Energy for Sustainable Development 43 (2018) 224–234

Contents lists available at ScienceDirect

Energy for Sustainable Development

Indoor air pollution from biomass cookstoves in rural Senegal

Candela de la Sota [a,*], Julio Lumbreras [a], Noemí Pérez [b], Marina Ealo [b], Moustapha Kane [c], Issakha Youm [c], Mar Viana [b]

[a] Technical University of Madrid, José Gutiérrez Abascal, 2, 28006 Madrid, Spain
[b] Institute for Environmental Assessment and Water Research, Spanish National Research Council (IDAEA-CSIC), Jordi Girona 18-26, 08034 Barcelona, Spain
[c] Centre for Studies and Research on Renewable Energy (CERER) of the Cheikh Anta Diop University of Dakar (UCAD), Route du Service géographique (HB-87) x HB-478, Hann Bel-Air, 476 Dakar, Senegal

ARTICLE INFO

Article history:
Received 22 October 2017
Revised 2 February 2018
Accepted 6 February 2018
Available online xxxx

Keywords:
West Africa
Biomass burning
Cooking emissions
Ventilation
Portable monitors
Women respiratory health

ABSTRACT

Although indoor air pollution from the use of biomass fuels is a serious health problem in Senegal, little effort has been made in this country to evaluate indoor air quality impacts from biomass combustion with traditional stoves and indoor air quality improvements derived from the use of improved cookstoves. A cross-sectional study was conducted in a rural village of Senegal to determine indoor air pollution during cooking and non-cooking periods. $PM_{2.5}$ and CO concentration levels were determined, along with two far less studied pollutants in cookstove studies, ultrafine particles and black carbon, using portable monitors. A total of 22 households were selected, 12 using the traditional stove and 10 using a locally produced rocket stove. Rocket stoves, the most extended type of improved stove used in sub-Saharan Africa, contributed to a significant reduction of total fine and ultrafine (UFP) particles and carbon monoxide (CO) (75,4%, 30,5% and 54,3%, respectively, $p < 0.05$) with regard to the traditional stoves, but increased black carbon (BC) concentrations (36,1%, $p < 0.05$). This proves that the climate and health-relevant properties of stoves do not always scale together and highlights that both dimensions should be always considered. Findings evidence that, in addition to a switch in the emission source (i.e. cookstove and/or fuel), successful strategies focused on the improvement of household air quality in Senegal should contemplate ventilation practices and construction materials.

Introduction

More than 80% of the Sub-Saharan Africa population depend on traditional biomass as the primary fuel for cooking (OECD/IEA, 2014). In Senegal, 83% of the demand for domestic fuel use in rural areas and 58% in urban areas is covered by biomass (The World Bank, 2013). In 2009, liquefied petroleum gas (LPG) subsidies were eliminated, and consumers returned in large numbers to wood-based biomass (primarily charcoal) for cooking (Sander, Hyseni, & Haider, 2011).

Indoor air pollution caused by traditional biomass burning for cooking purposes poses serious health risks, especially for women and surrounding children during cooking hours (Desai et al., 2004; Smith et al., 2014). In Senegal, indoor air pollution accounts for 4.8% of the national burden of disease (WHO, 2007), and 6300 people are estimated to die prematurely every year because of indoor air pollution (WHO, 2009).

Particulate matter (PM) emitted from biomass combustion is mostly in the fine and ultrafine size range (Tiwari, Sahu, Bhangare, Yousaf, & Pandit, 2014). Fine particles have an aerodynamic diameter less than or equal to 2.5 μm and are referred to as $PM_{2.5}$.

Recent studies show that most particles generated from biomass combustion are typically between 0.05 μm and 0.2 μm (Tiwari et al., 2014), and they may be more harmful to human health than coarser particles (Hawley & Volckens, 2013; Just, Rogak, & Kandlikar, 2013; Rapp, Caubel, Wilson, & Gadgil, 2016).

A major component of $PM_{2.5}$ is black carbon (BC) (Petzold et al., 2013), with well-known hazardous health effects (Janssen et al., 2012). Up to 80% of BC emissions in Africa and Asia have been attributed to residential solid fuel use (Bond et al., 2013).

Ultrafine particles (UFP) are those with an aerodynamic diameter <0.1 μm (Pope & Dockery, 2006). They are characterized by low mass and large surface area and, therefore, their concentrations are not accurately reflected by particle mass concentrations so they are monitored in terms of particle number concentrations (Sahu, Peipert, Singhal, Yadama, & Biswas, 2011). In addition, the lung-deposited surface area (LDSA) concentration is increasingly emphasized as relevant parameter to estimate health effects of UFPs in urban areas (Ntziachristos, Polidori, Phuleria, Geller, & Sioutas, 2007; Reche et al., 2015). However, to date, research on this parameter with regard to cookstove emissions is still relatively scarce (Hosgood et al., 2012; Leavey et al., 2015; Patel et al.,

* Corresponding author.
E-mail address: candela.delasota@upm.es (C. de la Sota).

https://doi.org/10.1016/j.esd.2018.02.002

2016; Sahu et al., 2011), especially when compared to studies focused on CO or PM mass.

In Senegal, the international donor community and national governments increased efforts since the 1980's to disseminate cleaner and more efficient burning stove designs. These devices are known as improved or clean cookstoves (Bensch & Peters, 2011) as they have the potential to substantially reduce emissions and subsequent exposure (Clark et al., 2013).

A number of studies have analysed impacts on household air pollution and personal exposure from cooking activities in Asia (Balakrishnan et al., 2015; Bartington et al., 2017; Chengappa, Edwards, Bajpai, Shields, & Smith, 2007; Chowdhury et al., 2013; Dasgupta, Huq, Khaliquzzaman, Pandey, & Wheeler, 2006; Dutta, Shields, Edwards, & Smith, 2007; Gao et al., 2009; Hu et al., 2014; Kar et al., 2012; Siddiqui et al., 2009), Latin America (Albalak, Bruce, McCracken, Smith, & de Gallardo, 2001; Armendáriz et al., 2008; Commodore et al., 2013; Fitzgerald et al., 2012; Naeher, Leaderer, & Smith, 2000; Northcross, Chowdhury, McCracken, Canuz, & Smith, 2010; Park & Lee, 2003; Riojas-Rodriguez et al., 2011; Smith et al., 2010; Zuk et al., 2007) and Africa (Ezzati, Mbinda, & Kammen, 2000; Ochieng, Vardoulakis, & Tonne, 2013, 2017; Pennise et al., 2009). However, in Senegal there are very few field studies evaluating indoor air quality impacts from biomass combustion with traditional stoves and indoor air quality improvements derived from the use of improved cookstoves (de la Sota et al., 2014), evidencing the need for this kind of research in the region. The complexity of these studies is strongly linked with their operational constraints such as the need for portable, battery-operated and lower-cost monitoring instrumentation (de la Sota et al., 2017). This study is, to the best of our knowledge, the first to provide a comprehensive real-world assessment of household pollutant concentrations from the combustion of biomass fuels for cooking in Senegal. It focuses on the quantification and characterization of BC, PM, UFP and CO indoor concentrations from burning wood fuel during cooking activities using traditional and improved cookstoves in a Senegalese rural village, which is considered representative of rural areas in the country.

Moreover, the study identifies parameters such as type of wood and household characteristics (i.e. construction materials, ventilation and kitchen size), which influence indoor air pollutant concentrations, in addition to the type of stove.

Experimental methods

Study area and cookstove usage

The study was conducted in March 2016 in Bibane, a rural village with approximately 650 inhabitants (74 families) in the commune of Niakhar, in the region of Fatick (Senegal) (Fig. 1). Typical home structures are made of earth bricks and thatched roof. The kitchen is physically separated from the bedroom area, and very poorly ventilated (Fig. 1). This type of household structure is very common in rural areas of Senegal and other Sub-Saharan West African countries (Ochieng et al., 2013).

Women are responsible for cooking, as well as for the rest of the household chores. Cooking is among the most time-consuming of women's responsibilities (Wodon & Blackden, 2006). They spend much of their time near the stove and performing other tasks related to food preparation, such as pounding the millet by hand, fetching water, etc. They usually cook inside the kitchen, to protect the food and fire from animals, wind and children, and to be protected from the sun.

Fuelwood is scarce in Bibane, so its collection requires long journeys to the forest. As a result, fuel used to cook is heterogeneous, with a high percentage of families frequently using crop residues and dung.

All of the families in the village used traditional three-stone fires before improved cook stoves were introduced in 2012, within the framework of a program to optimize the use of forest resources in the region. In total, 2500 improved cookstoves (known as Noflaye Jegg) were distributed in the region, 50 of them in Bibane. These stoves were locally produced adapting the rocket stove type (without chimney) (Bryden, Still, Ogle, & MacCarty, 2005) and have been also implemented in other regions of West Africa (de la Sota et al., 2014). However, the research team discovered that the majority of the improved cookstoves were in disuse, completely or partially damaged. This is not an isolated case. Indeed, a lot of improved cookstoves implementation actions have failed to achieve an adoption and sustained use of the technologies promoted for a wide variety of reasons (Rehfuess, Puzzolo, Stanistreet, Pope, & Bruce, 2013). Finally, only 10 out of 50 were in a good or fair state, and considered adequate to be included in the study. Cookstoves are shown in Fig. S1 in the Supplementary material.

Household selection and study design

Before starting measurements, a communal meeting was conducted to explain the study purpose and activities, where women provided oral consent to enrol in the study.

A cross-sectional study (Edwards, Hubbard, Khalakdina, Pennise, & Smith, 2007) was conducted to evaluate the comparative impact of improved and traditional stoves on indoor air pollutant concentrations ($PM_{2.5}$, UFP, BC and CO). Even though the air quality monitors were not worn by the women, it is assumed that indoor air pollutant concentrations may be considered as a proxy for personal exposure during cooking hours due to the small size of the kitchens and their low ventilation rates.

The sample size advisable in cross-sectional sample designs depends on the detectable difference in means and the covariance (COV) of measurements. For improved cookstoves without a chimney, it is realistic to expect a difference of 60%, and COV of 0.7. Therefore, the advisable sample size per stove type for our study was estimated to be 22 (Edwards et al., 2007).

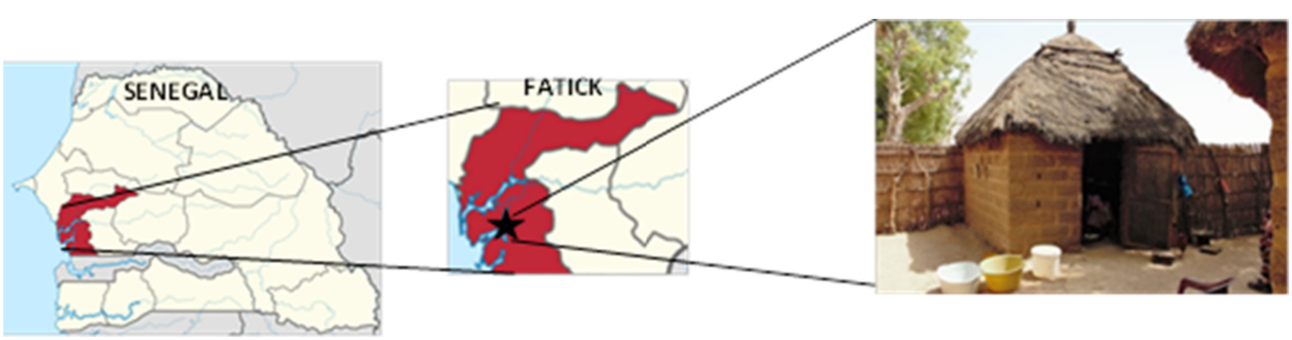

Fig. 1. Typical kitchen in Bibane, rural village in the region of Fatick, Senegal.