KRISTINA SMELSER

Berkeley, CA 94704 • (805) 440-3672 • kristinatsmelser@berkeley.edu

The following is a research paper written for the course *Environmental Health Sciences* during Fall of 2019. Structured as a scientific report, it synthesizes primary and secondary research from the fields of toxicology, epidemiology, and environmental health risk assessment. The paper explores research quantifying global biomass cookstove pollutant exposures; investigates the role that these exposures, specifically particulate matter (PM), play in increasing risk of acute lower respiratory infection (ALRI); and discusses existing interventions and potential paths forward for governments of countries with high prevalence.

The Impacts of Indoor Cookstove Use on Acute Lower Respiratory Infection

Introduction

An estimated 3 billion people globally rely on heavy-polluting biomass (such as wood, coal, charcoal, and animal dung) cookstoves for indoor cooking due to the wide accessibility of these fuels and their well-established role in traditional cooking methods (Gordon et al., 2014; Kammen & Dove, 1997). In fact, the practice is still widespread across developing countries in Asia, Latin America, and Africa, making it a leading global health risk factor because of the extreme levels of toxic air pollutants that biomass cookstoves emit (Shupler et al., 2018). There are significant economic drawbacks to these traditional cooking methods; purchasing cookstove fuel can constitute more than 20% of poor families' disposable income, while collecting the fuel can consume more than 25% of household labor. Additionally, these cookstoves are typically very inefficient in delivering potential heat (averaging a thermal efficiency of roughly 10-20%), thus demanding far greater consumption of fuel (Kammen & Dove, 1997).

Beyond these social and economic burdens, the household air pollution caused by biomass cookstoves has severe respiratory, metabolic, and cardiovascular health effects on those exposed, who primarily tend to be women and small children (Fullerton et al., 2008). One of the most prevalent of these effects is acute lower respiratory infection (ALRI), which includes pneumonia, acute bronchitis, influenza, and whooping cough (Jary, 2016). This paper aims to explore existing research quantifying global biomass cookstove pollutant exposures; to investigate the role that these exposures, specifically particulate matter (PM), play in increasing risk of ALRI; and to discuss existing interventions and potential paths forward for governments.

Exposure

Indoor burning of solid biomass fuels is an extremely widespread practice today given the relative accessibility of these fuels in rural regions. Biomass cookstove use results in incomplete combustion and thus releases harmful pollutants which include PM, carbon monoxide, ash, nitrogen dioxide, sulfur dioxide, and polycyclic aromatic hydrocarbons (Naeher et al., 2007). The traditional cooking method is generally used in homes with poor or absent ventilation; in fact, ventilation is deemed disadvantageous in regions with an extreme climate such as Nepal and northern India, where residents try to conserve heat in the home during very cold weather (Gordon et al., 2014).

The pollutants from biomass cookstoves are inhaled into the lungs of those in close proximity during use. This results in far greater exposures for women in developing countries, who typically bear the responsibility of cooking meals in homes for long periods of time each day (Gordon et al., 2014). Thus, this population of women, and often their small children whom they keep physically close, experience much higher levels of chronic exposure than do their male counterparts (Rennert et al., 2015). Children, particularly infants, newborns, and toddlers, are especially susceptible to the effects of pollutant exposure for several important reasons: their immune, reproductive, digestive, and central nervous systems are still in early developmental stages; they experience higher exposure-to-body-mass ratios than do adults; and their breathing rates during heavy exposures are higher than those of adults (World Health Organization [WHO] Environmental Risks).

Toxicology

Numerous epidemiological studies have measured levels of household air pollution in both urban and rural areas and found significant variation based on the cookstove design, fuel type, and ventilation of the home or building (Shupler et al., 2018, WHO Fact Sheets, Kammen & Dove, 1997; Naeher et al., 2007). Two of the most frequently-measured categories of pollution are $PM_{2.5}$, for which the WHO sets guideline values for annual and 24-hour means at 10 $\mu g/m^3$ and 25 $\mu g/m^3$ respectively, and PM_{10}, for which means are set of 20 $\mu g/m^3$ and 50$\mu g/m^3$ respectively (WHO Fact Sheets, 2018; Shupler et al., 2018). A recent study built a global exposure model for Household Air Pollution (HAP) $PM_{2.5}$ using various peer-reviewed studies from the WHO's Global HAP database. It found that for rural homes using traditional wood cookstoves, the global average kitchen $PM_{2.5}$ concentration was 395 $\mu g/m^3$; for coal, 319 $\mu g/m^3$; and for animal dung, 958 $\mu g/m^3$, ranging from 347 $\mu g/m^3$ in Andean Latin America to 2878 $\mu g/m^3$ in Eastern Sub-Saharan Africa (Shupler et al., 2018). These estimated household concentrations are extremely high compared to the WHO's guideline values and the exposure levels measured in epidemiological studies that are conducted in developed countries. They are particularly concerning, however, because of the severe health risks associated with them (Ezzeti, 2001).

The relationship between exposure to PM, as well as other biomass combustion pollutants, and ALRI is not well known. Although studies have identified an association between the exposure and illness outcomes, information on the dose-response relationships, toxicity of pollutant mixtures (combinations of $PM_{2.5}$, PM_{10}, CO, etc.) and the mechanisms of causation is very limited (Ezzeti, 2001; Kurmi et al., 2013). It is known that when inhaled, ambient pollutants from biomass burning remain present on the airway's macrophages (Fullerton et al., 2008). Developing hypotheses suggest that chronic exposure to these pollutants, particularly PM, can trigger an inflammatory response in lungs, increase oxidative stress, alter phagocytic function, and upregulate receptors vital in bacterial and viral binding — all factors that would likely increase risk of ALRI (Ezzeti, 2001; Kurmi et al., 2013; Capistrano et al., 2016; Lee et al., 2015). However, much more research is needed to explore such hypotheses, which may only prove accurate for some types of ALRIs, and to characterize the combined toxicity of these pollutants rather than each pollutant in isolation (Kurmi et al., 2013, Gurley et al., 2013).

Epidemiology

The vast majority of studies assessing the impacts of biomass combustion on ALRI are observational, including case-control, cohort, and cross-sectional studies. Most target women or young children as populations of interest given their consistently-higher levels of exposure (Jary, 2016; Gurley et al., 2013). While some studies have measured $PM_{2.5}$ and PM_{10} levels directly, many others have relied on questionnaire responses to estimate biomass pollutant exposures. Although these questionnaires are easier to conduct and less expensive than biological measurements, they have resulted in exposure misclassification and inconsistencies in systematic reviews (Gordon et al., 2014). Such observational studies have also been subject to confounding between biomass fuel use and other poverty-related ALRI risk factors, which when unrecognized and unaccounted for by researchers, contribute to inconsistencies across these estimates of exposure-outcome association (Smith et al., 2011).

Many researchers are now conducting variations of cluster-randomized or before-and-after control trials, which are preferred for assessing causality; these studies typically introduce one or more cleaner biomass cookstoves into a community and compare HAP-outcome risk ratios between types of cookstove used, either across time or location. However, very few of these experimental studies have selected ALRI as their outcome of interest (Jary, 2016; Gordon et al., 2014). Many studies generally also fail to specify between upper and lower acute respiratory infections, to differentiate between types of ALRI, or to measure risk ratios for specific types of pollutants (Ezzeti, 2001). These ambiguities make the consolidation of various research studies into a single estimate of risk difficult.

Despite methodological inconsistencies, there is a consensus among the vast majority of studies that daily biomass cookstove use increases the risk of ALRI (Jary, 2016; Naeher et al., 2007; Gordon et al., 2014; Phillips et al., 2016). Many studies have detected a dose-response relationship, which provides evidence for causality (Jary, 2016). The WHO estimates that exposure to HAP nearly doubles the risk for childhood pneumonia; their research attributes 45% of pneumonia deaths in children under age 5, and 28% of pneumonia deaths in adults, to HAP exposure (WHO Household Air Pollution & Health). A systematic review of epidemiological studies from 2016 estimates an odds ratio of 1.78 for HAP and childhood pneumonia (Dherani et al., 2008). A Kenyan prospective cohort study in *Environmental Health Perspectives* estimated an odds ratio of 2.40 for ALRI risk (specifically bronchitis, pneumonia, and bronchopneumonia) associated with daily biomass cookstove use (Ezzeti, 2001).

Based on the methodologies of these various studies, I believe that prospective cohort studies and cluster-randomized control trials will be most effective in future research. These allow researchers to use direct air sampling or human biomarkers in order to measure HAP exposures rather than relying on questionnaires, which tend to be far less accurate and precise; they also enable analyses of the temporality between HAP exposures and ALRI. Further, experimental studies allow researchers to affect levels of exposure by changing the participants' cookstove, fuel, or cooking techniques, and to then observe changes in outcomes; these analyses can serve as even greater evidence for causality. However, it is also important to ensure that such studies follow the ethical principles of community-based participatory research and the

Belmont Report, particularly when deciding whether to withhold information or resources that could mitigate health risks (such as a safer cooking method or cookstove) (National Commission, 1979).

Risk Management

ALRI, when combined with acute upper respiratory infection, is the leading cause of burden of disease worldwide (Ezzeti, 2001). Considering the current evidence of causality between biomass pollutant exposures and ALRI, reducing the levels of exposure to these pollutants would significantly reduce the global burden of ALRI. This can be achieved by better household ventilation, such as chimneys, windows, or fans; improved cookstove design that increases efficiency or captures pollutants; and use of cleaner fuels such as natural gas or renewables (Gordon et al., 2014). However, there are many examples of failed experimental projects, in which international research groups develop a new cookstove design that proves ineffective when piloted within a community; the primary reasons for these failures are that either the new cookstove still releases significant levels of toxic pollutants, or that the researchers failed to take into account the needs, preferences, and lifestyles of the actual cookstove users when developing the product (Yip et al., 2017; Pillarisetti et al., 2017).

Instead, awareness about and action to address the respiratory effects of biomass cookstoves requires the cross-disciplinary mobility of institutions and communities: specifically, creating and advancing partnerships between biomass cookstove users, local and national governments who can enable and ease the transition of cooking (and related lifestyle) choices, technical researchers designing cleaner cookstoves, healthcare providers, and local craftspeople who can continue to develop cookstoves (Kammen & Dove, 2017). Rather than imposing restrictive policies that punish biomass cookstove users, it is important for governments to facilitate the progression to cleaner yet equally-accessible cooking methods by creating subsidies and education programs.

Many governments are adopting these strategies around the world; India launched its National Biomass Cookstoves Initiative in 2010 to develop and distribute cleaner biomass cookstoves to Indian households and paired this with two national campaigns to encourage the use of liquefied petroleum gas as fuel (Pillarisetti et al., 2017). While Ghana's government adopted a similar campaign to India's, Kenya's government eliminated its 16% tax on cooking gas and Bangladesh's reduced its import duty on improved cookstoves by 10% (Clean Cooking Alliance). By identifying the institutionalized barriers to adopting cleaner cooking methods, these governments are targeting policies that mitigate such barriers and instead build up incentives.

Conclusion

Pollution from household use of biomass cookstoves is a significant cause of many health issues, including ALRI, among women and children in developing countries (Fullerton et al., 2008; Jary, 2016). The exposures to these pollutants, particularly PM, generally occur at levels far exceeding those considered safe or mild (Shupler et al., 2018; Gordon et al., 2014; Rennert et al., 2015) Although more epidemiological research is needed to analyze the impact of combined pollutant exposures and the immunomodulatory mechanisms by which HAP causes ALRI, there is sufficient evidence to attribute biomass cookstove pollutant exposure to these health impacts and many others (Ezzeti, 2001; Lee, 2015). This issue is of vital importance not only because it affects such a large proportion of the world population, but also because it points to inequities in global access to cleaner, more efficient sources of energy production.

Standalone technical innovations are ultimately insufficient in driving lasting lifestyle changes; many current and past cookstove intervention programs that solely invested their resources into designing cleaner stoves have ultimately proven inadequate, failing to meet the needs of cookstove users (Kammen & Dove, 1997; Yip et al., 2017). In contrast, cross-disciplinary community-oriented programs that have been effective in initiating the transition to cleaner cooking, such as those in India and Ghana, can serve as a model for other governments to develop similar programs tailored to their communities' needs. These collaborations utilize incentive-driven policies to facilitate the socio-economic transition to better household ventilation, high-efficiency cookstoves, and cleaner fuels. Together they possess the ability to introduce sustainable, safe cooking methods and to ultimately improve health outcomes for the billions of people who still rely on biomass cookstoves.

References

Capistrano, S. J., Zakarya, R., Hui Chen, & Oliver, B. G. (2016). Biomass Smoke Exposure Enhances Rhinovirus-Induced Inflammation in Primary Lung Fibroblasts. *International Journal of Molecular Sciences*, *17*(9), 1403. https://doi.org/10.3390/ijms17091403

Clean Cooking Alliance. (2016). *Global Alliance for Clean Cookstoves 2016 Progress Report*. Retrieved from http://cleancookingalliance.org/resources/reports/2016progress.html

Dherani, M., Pope D., Mascarenhas M., Smith K.R., Weber M., Bruce N. (2008). Indoor air pollution from unprocessed solid fuel use and pneumonia risk in children aged under five years: A systematic review and meta-analysis. *Bulletin of the World Health Organization*, *86*(5), 390–8C.

Ezzeti, M. (2001). Quantifying the Effects of Exposure to Indoor Air Pollution from Biomass Combustion on Acute Respiratory Infections in Developing Countries. *Environmental Health Perspectives*, *109*(5), 481.

Fullerton, D. G., Bruce, N., & Gordon, S. B. (2008). Indoor air pollution from biomass fuel smoke is a major health concern in the developing world. *Transactions of the Royal Society of Tropical Medicine and Hygiene*, *102*(9), 843–851. https://doi.org/10.1016/j.trstmh.2008.05.028

Gordon, S. B., Bruce, N. G., Grigg, J., Hibberd, P. L., Kurmi, O. P., Lam, K. H., … Martin, W. J. (2014). Respiratory risks from household air pollution in low and middle income countries. *The Lancet. Respiratory Medicine*, *2*(10), 823–860. https://doi.org/10.1016/S2213-2600(14)70168-7

Gurley, E. S., Homaira, N., Salje, H., Ram, P. K., Haque, R., Petri, W., … Azziz-Baumgartner, E. (2013). Indoor exposure to particulate matter and the incidence of acute lower respiratory infections among children: A birth cohort study in urban Bangladesh. *Indoor Air*, *23*(5), 379–386. https://doi.org/10.1111/ina.12038

Jary, H., Simpson, H., Havens, D., Manda, G., Pope, D., Bruce, N., & Mortimer, K. (2016). Household Air Pollution and Acute Lower Respiratory Infections in Adults: A Systematic Review. *PLoS ONE*, *11*(12), 1–14. https://doi.org/10.1371/journal.pone.0167656

Kammen, D. & Dove, M. (1997). The Virtues of Mundane Science. *Environment, 39*(6), 10-41.

Kurmi, O. P., Dunster, C., Ayres, J. G., & Kelly, F. J. (2013). Oxidative potential of smoke from burning wood and mixed biomass fuels. *Free Radical Research*, *47*(10), 829–835. https://doi.org/10.3109/10715762.2013.832831

Lee, A., Kinney, P., Chillrud, S., & Jack, D. (2015). A Systematic Review of Innate Immunomodulatory Effects of Household Air Pollution Secondary to the Burning of Biomass Fuels. *Annals of Global Health*, *81*(3), 368–374.

Naeher, L. P., Brauer, M., Lipsett, M., Zelikoff, J. T., Simpson, C. D., Koenig, J. Q., & Smith, K. R. (2007). Woodsmoke Health Effects: A Review. *Inhalation Toxicology*, *19*(1), 67–106. https://doi.org/10.1080/08958370600985875

National Commission for the Protection of Human Subjects of Biomedical and Behavioral Research. (1979). *The Belmont Report* [Text]. Retrieved from https://www.hhs.gov/ohrp/regulations-and-policy/belmont-report/read-the-belmont-report/index.html

Phillips, M. J., Smith, E. A., Mosquin, P. L., Chartier, R., Nandasena, S., Bronstein, K., … Brown, L. M. (2016). Sri Lanka Pilot Study to Examine Respiratory Health Effects and Personal PM2.5 Exposures from Cooking Indoors. *International Journal of Environmental Research and Public Health*, *13*(8). https://doi.org/10.3390/ijerph13080791

Pillarisetti, A., Jamison, D. T., & Smith, K. R. (2017). Household Energy Interventions and Health and Finances in Haryana, India: An Extended Cost-Effectiveness Analysis. In C. N. Mock, R.

Nugent, O. Kobusingye, & K. R. Smith (Eds.), *Injury Prevention and Environmental Health* (3rd ed.). Retrieved from http://www.ncbi.nlm.nih.gov/books/NBK525217/

Rennert, W. P., Porras Blanco, R. M., & Muniz, G. B. (2015). The effects of smokeless cookstoves on peak expiratory flow rates in rural Honduras. *Journal of Public Health (Oxford, England)*, *37*(3), 455–460. https://doi.org/10.1093/pubmed/fdu087

Shupler, M., Godwin, W., Frostad, J., Gustafson, P., Arku, R. E., & Brauer, M. (2018). Global estimation of exposure to fine particulate matter (PM2.5) from household air pollution. *Environment International*, *120*, 354–363. https://doi.org/10.1016/j.envint.2018.08.026

Smith, K. R., McCracken, J. P., Weber, M. W., Hubbard, A., Jenny, A., Thompson, L. M., … Bruce, N. (2011). Effect of reduction in household air pollution on childhood pneumonia in Guatemala (RESPIRE): A randomised controlled trial. *Lancet (London, England)*, *378*(9804), 1717–1726. https://doi.org/10.1016/S0140-6736(11)60921-5

World Health Organization. (2018, May). Fact Sheets: Air Pollution. Retrieved November 4, 2019, from https://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health

World Health Organization. (2018, May 8). Household Air Pollution and Health. Retrieved November 20, 2019, from https://www.who.int/news-room/fact-sheets/detail/household-air-pollution-and-health

World Health Organization. (n.d.). Environmental Risks: Children's Environmental Health. Retrieved November 4, 2019, from https://www.who.int/ceh/risks/en/

Yip, F., Christensen, B., Sircar, K., Naeher, L., Bruce, N., Pennise, D., … Kapil, V. (2017). Assessment of traditional and improved stove use on household air pollution and personal exposures in rural western Kenya. *Environment International*, *99*, 185–191. https://doi.org/10.1016/j.envint.2016.11.015