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Original Research Article

Emissions and fuel use performance of two improved stoves and determinants of their adoption in Dodola, southeastern Ethiopia

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ABSTRACT

Improved cook stoves (ICS) have perceived to exert a significant impact on households' economy, human health, and global climate change. There are few studies on ICS emissions and fuel use performance and on the factors that affect their adoption in Ethiopia. Thus, the objectives of this study were assessing: (a) the emissions of CO, CO_2 and fine particulate matter ($PM_{2.5}$) of improved Merchaye and Lakech charcoal stoves in comparison with traditional metal stoves; (b) specific fuel consumption (SFC) of the two ICS; and (c) the factors that affect their adoption. Data were collected using the Water Boiling Test in a laboratory and household survey. The results showed the Merchaye stove reduced emission of CO, CO_2 and $PM_{2.5}$ by 28, 22 and 27% respectively in comparison to a traditional charcoal stove. Whereas, the Lakech stove reduced emission of CO, CO_2 and $PM_{2.5}$ by 15, 8 and 13%, respectively. In non-sustainable fuel wood harvest circumstances, the annual emission reduction potential for individual Merchaye stoves was 0.33 t CO_2e and Lakech stoves 0.14 t CO_2e yr^{-1}. The SFC of Merchaye and Lakech were reduced by 222 and 164 g d^{-1}, respectively. The two ICS also reduced the time required for cooking. Regarding the status of adoption of ICS, 43.7% the sample households were adopters of Merchaye stoves and 31.3% Lakech, stoves. Whereas the non-adopters comprise 25% of the sample. Adoption of ICS was influenced by household head age, sex, education level and income. The results may have implication for mitigation of climate change, forest degradation and household workload.

1. Introduction

In developing countries, biomass is still the predominant cooking fuel [1] and currently there are a wide variety of stove technologies and designs. Among biomass fuels, charcoal is the predominant cooking fuel in sub-Saharan Africa's cities and towns [2], and in Ethiopia charcoal stoves are commonly used in urban and semi urban settings. Inefficient fuel combustion in traditional stoves release gaseous products with a higher global warming potential than carbon dioxide, such as carbon monoxide [3]. Traditional stoves are still the most prevalent way of cooking in the developing countries regardless of their inefficiency and risks associated to human health and the environment [4].

The main reason for the development of improved stoves is their environmental, health and socioeconomic benefits. Zhang et al. [5] have indicated that improved cook stoves (ICS) reduce the emission of health-risky pollutants in the short term and reduce greenhouse gases (GHG) emission in the long term. A study in China found that adoption of ICS reduced fuel wood consumption, wood collection time, and tree felling by 40.1, 38.2 and 23.7%, respectively [6]. In Guatemala the ‘Plancha’ ICS saved wood consumption by 39%, decreased time spent for wood collection and reduced indoor air pollution levels [7]. Pine et al. [8] asserted that ICSs reduced particulate matter (PM) by 74% and carbon monoxide (CO) concentrations by 78% in Mexico. The adoption of ICS (Patsari) has significantly contributed to improvements in living conditions through wood savings, and reducing indoor air pollution [9]. The adoption of ICS (patsari) improved womens' respiratory systems and eye comfort in Mexico [10]. In Gambia, ICSs saved fuel wood consumption by 40% and reduced indoor air pollution up to 90% [11]. Similarly, in Tanzania the adoption of ICSs saved fuel wood

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consumption, reduced women's workload by reducing time required for fuel collection, and created self-employment for the stove producers [12].

In developing countries like Ethiopia, whose energy supply is heavily dependent on biomass fuels, technical advances in energy efficiency are critical. In order to reduce pressure on forests and the adverse impact of indoor air pollution, the government of Ethiopia is trying to increase the availability of fuel saving technologies such as ICSs [13]. In this regard, non-governmental organizations, mainly GIZ, have been working on afforestation programs and dissemination of more efficient ICS technologies [14]. Although ICSs have magnificent contributions in reducing GHG emissions and PM, little attempt to quantify GHG emission from ICSs have been made in Ethiopia. Despite the fact that ICSs are a better option than traditional stoves, studies indicate that adoption of ICS has fallen behind expectations [15]. To our knowledge, there are no studies on improved charcoal stoves in Ethiopia. The objectives of this study, therefore, were to: (a) assess the CO, CO_2 and $PM_{2.5}$ emission reduction potential of Merchaye and Lakech charcoal stoves; (b) analyze their fuel and time saving efficiency, and (c) assess the factors that determine their adoption at Dodola, South East Ethiopia.

2. Methodology

2.1. Study area

The study was conducted in Dodola town, Oromia National Regional State, southeastern Ethiopia. It is located 320 km southeast of Addis Ababa in the Adaba-Dodola forest priority area. The town has a population of 26,176 and 3842 households. Cooking accounts for the bulk of domestic fuel consumption. Preparing sauce (commonly known as ‘wot’), boiling water, making coffee and similar activities involve burning a fire several times a day. Electricity and petroleum products are also available energy sources in this town.

2.2. Selection of the study area

Dodola was purposively selected as the study site due to (1) the accessibility of different types of charcoal stoves to the inhabitants, and (2) the town's close proximity to the Dodola Adaba forest reserve. Among the various available ICS, the researchers purposively selected Lakech, Merchaye as well as the traditional metal charcoal stove that is used by a large proportion of the inhabitants. The traditional stove was used as the control for comparison.

2.3. Description of charcoal stoves

The traditional metal charcoal stove (Fig. 1) is square shaped with removable grates and weighs approximately 1.5 kg. Typical dimensions 9.5 cm deep, an upper surface area of 441 cm^2, and a combustion area of 180 cm^2. Evenly distributed holes are located at the bottom of a square charcoal container. The cooking pot sits directly on the charcoal in the chamber. The cost of the stoves was 60 birr (USD 3) in July 2015.

The Lakech charcoal stove weighs 1.9 kg with combustion area of 179 cm^2 and depth of 8.5 cm. It has also an upper surface area of 400 cm^2. Pieces of charcoal are combusted in a bowl shaped combustion chamber. The stove's grates have 0.5 cm diameter holes. The pot sits on the stove's pan seat which is fixed to the metal part of the combustion chamber. The primary air metal entrance allows air to enter into the combustion chamber. The cost of a Lakech stove in June 2015 was 70 birr (USD 3.5).

In comparison to the Lakech, the Merchaye stove is lighter, with a smaller combustion area, depth, and upper surface area. It weighs 1.8 kg with a combustion area of 169 cm^2, depth of 7.8 cm and upper surface area of 324 cm^2. Charcoal is burned in a bowl shaped combustion chamber. The grates have 1–2 cm diameter holes. The pot sits on the stove's pan seat which is fixed to the metal side of combustion chamber. The primary metal air entrance enables air to enter into the combustion chamber. In June 2015, the cost of a Merchaye stove was 140–150 birr (USD 7–7.5). Merchaye and Lakech stoves are made from clay and sheet metal while the traditional stove is made from only sheet metal.

2.4. Water boiling test

The water boiling point test (WBT version 4.2.2) was conducted in the Addis Ababa laboratory of the Ethiopian Ministry of Water Irrigation and Energy to determine the performance of the stoves [16]. Although WBT was originally designed for wood-stoves, it has been adapted for charcoal stoves, with three phases – a cold-start phase, hot-start phase, and a simmering phase [16]. In a cold-start phase the tester begins with the stove at room temperature and boils 2.5 L of water in a 3 L pot without a lid. In the hot-start phase, water is boiled beginning with a hot stove to identify differences in performance between a hot and cold stove body. The tester then simmers the remaining water at approximately 3 °C below boiling for 45 min. These stove performance measurements help to simulate the process of cooking food. In order to estimate daily fuel consumption 2.5 L is multiplied by 3 (for morning, midday and night cooking time). Each stove's CO and CO_2 emissions data were measured using IAQ-CALC meter (Model No. 7545 instruments, Onset Computer Corporation, Bourne, MA, USA) while fine particulate matter ($PM_{2.5}$) data were collected using an indoor air pollution meter (IAP Meter-5000-Series, Aprovecho research center, 2008). Both the IAQ-CALC meter and IAP Meter stored the data on data logger minute-by-minute over the entire measurement period. The test was done three times for each stove type and data on CO_2, CO and $PM_{2.5}$ emissions were collected three times following the standard WBT version 4.2.2 in a controlled laboratory setting [16]. Background emissions were also accounted for by measuring concentrations of CO_2, CO and $PM_{2.5}$ before and during the test. The air temperature was 17.8–18.8 °C, the local boiling point was 91 °C, and the relative humidity was 64%. The charcoal used in this study was produced from an indigenous *Podocarpus falcatus*. Its moisture content was 9% and its pieces used in the study have a size of roughly 5–6 cm in diameter.

2.5. Household survey

Data on determinants affecting ICS adoption were collected by means of a household survey. The standard statistical equation was applied to determine the total sample size needed for this study [17]. As a result, 40 samples households, who did not adopt improved charcoal stoves, and 120 households who adopted improved charcoal stoves were selected randomly from the town's 3842 household inhabitants. The major issues included in the household survey were, the types of stoves adopted by the household, status of adoption of the ICS, the factors that contributed for the differences due to adopter and non-adopter households, the type of fuel wood used for cooking, the amount used per day, etc. The household survey questionnaires were pretested before the actual survey and, based on the results, and were revised avoiding ambiguity and terms of cultural sensitivity. Data collectors were employed for the household survey after training them on how to handle the interview. In addition a supervisor was assigned to follow the data collection in unannounced time of interviews

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