders such as stove stacking, misuse and inappropriate cooking stoves for local practices (Beltramo and Levine 2013).

For the cookstoves examined, we rely on emissions figures from Jetter et al (2012), who analyzes the emission of 22 cookstoves in a controlled laboratory environment. The selection of stoves in Jetter et al (2012) is based on availability, which excludes a large number of other non-standard stoves and chimney stoves, but covers those most widely disseminated. The authors measure the emission (in mg min\(^{-1}\)) from a low power and a high power scenario as defined in the Water Boiling Test (WBT) protocol. Although WBTs undoubtedly diverge from actual field use, they have the virtue of allowing comparison of many cookstoves under identical circumstances.\(^{13}\)

We focus on the high power scenario results, since emissions tend to be higher during this phase. Results for the low power scenario are presented in supplementary table 3 available at stacks.iop.org/ERL/12/115008/mmedia. The two scenarios are complementary: while the high power scenario simulates the actual high power use of the cookstove, such as quickly boiling water, the low power scenario simulates the long simmering of legumes or pulses (GACC 2014). The scenarios are nonetheless just a proxy indicator for actual field use, as they do not capture behavioral confounders such as stove stacking, misuse and inappropriate cooking stoves for local practices (Beltramo and Levine 2013).

The first four columns of table 2 show the cooking device, associated cooking fuel, indoor emissions and their tiers for the high power scenario. Among the cooking devices, values are presented for both a minimally tended and carefully tended three stone fire, as this is the most prevalent cooking technology in developing countries. Indoor emission rates vary considerably for the high power scenario, as can be seen in column 3 of table 2.

Based on the cookstove and their respective indoor emissions (measured in mg min\(^{-1}\)) depicted in table 2, we calculate average PM\(_{2.5}\) concentration levels (measured in \(\mu g\) m\(^{-3}\)) in the kitchen during cooking time. To this end, we apply a variant of the single zone box model developed by Johnson et al (2011), which was refined for easier implementation by the Aprovecho.

### Table 2. Cookstove emissions in the high power scenario.

| Cookstove device | Fuel | Indoor emissions, tiers and PM\(_{2.5}\) average concentration level during cooking time (\(\mu g\) m\(^{-3}\)) | Assumed outdoor reduction level and PM\(_{2.5}\) average concentration level during cooking time (\(\mu g\) m\(^{-3}\)) |
|------------------|------|------------------------------------------------------------------|-------------------------------------------------|
|                  | Emission (mg min\(^{-1}\)) | Tier | Concentration level (\(\mu g\) m\(^{-3}\)) | 40% | 60% | 80% |
| Three stone minimally tended | Wood | 93.8 | 0 | 7373 | 4424 | 2949 | 1475 |
| Three stone carefully tended | Wood | 56.9 | 0 | 4473 | 2684 | 1789 | 895 |
| Envirofit—G3300 | Wood | 52.6 | 0 | 4135 | 2481 | 1654 | 827 |
| Philips HD4008 Natural Draft | Wood | 53.8 | 0 | 4229 | 2537 | 1692 | 846 |
| Sampada | Wood | 56.9 | 0 | 4473 | 2684 | 1789 | 895 |
| StoveTec Greenfire | Wood | 46.3 | 0 | 3639 | 2183 | 1456 | 728 |
| Upezi Portable | Wood | 69.2 | 0 | 5440 | 3264 | 2176 | 1088 |
| GERES | Charcoal | 44.2 | 0 | 3474 | 2084 | 1390 | 695 |
| Gypsy | Charcoal | 26.0 | 1 | 2044 | 1226 | 818 | 409 |
| Jiko Ceramic | Charcoal | 22.6 | 1 | 1776 | 1066 | 710 | 355 |
| Jiko Metal | Charcoal | 17.5 | 1 | 1376 | 826 | 550 | 275 |
| KCJ Standard | Charcoal | 18.3 | 1 | 1438 | 863 | 575 | 288 |
| Kenya Uhai | Charcoal | 20.8 | 1 | 1635 | 981 | 654 | 327 |
| StoveTec Charcoal | Charcoal | 26.3 | 1 | 2067 | 1240 | 827 | 413 |
| StoveTec Greenfire, reduced fuel feed Wood | Wood | 25.1 | 1 | 1973 | 1184 | 789 | 395 |
| Mayon Turbo | Rice hulls | 31.3 | 1 | 2460 | 1476 | 984 | 492 |
| Berkeley Darfur | Wood | 18.4 | 1 | 1446 | 868 | 578 | 289 |
| Envirofit—G3300, reduced fuel feed Wood | Wood | 23.2 | 1 | 1824 | 1184 | 789 | 395 |
| Protos | Plant oil | 34.5 | 1 | 2712 | 1627 | 1085 | 542 |
| Belonio | Rice hulls | 8.2 | 2 | 645 | 387 | 258 | 129 |
| Philips HD4012 fan | Wood | 6.6 | 6 | 519 | 311 | 208 | 104 |
| Oorja Stove | Biomass pellets | 2.9 | 3 | 228 | 137 | 91 | 46 |
| StoveTec TLUD | Wood pellets | 4.4 | 3 | 346 | 208 | 138 | 69 |

Note: High power scenario refers to a scenario of the Water Boiling Test where the indoor emission is measured in the time from the start of the cooking process until a 5 l pot of water is boiling. This is done with a cold start, where the cookstove has not been used for some time before and a hot start where the stove was used immediately before. For the high power scenario values here, the average is taken for the values obtained in the hot start and cold start scenario as it was done by Jetter et al (2012). Cooking time is assumed to be 4 h and the average value during cooking time is taken for the concentration level.

Source: Jetter et al (2012) and own calculations.

\(^{13}\) A typical WBT consists of three phases that immediately follow each other: A cold start high power phase, in which a measured quantity of water is boiled. After the first phase, the water is replaced by new water. This is called the high power, hot start phase. After the water is again boiled, in the last phase (low power), the water simmers just below boiling point for 45 min. For the high power values the average is calculated for the emissions from the two high power phases (see GACC 2014 for a detailed description of the procedure).
Figure 3. Indoor emissions, outdoor cooking reduction and tiers. Own calculation based on Jetter et al (2012).
stove is within tier 1 with indoor emissions, but tier 2 assuming an outdoor reduction of 40% and tier 3 in case of a reduction of 60% or 80%.

These examples illustrate that when scarce public resources constrain the coverage of an intervention to disseminate clean cookstoves, which can cost upwards of USD$90, consideration of cooking location should be at least one of the factors that bears on the decision of which region is targeted, prioritizing those regions where indoor cooking predominates. This prioritization applies equally to instances where stoves are not disseminated gratis but in exchange for partial or full payment, given that affordability is one of the documented barriers to adoption of lower-cost cooking technologies using market based dissemination (Betrano et al 2016, Bensch et al 2015, Mobarak et al 2012, Lewis and Pattanayak 2012, Pattanayak et al 2016).

6. Limitations

The above analysis provides an indicative estimate of the potential for ICSs to improve health, but it is subject to several technical and behavioral simplifications that should be relaxed in future research. Perhaps most importantly, research is needed on area concentration and smoke exposure under different ventilation conditions as well as cooking locations using rigorous evaluation methods that rely on real-world data rather than laboratory tests. For example, negative health effects may also result from disseminating bricked stoves installed in kitchens because people switch from outside to inside cooking. Furthermore, there may also be a negative impact from ambient air pollution to those cooking outside that would increase if everyone cooked outside, though this effect is likely to be small in comparison to indoor air pollution, particularly in rural areas. Seasonal variation is another area warranting study. In this regard, the extent to which households that otherwise cook outdoors move indoors during inclement weather cannot be discerned from the DHS data.

7. Conclusion

Although large cookstove initiatives are currently slated for implementation, reaching the target of universal adoption of clean cookstoves and fuels is a long-term endeavor that will require massive investments extending well beyond current commitments. Given the urgency and breadth of the challenges, it behooves development agencies to chart a course of improved cookstove distribution that accounts for the interaction of this new technology with cooking behaviors. This paper has argued that the cooking location—whether indoors or outdoors—is a key mediating factor on the effectiveness of clean cookstove adoption. We further document that outdoor cooking rates are high but vary tremendously between countries and continents as well as between rural and urban areas. Our main conclusion is that while clean cookstoves are the best option to reduce the exposure to air pollution among households that cook indoors, simple improved biomass stoves are potentially the more cost-efficient policy intervention in regions where outdoor cooking prevails. While we do not claim that ventilation and outdoor cooking brings exposure levels down to what is optimal from a public health perspective, it is the absence of affordable solutions in most of rural Africa that makes our finding very pertinent. For these parts of the world, it is unlikely that in the years to come LPG-supply chain bottlenecks will be solved or the electricity grid will be rolled out. Given these constraints, simple improved biomass stoves and better ventilation thus appear as a second-best solution. Behavioral change interventions, such as health education that sensitizes to ventilation, and the coupling of those interventions with cookstove distribution, is another promising avenue for reducing smoke exposure (e.g. Barnes 2014, Grabow et al 2013, Zhou et al 2006).

Acknowledgments

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## Appendix

### Table A1. Overview of the countries, survey years and number of observations.

| Country                  | Continent (Region) | Survey year | Rural areas | Urban areas |
|--------------------------|--------------------|-------------|-------------|-------------|
| Bangladesh               | Asia               | 2011        | 12 823      | 4291        |
| Benin                    | Africa (West)      | 2012        | 9631        | 7599        |
| Burkina Faso             | Africa (West)      | 2010        | 10 590      | 3444        |
| Burundi                  | Africa (East)      | 2010        | 7711        | 718         |
| Cameroon                 | Africa (Central/South) | 2011      | 6820        | 6951        |
| Comoros                  | Africa (East)      | 2012        | 2936        | 1467        |
| Republic of the Congo    | Africa (Central/South) | 2012     | 4238        | 7190        |
| Cote d'Ivoire            | Africa (West)      | 2012        | 4921        | 4064        |
| Dominican Republic       | Latin America      | 2013        | 2909        | 7987        |
| Democratic Republic of the Congo | Africa (Central/South) | 2014      | 12 344      | 5695        |
| Ethiopia                 | Africa (East)      | 2011        | 12 809      | 3569        |
| Gabon                    | Africa (Central/South) | 2012      | 1591        | 7636        |
| Gambia                   | Africa (East)      | 2013        | 2480        | 3330        |
| Ghana                    | Africa (West)      | 2008        | 5997        | 5385        |
| Guinea                   | Africa (West)      | 2012        | 4715        | 2205        |
| Haiti                    | Latin America      | 2012        | 7555        | 5162        |
| Honduras                 | Latin America      | 2012        | 10 021      | 10 785      |
| India                    | Asia               | 2006        | 73 293      | 35 309      |
| Indonesia                | Asia               | 2012        | 22 156      | 20 688      |
| Kenya                    | Africa (East)      | 2009        | 6662        | 2315        |
| Lesotho                  | Africa (Central/South) | 2009      | 6595        | 2771        |
| Liberia                  | Africa (West)      | 2013        | 4015        | 5145        |
| Madagascar               | Africa (East)      | 2009        | 15 091      | 2719        |
| Malawi                   | Africa (East)      | 2010        | 20 676      | 4104        |
| Mali                     | Africa (West)      | 2013        | 7825        | 2105        |
| Mozambique               | Africa (East)      | 2011        | 9697        | 4141        |
| Namibia                  | Africa (Central/South) | 2013     | 4718        | 5092        |
| Nepal                    | Asia               | 2011        | 9212        | 1531        |
| Niger                    | Africa (West)      | 2012        | 8815        | 1707        |
| Nigeria                  | Africa (East)      | 2013        | 21 344      | 16 099      |
| Pakistan                 | Asia               | 2013        | 8529        | 4370        |
| Peru                     | Latin America      | 2011        | 7965        | 17 366      |
| Philippines              | Asia               | 2013        | 7671        | 7049        |
| Rwanda                   | Africa (East)      | 2010        | 10 675      | 1701        |
| Senegal                  | Africa (East)      | 2011        | 4016        | 3770        |
| Sierra Leone             | Africa (West)      | 2013        | 8531        | 3845        |
| Togo                     | Africa (West)      | 2014        | 5285        | 4096        |
| Uganda                   | Africa (East)      | 2011        | 7222        | 1578        |
| Zambia                   | Africa (East)      | 2014        | 9259        | 6631        |
| Zimbabwe 2011            | Africa (East)      | 2011        | 6463        | 3287        |

**Total**: 405 806 244 917

### Table A2. Characteristics of the included cookstoves.

| Cooking device                                | Category                          | Fuel            | Retail price (in US-dollar) |
|------------------------------------------------|-----------------------------------|-----------------|----------------------------|
| 3 stone minimally tended                       | No stove                          | Wood            | 0                          |
| 3 stone carefully tended                       | No stove                          | Wood            | 0                          |
| Enviroti—G3300                                | Natural draft stove               | Wood            | 31                         |
| Philips HD4008 Natural Draft                   | Natural draft stove               | Wood            | 31                         |
| Sampada                                        | Natural draft stove               | Wood            | 38                         |
| StoveTec Greenfire, reduced fuel feed          | Natural draft stove               | Wood            | 9                          |
| Upesi Portable                                | Natural draft stove               | Wood            | 9.5                        |
| GERES                                          | Charcoal stove                    | Charcoal        | 3.5                        |
| Gyapa                                          | Charcoal stove                    | Charcoal        | N/A                        |
| Jiko Ceramic                                   | Charcoal stove                    | Charcoal        | N/A                        |
| Jiko Metal                                     | Charcoal stove                    | Charcoal        | N/A                        |
| KCL Standard                                   | Charcoal stove                    | Charcoal        | 6                          |
| Kenya Ubai                                     | Charcoal stove                    | Charcoal        | 11                         |
| StoveTec Charcoal                              | Charcoal stove                    | Charcoal        | N/A                        |
| StoveTec Greenfire, reduced fuel feed          | Natural draft stove               | Wood            | 9                          |
| Mayon Turbo                                    | Natural draft stove               | Rice Hulls      | 15                         |
| Berkeley Darfur                                | Natural draft stove               | Wood            | 25                         |
| Enviroti—G3300, reduced fuel feed             | Natural draft stove               | Wood            | 31                         |
| Protos                                         | Liquid Fuel Stove                 | Plant Oil       | 50                         |
| Belonio                                        | Forced draft stove                | Rice Hulls      | 40                         |
| Philips HD4012 fan                             | Forced draft stove                | Wood            | 89                         |
| Oorja Stove                                    | Forced draft stove                | Biomass Pellets | N/A                        |
| StoveTec TLUD                                   | Natural draft stove               | Wood Pellets    | N/A                        |

*Source: Jetter et al (2012).*
Table A3. Cookstove emissions for the low power scenario.

| Cooking device | Fuel          | Indoor emissions, tiers and PM$_{2.5}$ average concentration level during cooking time ($\mu g m^{-3}$) | Assumed outdoor reduction level and PM$_{2.5}$ average concentration level during cooking time ($\mu g m^{-3}$) |
|----------------|---------------|-------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------|
|                |               | Emission Tier                                                                                   | 40%                                                                                               |
|                |               | Concentration level ($\mu g m^{-3}$)                                                             | 60%                                                                                               |
|                |               |                                                                                                 | 80%                                                                                               |

| 3 stone minimally tended | Wood | 70.2 | 0 | 5518 | 3311 | 2207 | 1104 |
| 3 stone carefully tended | Wood | 42.8 | 0 | 3364 | 2018 | 1346 | 673  |
| Environ-F5300 | Wood | 11.3 | 2 | 888 | 533 | 335 | 178 |
| Philips HD4008 Natural Draft | Wood | 29 | 1 | 2280 | 1368 | 912 | 456 |
| SampaDa | Wood | 33 | 1 | 2594 | 1556 | 1038 | 519 |
| StoveTecGreenfire | Wood | 13.4 | 2 | 1033 | 632 | 421 | 211 |
| Upesi Portable | Wood | 31.3 | 1 | 2480 | 1476 | 984 | 492 |
| GERES | Charcoal | 4.9 | 3 | 385 | 231 | 154 | 77 |
| Guaya | Charcoal | 6.4 | 3 | 503 | 302 | 201 | 101 |
| Jiko Ceramic | Charcoal | 4.7 | 3 | 369 | 221 | 148 | 74 |
| Jiko Metal | Charcoal | 1.3 | 1 | 102 | 61 | 41 | 20 |
| KCI Standard | Charcoal | 1.9 | 4 | 149 | 89 | 60 | 30 |
| Kenya Uhai | Charcoal | 1.2 | 4 | 94 | 56 | 38 | 19 |
| StoveTecCharcoal | Charcoal | 6.6 | 3 | 519 | 311 | 208 | 104 |
| StoveTecGreenfire, reduced fuel feed | Wood | 14.7 | 2 | 1156 | 694 | 462 | 231 |
| Mayon Turbo | Rice Hulls | 37.6 | 1 | 2956 | 1774 | 1182 | 591 |
| Berkeley Darfur | Wood | 16.8 | 2 | 1321 | 793 | 528 | 264 |
| Environ-F5300, reduced fuel feed | Wood | 9.3 | 2 | 731 | 439 | 292 | 146 |
| Protons | Plant Oil | 34.8 | 1 | 2735 | 1641 | 1094 | 547 |
| Belonio | Rice Hulls | 15.7 | 2 | 1234 | 740 | 494 | 247 |
| StoveTecGreenfire | Wood | 6.6 | 3 | 519 | 311 | 208 | 104 |
| Ooruja Stove | Biomass Pellets | 6.1 | 3 | 479 | 287 | 192 | 96 |
| StoveTec TLUD | Wood Pellets | 2.3 | 3 | 181 | 109 | 72 | 36 |

Note: Compared to the high power scenario is the water in the low power scenario not boiled but simmers for 45 min.

Source: letter et al (2012).

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