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# Outdoor Cooking Prevalence in Developing Countries and its Implication for Clean Cooking Policies

## Abstract

*More than 3 billion people use wood fuels for their daily cooking needs, with detrimental health implications related to smoke emissions. Global initiatives to disseminate clean cooking stoves emphasize technologies that are either expensive, such as electricity and gasifier stoves, or for which supply chains hardly reach rural areas, such as LPG. This emphasis neglects that many households in the developing world cook outdoors. Our calculations demonstrate that for such households, already 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.*

*JEL Classification: Q53, I12, O13*

*Keywords: Air pollution; health behavior; energy access*

*March 2017*

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# 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 household air pollution 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, 2016; Martin, 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 (Simon et al. 2014). Notwithstanding their considerably higher costs and often fragmented supply chains, a recent WHO report advocates “energy solutions that are clean for health at the point-of-use” (WHO, 2016, p. 87), these being primarily LPG and electricity or advanced gasifier biomass stoves.

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 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 exposure considerably, with an associated reduction in the beneficial impact of the clean cookstove.[1] 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.

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 exposure reductions for different stove types and ventilation scenarios and then categorize the stoves into different internationally recognized emissions categories, or tiers. This exercise demonstrates that depending on the scenario, stoves that would otherwise be categorized in the lowest tier (Tier-Zero), are re-categorized in higher tiers when used outdoors. Based on the documented heterogeneity in cooking patterns, we suggest that the distribution of cheaper biomass stoves should be given serious consideration as a cost-effective instrument to bring down exposure levels among households that cook outdoors.

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

# 2 Policy and literature background

## 2.1 Health effects of household air pollution and cooking ventilation

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 Kammen, 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 estimated that the exposure to household air pollution from cooking with solid fuels caused 4.3 million premature deaths in 2012 (WHO, 2016).

There are only two studies that systematically analyze the effect of outdoor cooking on health. Rehfuess et al. (2009) and Buchner and Rehfuess (2015) conduct cross country studies among 16 African countries and 9 Sub-Saharan countries, respectively, finding that the effect of cooking with solids fuels on acute lower respiratory infections varies among children with regards to ventilation practices and the cooking location. 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 provide explorative evidence for the transmission channel and find that a reduction in smoke exposure due to a shorter cooking duration and increased outside cooking might explain this result.

A few studies drawn from cross-sectional field surveys examine the particulate matter (PM) concentration level once the cooking location is outdoors. The suggested range of the effect is broad. Balakrishnan et al. (2002) find a reduction of particulate matter concentration between 40 and 44 percent in India, while Rosa et al. (2014) find a reduction of 57 percent in Rwanda. The highest estimate of which we are aware is from Albalak et al. (1999), who find a 77 percent reduction in Bolivia.

## 2.2 Policy background

Improved cooking is high on the agenda of international policy, spearheaded by WHO and the Global Alliance for Clean Cookstoves. 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 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.

**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) | >40 | ≤40 | ≤17 | ≤8 | ≤2 |
| Emissions in high power scenario $PM_{2.5}$ ($mg/MJ_d$) | >979 | ≤979 | ≤386 | ≤168 | ≤ 41 |
| Emissions in low power scenario $PM_{2.5}$ (mg/min/L) | >8 | ≤8 | ≤4 | ≤2 | ≤1 |

*Source:* ISO, 2012

While all stakeholders are dedicated to eradicate energy poverty and to provide 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 that are designed to save fuels in order to reduce deforestation pressures and improve livelihoods through reduced firewood collection time or charcoal expenditures. These stoves, which fall under Tiers 1, 2, and 3, are not designed to completely eliminate smoke emissions. WHO and GACC, by contrast, clearly concentrate on the adverse health effects of woodfuel cooking and thus only consider an ICS as improved if it is classified as Tier 4. The rationale behind this is the so-called non-linear particulate exposure-response relation found in medical 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; Burnett et al., 2014).

The present paper argues that cooking behavior that affects ventilation, particularly outdoor cooking, can have a considerable effect on particulate matter exposure and 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.

# 3 Data

We use data from the latest waves of the nationally representative Demographic and Health Surveys (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.[2] 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

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[2] This excludes Cambodia, Eritrea, Equatorial Guinea, Samoa, Sri Lanka, Vietnam, and Yemen.

was conducted.[3] 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).[4]

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 place. Households that cook at home were asked whether they usually cook in the house, in a separate building, or outside. It was not possible to give multiple answers.

We divide the sample between rural and urban areas, since we expect different outdoor cooking patterns for these two groups. All results are furthermore 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 percent in rural Niger. Notwithstanding substantial heterogeneity, a few patterns in the data can be discerned. Out of the 20 countries with the highest outdoor cooking rates, 18 are located in Africa. Further differencing 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

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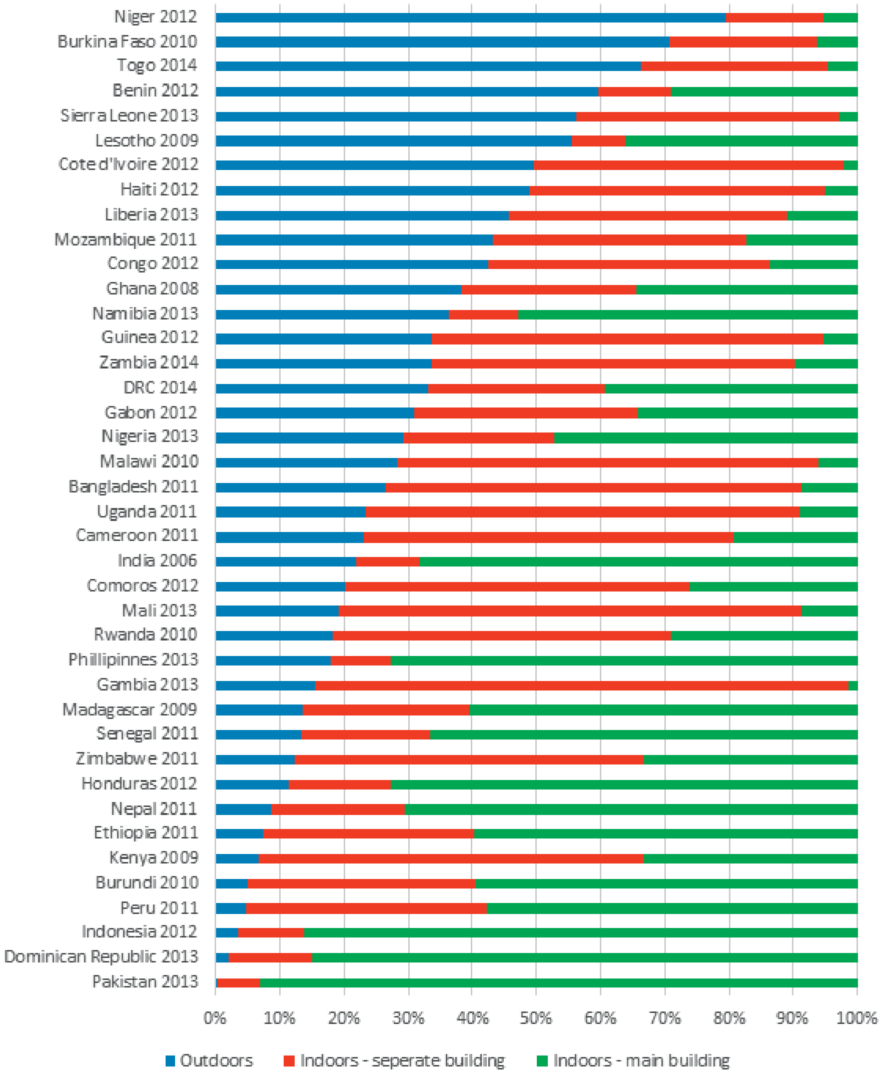
[3] This excludes Botswana, Cape Verde, Central African Republic, Colombia, Guatemala, Guyana, Laos, Mauritania, Paraguay, Sao Tome and Principe, South Africa, Swaziland, and Tanzania.

[4] See Table A.1 in the Appendix for a list of included countries and respective number of observations.

Caribbean, South East Asia and Asia, with Pakistan registering the lowest rate of about 1 percent.

Large differences between urban and rural outside cooking patterns are evident 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.

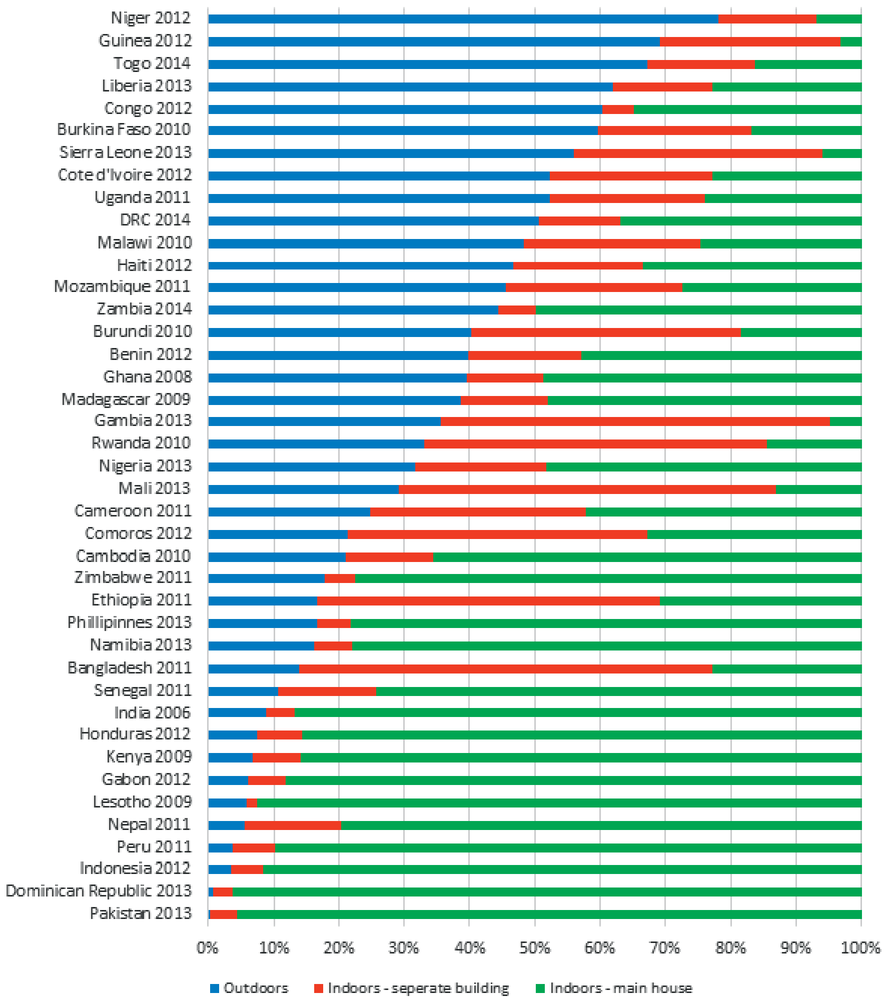
**Figure 1:** Cooking place in rural areas in developing countries



*Note:* DRC refers to Democratic Republic of Congo and Congo refers to Republic of Congo.

*Source:* Demographic and Health surveys (2006-2014)

**Figure 2:** Cooking place in urban areas in developing countries



*Note:* DRC refers to Democratic Republic of Congo and Congo refers to Republic of Congo.

*Source:* Demographic and Health surveys (2006-2014)

# 5 Implications for air pollution - a stylized numerical comparison

The variation in cooking location has considerable implications for the emission-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 in Section 2.2). 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. All stoves have in common that they are non-traditional, portable, household biomass stoves without a chimney and not used for commercial purposes.[5]

For the cookstoves examined, we rely on emissions figures from Jetter et al. (2012), who analyze the emission of 22 cookstoves in a controlled environment in the laboratory. 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/minute) from a low power and a high power scenario as defined in the Water Boiling Test Protocol. Although Water Boiling Tests undoubtedly diverge from actual field use, they have the virtue of allowing comparison of many cookstoves under identical circumstances.[6]

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[5] See Table A.2 in the Appendix for a list of the cookstoves, their categories, fuel and retail price.

[6] 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 minutes. For the

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 Table A.3 in the Appendix. Whereas 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 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. Jetter et al. (2012) report a minimally tended three-stone fire to be closer to the values that are observed in the field. 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) depicted in Table 2, we calculate average $PM_{2.5}$ concentration levels (measured in $\mu g/m^3$) in the kitchen during cooking time under different scenarios. To this end, we apply a variant of the single zone box model developed by Johnson et al. (2011) that was refined for easier implementation by the Aprovecho Research Center (2016) in the form of a spreadsheet tool.[7] The model abstracts from different concentration levels in different parts of a room or house and has been used in the analysis of biomass cooking emissions (e.g. WHO, 2014b). In line with Johnson et al. (2011), further assumptions are four hours of cooking per day (1 hour in the morning, 1 hour at lunch time, and two hours for dinner) as well a kitchen volume of $30m^3$ and 25 air exchanges per hour. Plugging the

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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).

[7] The reliability of the tool was corroborated by comparing the results to those obtained by Johnson et al. (2011) and WHO (2014b). The results were similar.

values of the indoor emissions of the respective cookstoves into the spreadsheet yields the respective indoor $PM_{2.5}$ concentration levels ($\mu g/m^3$), presented in column 5 of Table 2.

As discussed in section 2.1, effects from moving the location outdoors on particulate matter concentration level occur on a broad range. Accordingly, we account for this variability by showing exposure reductions for three scenarios: 40, 60, and 80 percent reductions (see Table 2, column 6, 7, 8).[8]

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[8] Note that the outside-cooking studies we are referring to observe differences in PM concentrations under real-world conditions, while the Jetter et al. (2012) emission measurements are determined in standardized low- and high-power scenario.

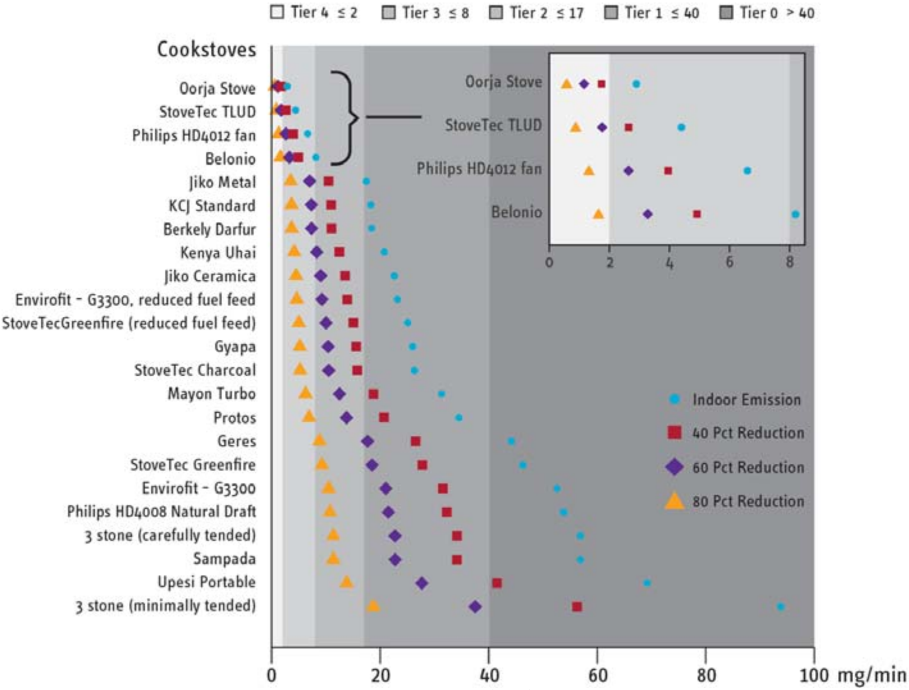
**Table 2:** Cookstove emissions in the high power scenario

| **Cooking device** | **Fuel** | **Indoor** | | | **Outdoor** | | |
|---|---|---|---|---|---|---|---|
| | | Indoor emissions, tiers and $PM_{2.5}$ average concentration level during cooking time | | | Assumed outdoor reduction level and $PM_{2.5}$ average concentration level during cooking time ($\mu$ g/m$^3$) | | |
| | | mg/min | Tier | Concentration level $\mu$ g/m$^3$ | 40 percent | 60 percent | 80 percent |
| 3-stone minimally tended | Wood | 93.8 | 0 | 7373 | 4424 | 2949 | 1475 |
| 3-stone carefully tended | Wood | 56.9 | 0 | 4473 | 2684 | 1789 | 895 |
| Envirofit-G330 | 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 |
| Upesi Portable | Wood | 69.2 | 0 | 5440 | 3264 | 2176 | 1088 |
| GERES | Charcoal | 44.2 | 0 | 3474 | 2084 | 1390 | 695 |
| Gyapa | 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 fee | 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 | 23.2 | 1 | 1824 | 1094 | 730 | 365 |
| 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 | 3 | 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 liter 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 hours and the average value during cooking time is taken for the concentration level.
Source: Jetter et al. (2012)

Since the $PM_{2.5}$ concentration levels ($\mu g/m^3$) are directly proportional to the emission (mg/min), we can convert the concentration figures from Table 2 into the emission levels, thereby yielding the yardstick used in the SE4All-Tier system. Figure 3 shows that there is a strong effect of outdoor cooking on how the stove should be categorized. Most stoves would improve by one tier in the 40 and 60 percent reduction scenarios and by two tiers for the 80 percent reduction scenario. The effect is similar in a low power scenario (see Table A.3 in the Appendix).

**Figure 3:** Indoor emissions, outdoor cooking reduction and tiers



*Note:* Own calculations based on Jetter et al. (2012).

Importantly, the difference in tier categorization applies even to very simple and inexpensive cooking devices, such as the KCJ Standard, a charcoal stove that costs six US-Dollars. This device advances up the scale when used outdoors, from tier 1 to tier 3 under the 80 percent reduction scenario. As an example for a fuelwood driven stove, the Berkeley Darfur stove is within tier 1 with indoor emissions, but tier 2 assuming an outdoor reduction of 40 percent and tier 3 in case of a reduction of 60 or 80 percent. Its cost amounts to 25 US-Dollars. These examples illustrate that when scare resources constrain the coverage of an intervention to disseminate clean cookstoves, which can cost upward of 90 US-Dollar, 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 within country contexts in instances where cooking patterns differ between rural and urban areas.

# 6 Conclusion

Although large cookstove initiatives are currently slated for implementation, reaching the target of universal adoption of clean fuels and improved cookstoves is a long-term endeavor that will require massive investments extending well beyond current commitments. Given the urgency and breadth of the challenges, including LPG-supply chain bottlenecks, 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.

Given this heterogeneity, we regard the fixation on the dissemination of Tier 4 stoves evident in much of the donor community as unfortunate, as it risks missing opportunities to substantially reduce exposure through the distribution of lower cost stoves among households that cook outdoors. It is important to emphasize that these simple improved biomass stoves, which are often a fraction of the cost of more advanced models, also generate additional benefits of improved cooking that are related to deforestation, climate, time and monetary savings (see for example Bensch and Peters, 2013, 2015; Beyene et al., 2015; Jagger and Perez-Heydrich, 2016; Jeuland and Pattanayak, 2012; Martin et al., 2011). Furthermore, affordability is already one of the documented barriers to adoption of lower-cost cooking technologies using market based dissemination (Bensch et al., 2015; Mobarak et al., 2012; Lewis and Pattanayak, 2012), a barrier that would even be higher for Tier 4 stoves. To increase the effectiveness of policy measures, the following lessons should be taken from these results:

In prioritizing regions and stove technologies for dissemination, the effectiveness of a program can be increased by taking the cooking locations into account. While clean cookstoves are likely to be the best option to reduce the exposure to air pollution among households that cook indoors, improved biomass stoves are potentially the more cost-efficient policy intervention in regions where outdoor cooking prevails. Our results give indications for hot spot regions where exposure is the highest owing to cooking location.

Further research is needed on smoke exposure under different ventilation conditions as well as cooking locations using rigorous evaluation methods. For example, negative health effects may also result from disseminating bricked stoves installed in kitchens because people switch from outside to inside cooking.[9] Furthermore, there may also be a negative impact from ambient air pollution to those cooking outside, though this effect seems to be negligible in comparison to indoor air pollution. Behavioral change interventions, such as health education including sensitization to ventilation, and the coupling of those interventions with cookstove interventions could be one promising avenue for the future but still requires further research (e.g. Barnes, 2014; Grabow et al., 2013; Zhou et al., 2006).

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[9] Note that this may be aggravated for chimney stoves if the chimneys are not well maintained (see Hanna et al. (2016) and Grimm and Peters (2012)).

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# Appendix

**Table A.1:** Sample description

| | | | Number of observations | |
|---|---|---|---|---|
| **Country** | **Continent(Region)** | **Survey year(s)** | **Rural areas** | **Urban areas** |
| Bangladesh | Asia | 2011 | 12,823 | 4,291 |
| Benin | Africa(West) | 2012 | 9,631 | 7,599 |
| Burkina Faso | Africa (West) | 2010 | 10,590 | 3,444 |
| Burundi | Africa (East) | 2010 | 7,711 | 718 |
| Cameroon | Africa (Central/South) | 2011 | 6,820 | 6,951 |
| Comoros | Africa (East) | 2012 | 2,936 | 1,467 |
| Cote d'Ivoire | Africa (West) | 2012 | 4,921 | 4,064 |
| Dominican Republic | Latin America | 2013 | 2,909 | 7,987 |
| Democratic Republic of the Congo | Africa (Central/South) | 2014 | 12,344 | 5,695 |
| Ethiopia | Africa (East) | 2011 | 12,809 | 3,569 |
| Gabon | Africa (Central/South) | 2012 | 1,591 | 7,656 |
| Gambia | Africa (West) | 2013 | 2,480 | 3,330 |
| Ghana | Africa (West) | 2008 | 5,997 | 5,385 |
| Guinea | Africa (West) | 2012 | 4,715 | 2,205 |
| Haiti | Latin America | 2012 | 4,715 | 2,205 |
| 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 | 6,662 | 2,315 |
| Lesotho | Africa (Central/South) | 2009 | 6,595 | 2,771 |
| Liberia | Africa (West) | 2013 | 4,015 | 5,145 |
| Madagascar | Africa (East) | 2009 | 15,091 | 2,719 |
| Malawi | Africa (East) | 2010 | 20,676 | 4,104 |
| Mali | Africa (West) | 2013 | 7,825 | 2,105 |
| Mozambique | Africa (East) | 2011 | 9,697 | 4,141 |
| Namibia | Africa (Central/South) | 2013 | 4,718 | 5,092 |
| Nepal | Asia | 2011 | 9,212 | 1,513 |
| Niger | Africa (West) | 2012 | 8,815 | 1,707 |
| Nigeria | Africa (West) | 2013 | 21,344 | 16,099 |
| Pakistan | Asia | 2013 | 8,529 | 4,370 |
| Peru | Latin America | 2011 | 7,965 | 17,366 |
| Philippines | Asia | 2013 | 7,671 | 7,049 |
| Republic of the Congo | Africa (Central/South) | 2012 | 4,238 | 7,190 |
| Rwanda | Africa (East) | 2010 | 10,675 | 1,701 |
| Senegal | Africa (West) | 2011 | 4,016 | 3,770 |
| Sierra Leone | Africa (West) | 2013 | 8,531 | 3,845 |
| Togo | Africa (West) | 2014 | 5,285 | 4,096 |
| Uganda | Africa (East) | 2011 | 7,222 | 1,578 |
| Zambia | Africa (East) | 2014 | 9,259 | 6,631 |
| Zimbabwe | Africa (East) | 2011 | 6,463 | 3,287 |
| **Total** | | | 405,806 | 244,917 |

*Source:* DHS all country dataset from 2006–2014.

**Table A.2:** 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 |
| Envirofit-G330 | Natural draft stove | Wood | 31 |
| Philips HD4008 Natural Draft | Natural draft stove | Wood | 31 |
| Sampada | Natural draft stove | Wood | 38 |
| StoveTec Greenfire | 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 |
| KCJ Standard | Charcoal stove | Charcoal | 6 |
| Kenya Uhai | Charcoal stove | Charcoal | 11 |
| StoveTec Charcoal | Charcoal stove | Charcoal | N/A |
| StoveTec Greenfire, reduced fuel fee | Natural draft stove | Wood | 9 |
| Mayon Turbo | Natural draft stove | Rice Hulls | 15 |
| Berkeley Darfur | Natural draft stove | Wood | 25 |
| Envirofit-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 A.3:** Cookstove emission for the low power scenario

| **Cooking device** | **Fuel** | **Indoor** | | | **Outdoor** | | |
|---|---|---|---|---|---|---|---|
| | | Indoor emissions, tiers and $PM_{2.5}$ average concentration level during cooking time | | | Assumed outdoor reduction level and $PM_{2.5}$ average concentration level during cooking time ($\mu$ g/m$^3$) | | |
| | | mg/min | Tier | Concentration level $\mu$ g/m$^3$ | 40 percent | 60 percent | 80 percent |
| 3-stone minimally tended | Wood | 70.2 | 0 | 5518 | 3311 | 2207 | 1104 |
| 3-stone carefully tended | Wood | 42.8 | 0 | 3364 | 2018 | 1346 | 673 |
| Envirofit-G330 | Wood | 11.3 | 2 | 888 | 533 | 355 | 178 |
| Philips HD4008 Natural Draft | Wood | 29 | 1 | 2280 | 1368 | 912 | 456 |
| Sampada | Wood | 33 | 1 | 2594 | 1556 | 1038 | 519 |
| StoveTec Greenfire | Wood | 13.4 | 2 | 1053 | 632 | 421 | 211 |
| Upesi Portable | Wood | 31.3 | 1 | 2460 | 1476 | 984 | 492 |
| GERES | Charcoal | 4.9 | 3 | 385 | 231 | 154 | 77 |
| Gyapa | Charcoal | 6.4 | 3 | 503 | 302 | 201 | 101 |
| Jiko-Ceramic | Charcoal | 4.7 | 3 | 369 | 221 | 148 | 74 |
| Jiko-Metal | Charcoal | 1.3 | 4 | 102 | 61 | 41 | 20 |
| KCJ Standard | Charcoal | 1.9 | 4 | 149 | 89 | 60 | 30 |
| Kenya Uhai | Charcoal | 1.2 | 4 | 94 | 56 | 38 | 19 |
| StoveTec Charcoal | Charcoal | 6.6 | 3 | 519 | 311 | 208 | 104 |
| StoveTec Greenfire, reduced fuel fee | 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 |
| Envirofit-G3300, reduced fuel feed | Wood | 9.3 | 2 | 731 | 439 | 292 | 146 |
| Protos | Plant oil | 34.8 | 1 | 2735 | 1641 | 1094 | 547 |
| Belonio | Rice hulls | 15.7 | 2 | 1234 | 740 | 494 | 247 |
| Philips HD4012 fan | Wood | 2.8 | 3 | 220 | 132 | 88 | 44 |
| Oorja 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 minutes.
*Source:* Jetter et al. (2012)