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Emissions from residential combustion considering end-uses and spatial constraints: Part II, emission reduction scenarios

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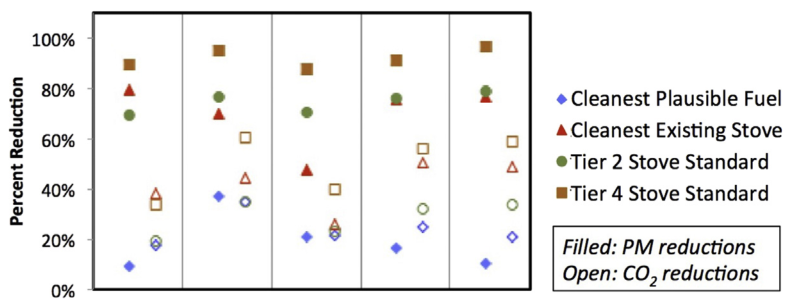
HIGHLIGHTS

- Residential emission scenarios based on spatial distribution and end-use.
- Clean-fuel scenario reduces emissions by 18–25%, depending on pollutant.
- Stove improvements with existing technology reduce emissions by 25–82%.
- If stoves meet tightest performance standards, particulate matter is reduced by 95%.

GRAPHICAL ABSTRACT



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ABSTRACT

Cooking, heating, and other activities in the residential sector are major sources of indoor and outdoor air pollution, especially when solid fuels are used to provide energy. Because of their deleterious effects on the atmosphere and human health, multinational strategies to reduce emissions have been proposed. This study examines the effects of some possible policies, considering realistic factors that constrain mitigation: end-uses, spatial constraints involving proximity to forest or electricity, existing technology, and assumptions about user behavior. Reduction scenarios are applied to a year-2010, spatially distributed baseline of emissions of particulate matter, black carbon, organic carbon, nitrogen oxides, methane, non-methane hydrocarbons, carbon monoxide, and carbon dioxide. Scenarios explored are: (1) cleanest current stove, where we assume that existing technology in each land type is applied to burn existing fuels; (2) stove standards, where we assume that stoves are designed to meet performance standards; and (3) clean fuels, where users adopt the cleanest fuels plausible in each land type. We assume that people living in forest access areas continue to use wood regardless of available fuels, so the clean-fuels scenario leads to a reduction in emissions of 18–25%, depending on the pollutant, across the study region. Cleaner stoves preferentially affect land types with forest access, where about half of the fuel is used; emission reductions range from 25 to 82%, depending on the pollutant. If stove performance standards can be met, particulate matter emissions are reduced by 62% for the loosest standards and 95% for the tightest standards, and carbon monoxide is reduced by 40% and 62% for the loosest and tightest standards. Reductions in specific regions and countries depend on the existing fuel mixture and the population division among land types, and are explored for Latin America, Africa, East Asia, South Asia, and Southeast Asia.

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1. Introduction

Cooking, heating, and other activities in the residential sector are major sources of indoor and outdoor air pollution, especially when solid fuels are used to provide energy (Ezzati and Kammen, 2002; Mehta and Shahpar, 2004; Jetter and Kariher, 2009; Kim et al., 2011). In rural areas and resource-constrained countries, solid fuel can provide a large fraction of the household energy budget (Pandey, 2002; Tabuti et al., 2003; Bhatt and Sachan, 2004; Sumati, 2006). WHO (2006) estimated that more than three billion people depend on solid fuels (coal, charcoal, fuelwood, agricultural waste, and dung) to fulfill their basic household energy needs. High emissions from solid fuel combustion create indoor air pollution (Ezzati et al., 2000; Albalak et al., 2001), climate change and regional haze (Bond et al., 2004; Edwards et al., 2004; MacCarty et al., 2008; Ramanathan and Carmichael, 2008; Ramanathan et al., 2008). Deforestation by fuelwood collection is another pressing environmental problem in many regions (Bhatt and Sachan, 2004; Dovie et al., 2004).

Although the impacts may be severe, users at subsistence level are not expected to ameliorate them on their own. Thus, there has been attention from organizations that provide support to reduce negative impacts. Examples of current initiatives include the Global Alliance for Clean Cookstoves (UN foundation, 2013), which has set a goal of using clean and efficient stoves and fuels in an additional 100 million homes by 2020, and The World Bank (2013), which provides about $8 billion a year in financing to boost access to electricity, clean fuels, renewable energy, and energy efficiency.

Two basic approaches to achieving improvement are better stoves and cleaner fuels (Goldemberg et al., 2004; Bazilian et al., 2011; Foell et al., 2011; Lewis and Pattanayak, 2012; Pachauri et al., 2013). Since the 1980s, more efficient stoves have been introduced in China, India, and other parts of the world (Lu, 1993; Edwards et al., 2004; Kumar et al., 2013). The primary goal of early programs was to reduce deforestation, while improving health was a focus in later years (Boy et al., 2000; Edwards et al., 2004; Smith et al., 2007; Romieu et al., 2009). One of the most successful stove programs has been the Chinese National Improved Stove program, which introduced approximately 129 million improved biomass cookstoves into rural areas during 1982–1992, of which more than 100 million are still in use (Smith et al., 1993; Kumar et al. 2013).

Another approach to reduce the negative impacts of household energy is making cleaner, higher-efficiency fuels more accessible through subsidies or reduced fuel price. The factors that affect fuel switching are not fully understood. Even when liquefied petroleum gas (LPG) is subsidized, it usually does not replace fuelwood completely (Masera et al., 2000). Fuelwood is still used to cook some foods for both practical and cultural reasons. Fuel switching is triggered by a range of changes associated with development, urbanization, electrification, and education to some extent (Heltberg, 2004). Fuel choice and consumption decisions are also sensitive to fuel access and energy prices (Barnes et al., 2005).

Several studies estimate atmospheric or health impacts of residential fuel consumption, and some evaluate the benefits of changing fuels or stoves. Bhattacharya and Salam (2002) estimated that switching to biofuel, biogas, and gasifier stoves could provide 38–61% reductions in greenhouse gas emissions compared with traditional stoves used in Asian countries. GAINS (2012) estimates country-level emissions for present day until 2030. Grieshop et al. (2011) found that replacing traditional stoves with kerosene, LPG stoves, and improved stoves with fans could provide benefits to indoor health and global climate. UNEP (2011), relying on *GAINS* emission inventories, estimated that reducing black carbon through improved biomass stoves or switching to cleaner-burning fuels would deliver the greatest health and near-term climate benefits, compared with improving transportation, banning open burning of agricultural waste, or providing modern brick kilns and coke ovens. IEA (2010) estimated energy consumption reduction in a scenario called "Universal Modern Energy Access", in which universal access to cleaner fuels occurred by 2030. The Global Energy Assessment (Riahi et al., 2011) also suggested that final energy consumption would be significantly reduced with a shift from biomass to LPG, while greenhouse gas emissions would either remain constant or increase.

IEA (2010) and the Global Energy Assessment (Riahi et al., 2011) estimated that investment between $17 and $38 billion per year would be required, beyond IEA's reference scenario, in order to provide 100% universal access to clean cooking facilities, including electricity, LPG stoves, biogas systems or advanced biomass cookstoves in 2030 (Foell et al., 2011). To achieve the same target, Pachauri et al. (2013) estimated a requirement of $65–86 billion per year until 2030 and dedicated policies.

All of the studies discussed above infer emissions by combining measured emission factors and efficiencies with fuel consumption. Although the benefits of cleaner stoves, emission reduction policies, and fuel switching have been widely reported, other considerations related to feasibility have been neglected. Estimates of emissions and mitigation potential often rely on national aggregate data, not considering factors that vary between nations or within the nation. This paper is the second in a series that explores potential changes in emissions with constraints on plausibility guided by the spatial distribution of users and resources. It considers the appropriateness of cleaner stoves for the wide variety of residential end-uses, and the likelihood of adopting better fuels based on users' proximity to free fuels. This paper relies on the method for spatially allocating current fuel use and emissions among land types developed in a companion paper (Winijkul et al., 2015). Here, we examine the effects of hypothetical programs that could reduce current emissions, considering end-uses, current technology, and plausible assumptions about user behavior. We estimate emissions that have both local and global impacts: particulate matter (PM), black carbon (BC), and organic carbon (OC), carbon monoxide (CO), carbon dioxide (CO_2), nitrogen oxides (NOx), methane (CH_4), and non-methane hydrocarbons (NMHC).

2. Methodology

2.1. Overview of fuel allocation and emission calculation method

The detailed methodology describing spatial distribution of fuel consumption in the residential sector is discussed in a companion paper (Winijkul et al., 2015). Briefly, our distribution method hybridizes top–down calculations using national residential fuel consumption data from International Energy Agency (IEA, 2012a, b) and Fernandes et al. (2007), and bottom–up calculations of energy requirements for major end-uses in households. In each country, we classify five land types using population, forest, and nighlight data: Urban, Non-Forest access (URB); Electrified Rural with Forest Access (ERFA); Electrified Rural, Non-Forest access (ERNF); Non-electrified Rural with Forest Access (NRFA); and Non-electrified Rural, Non-Forest access (NRNF).

We calculate energy consumption for cooking, heating, and lighting end-uses, as well as a miscellaneous category called "Other." We then estimate the types and quantity of fuels used for each end-use. Next, we distribute fuels among land types and end-uses. In ERFA and NRFA, fuelwood is free and we assume it is preferentially used there. The highest efficiency fuels go to urban areas. In ERNF, without easy access to forest and with available electricity, we assumed that the next most efficient fuels are used,