Energy for Sustainable Development 17 (2013) 489–496

Contents lists available at ScienceDirect

Energy for Sustainable Development

Upgrading to cleaner household stoves and reducing chronic obstructive pulmonary disease among women in rural China — A cost-benefit analysis☆

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ARTICLE INFO

Article history:
Received 19 November 2012
Revised 12 June 2013
Accepted 12 June 2013
Available online 10 July 2013

Keywords:
Chronic obstructive pulmonary disease
Household air pollution
$PM_{2.5}$ exposure
Intervention
Cost-benefit analysis

ABSTRACT

Exposure to fine particles ≤2.5 μm in aerodynamic diameter ($PM_{2.5}$) from incomplete combustion of solid fuels in household stoves is recognized as a major contributor to global ill health. Still there are few attempts to estimate the economic costs and health benefits of interventions to reduce exposure. The objective of this paper is to estimate costs and health benefits to women of possible interventions to replace current biomass stoves in Guizhou Province, southwest China, with cleaner burning stoves. Prevalence of chronic obstructive pulmonary disease (COPD) was measured in women ≥30 y living in households using biomass as fuel. In a sub-sample of households indoor $PM_{2.5}$ concentrations were measured. Reduced exposure from replacing stoves in individual homes and at the community level was estimated using information about stoves, concentration levels, and time-activity patterns. Annual avoided new cases of COPD were estimated. The economic value of avoided cases was compared to intervention costs. Probabilistic cost-benefit analysis was performed using Monte-Carlo simulation and the impact of uncertainty in single parameters was explored. The mean reduction in annual average $PM_{2.5}$ exposure is estimated at 127–294 μg/m^3, which corresponds to a 41–77% reduction. Annually 0.6–3.2 new cases of COPD among women may be avoided per 1000 households. The present value net benefit is 1766–22,500 Yuan (Yuan/USD ≈ 0.16) per household and mean benefit/cost-ratios (B/C) are 3.3–14.7. We conclude that policy interventions to increase access to cleaner burning stoves may bring large net benefits to rural women and their families, and to society.

Introduction

Smoke from household stoves is a major contributor to global ill health (Lim et al., 2012). Women in developing countries may spend several hours a day near the stove, exposed to levels of household air pollution (HAP) that have large impacts on their respiratory health and may lead to COPD (Kurmi et al., 2010; Po et al., 2011). COPD is a chronic inflammatory condition of the lower airways. The basic abnormality in COPD patients is airflow limitation, which causes shortness of breath, usually accompanied by chronic cough, wheezing, chest tightness and an increasing disability over time (WHO, 2007).

A substantial share of the global disease burden linked to HAP occurs in China (Lim et al., 2012). The burden of COPD is particularly high. Reported COPD prevalence in China varies between 5% and 13% in different provinces and cities across the country. In 2008, COPD ranked third as a cause of death in rural areas. Crude prevalence of COPD in Chinese women was 3.8%–7.1% in a cross-sectional survey conducted between 2002 and 2004 and was higher in rural areas (Fang et al., 2011). A study in South China reported higher COPD prevalence among non-smoking women in rural than in urban areas (7.2% vs 2.5%) (Liu et al., 2007). Tobacco smoking and biomass smoke are the largest contributors to COPD in China (Lin et al., 2008). Few women smoke, however. The smoking rate was 2.4% among women and 52.9% among men in 2010 (Li et al., 2011).

Lin et al. (2008) estimate that halving household solid fuel use in China by 2033 would reduce the annual number of female COPD deaths by 12%. In a retrospective cohort study in Yunnan Province a significant reduction in COPD was observed among people who changed from unvented stoves to stoves with a chimney. Even though average PM_{10} (particles ≤10 μm in aerodynamic diameter) levels

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http://dx.doi.org/10.1016/j.esd.2013.06.002

were still high near the stove (710 μg/m^3), a significant risk reduction was observed in women after installation of a chimney (Relative Risk (RR) 0.75 (95% Confidence Interval (CI): 0.62, 0.92)) (Chapman et al., 2005). The impact of improved stoves has been found to be higher when coupled with education and behavioral change (WB, 2007a).

During the 1980s and 1990s the National Improved Stove Program (NISP) was implemented in China, and a large fraction of biomass stoves were upgraded to so-called first generation improved stoves, which in practice meant that the stove had a chimney and a grate. A comprehensive assessment of NISP found that the thermal efficiency of rural stoves was only 9–14% (Sinton et al., 2004). Recently, companies have marketed better stoves, among them a range of cast iron gasifier and semi-gasifier biomass stoves (Spautz et al., 2006). If properly used and maintained, and given that they not just add to old stoves, these second generation improved stoves are expected to result in reduced HAP and significant health benefit.

In spite of the potentially large health benefit, there are few attempts to estimate the economic cost and benefit of interventions to promote cleaner burning stoves. Bruce et al. (2011) summarize previous studies of costs and benefits of biomass stove interventions, including community-based studies in Africa and Nepal (Malla et al., 2011) and a study for WHO regions (Hutton et al., 2006). All studies found benefits larger than costs. Various health and socio-economic benefits, including less time spent collecting fuels, are included in these studies and results are not directly comparable. When estimating impacts on COPD the studies treated exposure as a dichotomous variable based on fuel statistics ('exposed': household solid fuel are used versus 'not exposed': household solid fuels are not used). The fuel-based approach is a rough approximation applied when exposure measurements are not available (Smith et al., 2004).

The objective of this paper is to estimate the costs and health benefits among women of replacing current biomass stoves in a rural area of China with second generation improved stoves. The novelty of our analysis is that field data on HAP concentrations enables a detailed exposure assessment. Current COPD prevalence is measured. The detailed information about current exposure levels and disease prevalence together with modeled exposure levels in scenarios allow us to use exposure–response relationships from epidemiological studies to estimate health benefits. While a long-term intervention study would have been ideal, we aim in this paper to improve on the current fuel based approach by using measurement data for the pre-intervention stage. In addition, in spite of addressing only one health end-point among a range of potential health effects, our paper adds a valuable data point to the scant evidence of the social cost of stove interventions.

Material and methods

Cost-benefit analysis

The essence of cost-benefit analysis is to calculate net benefits (gross benefits less costs) of an intervention. In our case the intervention is 'replacing current biomass stoves with second generation improved stoves' at the household or community level. Cost equals the cost of purchasing and installing the stove, plus any fuel and maintenance cost over the life-time of the stove. Benefits come in many fashions, including health benefits and convenience benefits.

As noted we focus here on COPD health benefits among women. The idea is that demonstrating net benefits based on COPD benefits among women is sufficient for demonstrating net benefits in general. The unit of analysis is 'one household'. We estimate the expected annual avoided new cases of COPD in women per household and use valuation methods from economics to estimate the monetized value of the avoided cases (see detailed method below).

We assume that benefits persist for as long as the improved stove is in function. If the intervention generates net benefits over this period, a second round of the same intervention will also have net benefits etc. Demonstrating net benefits over the life time of the stove is sufficient for demonstrating net benefits for any length of time.

In order to compare benefits and costs accruing over different time periods we use a discount rate. The discount rate is higher in a high-growth economy such as the Chinese. Our real discount rate is 8%. It is applied equally to benefits and costs. However, economic growth implies growing valuation of risk. Hence the effective discount rate of benefits is in fact slightly negative.

Study area

We study villages of Guizhou Province. Guizhou is a mountainous province of 35 million inhabitants in the southwest of China. Rural households in Guizhou are poor (net income ~ 500 USD/cap), with about 50% income share for food (NBS-GZ, 2011). Traditional biomass stoves are widespread in rural areas and are previously described by Jin et al. (2006) (Fig. 1). Some households still use open fire. According to China Census data, 30% of households used coal and 32% used biomass as their main cooking fuel in 2010. Among rural households 35% use coal and 46% use biomass (NBS, 2012). During 2000–2007, biomass energy use in households increased from a total of 6.0 Mtce to 10.1 Mtce (NBS, 2010).

Data collection

An interviewer administered questionnaire was used to collect information on characteristics of 1200 rural households in 24 villages where biomass was the main fuel. The survey was carried out during the period Feb 2009–Jan 2010. Lung function was measured by spirometry. The participants had to perform at least 2 satisfactory maximum forced expiratory flow-volume curves. COPD was defined as forced expiratory volume in one second over forced vital capacity (FEV1/FVC) below 0.7 based on post-bronchodilator measurements (Celli et al., 2004). 0.6% were cigarette smokers and were excluded from the analysis. COPD prevalence and odds ratios (OR) were estimated on a sample of about 850 participating women ≥30 y of age (Alnes et al., 2011).

In a subsample of households (110 in winter and 117 in summer), measurements of indoor concentrations of $PM_{2.5}$ were carried out for 48 h using the particle and temperature monitor UCB-PATS (Edwards et al., 2006). The monitor has been used in multiple studies in developing countries (Armendariz et al., 2008; Chowdhury et al., 2007). The monitors were placed in the kitchen and living room. Details about the study on air pollution measurements are reported elsewhere (Alnes et al., 2013).

Fig. 1. Example of a traditional biomass stove often seen in rural households in Guizhou, China.