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Impacts of household energy programs on fuel consumption in Benin, Uganda, and India

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A B S T R A C T

This paper presents results of three United States Environmental Protection Agency (U.S. EPA) sponsored field studies which assessed the fuel consumption impacts of household energy programs in Benin, Uganda, and Gujarat, India. These studies expand on a previous round of U.S. EPA supported efforts to build field testing capacity and collect stove performance data in Peru, Nepal, and Maharashtra, India. Daily fuel consumption estimates of traditional and intervention technologies were made using the Kitchen Performance Test (KPT) protocol to determine the potential fuel savings associated with the respective programs. The programs in Benin and Gujarat, India resulted in significant fuel savings of approximately 29% and 61%, respectively. In Uganda, the homes using liquefied petroleum gas (LPG) consumed approximately 31% less charcoal than those not using LPG, although the total energy consumption per household was similar between the baseline and LPG user groups.
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Introduction

The majority of households in developing countries depend on solid fuels as their primary cooking energy source (Bonjour et al., 2013). The pollutants from combusting solid fuels in inefficient cookstoves are estimated to be responsible for four million premature deaths per year (Lim et al., 2012) and 25% of annual black carbon emissions (Bond et al., 2013).

Growing interest and resources have been focused on finding clean and efficient stoves and fuels, which, when used in place of traditional stoves and fuels, can help mitigate these impacts (Smith, 2010). With this growing interest comes increased scrutiny that impacts attributed to cookstove programs are real and meaningful.

Given the scope of the problem and growing global interest, current, peer-reviewed estimates of fuel savings from in-home assessments are surprisingly limited (Berkeley Air, 2012). Cookstove performance is often assessed through controlled laboratory testing rather than by in-home measurements of performance, as field based assessments generally require more resources and can be logistically intensive. Controlled laboratory testing of cookstoves, while useful for technology development and standardized testing, is often not predictive of real-world performance (Berkeley Air, 2012).

To promote the collection of more field-based cookstove performance data, the United States Environmental Protection Agency (U.S. EPA) has been supporting coordinated capacity building and field study efforts. The first round of U.S. EPA funded fuel consumption studies, reported in (Johnson et al., 2013), was done with stove programs in Nepal, Peru, and Maharashtra, India. This paper, building on results from the previous projects, presents the second round of fuel consumption studies under this program focusing on a charcoal stove in Benin, an liquefied petroleum gas (LPG) program in Uganda, and a forced-draft wood stove in Gujarat, India. These projects represent a variety of potential household energy solutions whose fuel consumption impacts have not been well characterized.

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Methods

Kitchen Performance Testing

The Kitchen Performance Test (KPT) protocol used for this study is an uncontrolled, household-level test that measures real-world fuel consumption (Bailis, 2007), for which all household fuels are weighed daily for four continuous days, providing three days of fuel consumption estimates. Fuel was weighed with calibrated, digital, hand-held scales (maximum 50 kg; resolution 0.01 kg), and wood moisture was measured daily where relevant. Household fuel consumption estimates are presented as fuel mass per "standard adult" (SA) per day and fuel energy per SA per day. The SA metric is used in the KPT to normalize the caloric energy needs across gender and age with the following weights: child 0–14 years = 0.5; female over 14 years = 0.8; male 15–59 years = 1; and male over 59 years = 0.8 (FAO, 1983). The fuel consumption estimates are at a household level, which subsumes fuel use from different stoves, although each fuel type is estimated separately. In situations where multiple stoves and fuels are used to meet household energy demands, known as stove/fuel stacking (Ruiz-Mercado et al., 2011), the estimates represent the fuel use for a given fuel type regardless of whether one or many stoves were used. The technical KPT methods used here are the same as those described in Johnson et al. (2013), in which more detailed descriptions of the approach can be found.

KPT program overview

Participating cookstove programs were selected from a pool of applications sent to the U.S. EPA based on the readiness and resources of the program, location, and other factors. Berkeley Air, U.S. EPA, and Winrock International conducted an on-site training workshop in each location with staff from the selected programs as well as participants from other organizations in the country or region. The respective KPT field campaigns immediately followed the workshops. The specific projects are as follows:

Benin: The Éclair stove, developed by GIZ and locally manufactured by GIZ trained artisan producers, was the intervention technology evaluated in Benin (see Fig. 1). The charcoal burning Éclair is produced in four different designs of varying size and shape, all of which are constructed from recycled metal with secondary air holes intended to increase the thermal and combustion efficiencies by regulating airflow and more fully oxidizing the fuel carbon. The cross-sectional study took place along the southern coast of Benin in the cities of Cotonou and Porto Novo and the peri-urban community Ouidah, where charcoal is the dominant cooking fuel. Although traditional charcoal stoves were varied in this region, the Cloporte stove was predominantly used and, therefore, primarily sampled during the KPT. The Cloporte is a square or circular conical stove constructed of reclaimed metal, and comes in various sizes (see Fig. 1). A team of six university students from Cotonou surveyed 57 homes using traditional stoves and 63 homes using Éclair stoves, which were recruited by GIZ from their customer database. Participants were instructed to follow their normal stove routine during the KPT. The study took place over a two-week period during the rainy season in July 2013.

Uganda: The Ugandan project partner, Wana Energy Solutions, is a local supplier of household liquefied petroleum gas (LPG) and stoves. The KPT, which assessed the displacement of solid biofuels with cleaner burning LPG, was conducted in urban and peri-urban neighborhoods to the south of central Kampala. The stove/fuel combinations in this area were varied and usage patterns were dynamic. The most common fuels were charcoal, wood, and LPG. The study was cross-sectional, with the surveyors from Wana Energy visiting 48 homes using charcoal and LPG to satisfy daily cooking requirements, and 54 homes using primarily charcoal as the baseline comparison group. The traditional and LPG stoves are shown in Fig. 1. LPG users were identified from a list of Wana Energy customers, and the baseline charcoal users were selected from the same neighborhoods and responded that they would be able to afford LPG at the current price, helping to ensure comparability with the LPG users. The KPT was conducted during the dry season, in August 2012.

Gujarat, India: The Eco Chulha, designed and produced by Alpha Renewable Energy, Pvt. Ltd., was the intervention stove for the study in Gujurat. The Eco Chulha, shown in Fig. 1, is a forced-draft gasifier that was used primarily with wood during the KPT, although it can be used with a variety of solid biomass fuels. A total of 117 homes were sampled using a 'before-and-after' study design. Baseline measurements were carried out on traditional mud chulhas during the rainy season in early August 2013. The Eco Chulha was then disseminated and follow-up measurements were collected at the end of the rainy season in late October 2013. Two different sizes of the Eco Chulha were sampled during the study but were treated as a single group as there was no significant difference in fuel consumption performance. Homes were recruited and surveyed by members of the Self Employed Women's Association (SEWA), with the participants agreeing to pay for the Eco Chulha at a subsidized rate (Rs. 700, USD 11.29). The KPT took place in the rural Mehsana and Anand districts of Gujarat, India. SEWA hosted the project, in partnership with Alpha Renewable Energy.

Initial round of KPT studies: For context, the studies presented in Johnson et al. (2013) are briefly summarized here:

Maharashtra, India — Conducted in homes using the Oorja, a forced-air gasifier designed to burn sugarcane pellets, with the comparison groups being the users of traditional wood burning chulhas and homes using exclusively LPG.

Nepal — Conducted in homes using the Improved Biomass Stove, which is a stationary, wood burning stove made of mud and brick, with the comparison group homes using traditional wood burning chulos.

Peru — Conducted in homes using the Inkawasi stove, a built-in chimney stove constructed from adobe and either ceramic or mud bricks, which were compared to traditional open-fire stoves.

Results and discussion

Benin

Fuel consumption results for Benin are presented in Table 1, reported as mass and energy equivalent of fuel used per SA per day. Households using Éclair stoves used ~18% less charcoal per home ($p = 0.02$) and 29.5% less charcoal per SA ($p < 0.01$). These differences are based on means of the entire Éclair and baseline groups, respectively. Within each group, however, there were a variety of stove designs. The majority of traditional charcoal stoves were a version of the Cloporte, though a few alternative, metal, bucket-style stoves were also used. The Éclair designs also varied in size and shape, with four versions present in study homes. No significant differences in charcoal consumption were found between homes using different Éclair stove designs.

In addition to economic benefits for Éclair users, the charcoal savings imply substantial environmental benefits as it typically takes ~4–8 kg of wood to produce 1 kg of charcoal (FAO, 1990). Given the charcoal savings of 0.11 kg/SA/day, the use of an Éclair stove would translate into 550–830 kg of wood saved per home over the course of a year.

The 31% charcoal savings found during the KPT study are less than the 41% fuel savings derived from the Water Boiling Test 4.2.2 (WBT

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