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A model for cost-benefit analysis of cooking fuel alternatives from a rural Indian household perspective

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ABSTRACT

Nearly half of the world's population does not have access to cleaner cooking fuels, and this is attributed to several things including the lack of resources (fuel), infrastructure (production and distribution), purchasing power (poverty), relevant policies, and a combination of these reasons. A household's fuel choice aims to minimize cost and maximize benefit, both of which are intricate functions of many factors. The factors influencing a household's fuel preference, and how manipulating these factors such as subsidies, improved distribution networks and user awareness will affect fuel preference is reported. A cost-benefit analysis (CBA) model was developed to study the fuel preferences of rural Indian households. Seven cooking fuels (biomass (wood and crop residue), dung, charcoal, liquefied petroleum gas (LPG), biogas, kerosene and electricity) were ranked in order of household preference. Various scenarios were considered to demonstrate the sensitivity of fuel preference to multiple factors such as subsidies and improvement in cooking technology. Results obtained from the model demonstrated strong agreement with the current fuel usage pattern in rural India. The model was then applied to compare traditional cookstoves (TCS) to non-subsidized improved cookstoves (ICS). The benefit-to-cost ratio of solid fuels when used in ICS was lower than that when used in TCS. A similar trend was observed for fully-subsidized ICS; indicating that price is not the only obstacle to the adoption of an ICS. Sensitivity analysis was performed to demonstrate the utility of this CBA model in framing policies to promote fuel transition in rural India. Although providing subsidies on LPG and electricity can make these cleaner fuels an attractive option, biomass will remain a household's preferred fuel unless distribution networks and infrastructure is developed to ensure their uninterrupted supply and accessibility.

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1. Introduction

The domestic sector accounts for 40% of the total primary energy demand in India [1]. The major fraction of this demand is satisfied by solid fuels such as firewood, crop residue, cow dung cake, coal and charcoal. According to the 2011 Census of India [2], 67.2% of the total households used solid fuels and 88% of these households are in rural India. Inefficient combustion of solid fuels results in dangerously high levels of indoor air pollution, and it has recently been recognized as the world's largest environmental health risk [3]. Firewood is the most widely used solid fuel in rural areas. While 65% of urban households have adopted liquefied petroleum gas (LPG) and piped natural gas (PNG), only 11.4% of rural households have followed suit, highlighting the energy source disparity between the urban and rural population. The other cooking fuel alternatives, electricity, biogas and kerosene, are currently being used by less than 4% of Indian households. A household's cooking fuel preference is governed by a range of factors, income and fuel cost being most critical [1,4]. Other factors, such as fuel availability, supply reliability, geography and impact on health also influence a household's fuel choice [5], but are difficult to quantify. Understanding how these factors affect the fuel preference of a household is critical for the success of initiatives targeting the dissemination of cleaner fuels or cooking systems. Policy options to promote fuel switching is limited and energy interventions with realistic goals and targets need to be implemented [6].

There are limited studies that model fuel preferences of Indian households. While Farsi et al. [7] used an ordered discrete choice framework to model the fuel preference of firewood, kerosene and LPG among urban Indian households, other models examining cooking fuels in India have focussed on either resource allocation or the usage patterns of cooking fuels [8–13] but have failed to incorporate the multitude of factors that influence a household's fuel preference. Linear programming and its extension, goal programming, are the most commonly used tool for resource allocation [11–16]. This technique is best suited for quantitative data and can be applied to qualitative parameters only if they are quantified using methods such as the analytical hierarchy process (AHP) [17,18]. Ramanathan and Ganesh [13] used AHP to quantify the long-term availability, convenience and safety of different fuel alternatives and performed linear optimization to provide cooking portfolios maximizing these parameters. However, linear optimization fails to capture the effect of multiple factors simultaneously on the model outcome. These drawbacks can be overcome with cost-benefit analysis (CBA). With CBA, the effects of co-varying factors can be examined. Unlike optimization using linear programming, CBA does not provide a portfolio for resource allocation but instead ranks fuels in order of preference. Previous studies have used CBA for decision making and for policies related to health and power decentralization [19–22]. To the best of our knowledge, no work has been done using CBA to determine cooking fuel preferences in rural India.

This paper unravels the intricacies involved in the decision-making process governing a household's fuel selection. The first objective is to identify the key factors influencing a household's fuel preference and the extent of their influence. The second objective is to demonstrate how manipulating factors such as subsidies, improved distribution networks and user awareness will affect fuel preference. A CBA model was developed to determine the cooking fuel preferences of rural households in India. Seven fuel alternatives were considered: biomass (wood and crop residue), biogas, dung, charcoal, LPG, kerosene and grid electricity. The AHP was implemented to assign weights to all factors constituting either a cost or a benefit to the user. This was repeated for each fuel alternative. The benefit-to-cost ratio, which governs a household's fuel preference, was used to rank the fuel alternatives. A sensitivity analysis was then performed to assess the importance of each criteria on fuel selection. Different cases such as the promulgation of improved technology (traditional vs improved cookstove) and subsidies on cleaner fuels, were investigated to highlight the utility of this CBA model as a decision-making tool.

2. Model description and methodology

2.1. Cost-benefit analysis model

Saaty [18,23] proposed AHP, a multi-criteria decision-making approach, which incorporates both rationality (mathematical) and intuition (psychological) to determine the best alternative for a specific goal. CBA using AHP requires the construction of a hierarchical map for both cost (Fig. 1A) and benefit (Fig. 1B). The top level (*goal*) defines the objective i.e. to calculate the total cost or total benefit associated with different cooking fuels. The *goal* is constituted of various criteria (C_i: i^{th} criteria) forming the second level. *Direct cost* and *indirect cost* were considered as the criteria for *total* cost whereas *total benefit* was categorized into three criteria by associating possible household benefits with the person cooking (user), the fuel used and the cooking system. The third level of the hierarchical map contains sub-criteria for each of the criteria, C_i ($SC_{i,j}$: j^{th} sub-criteria of the i^{th} criteria). Sub-criteria (Fig. 1) for both *total cost* and *total benefit* are described in Table 1. In this paper, only criteria and their sub-criteria were considered but the sub-criteria could be further deconstructed to form an additional level. Thus, in general there can be any number of levels in the hierarchical map depending on the nature of analysis. The last level of the hierarchical map contains cooking fuel alternatives (A_k: k^{th} alternative). Seven cooking fuels were considered based on the fraction of households using these fuels in rural India: biomass (74.8%), dung (10.9%), charcoal (0.8%), LPG (11.4%), biogas (0.4%), kerosene (0.7%) and electricity (0.1%) [2]. Other alternatives such as solar cookers, were not considered owing to their very limited use in Indian households ($<$ 0.6%).

2.2. Weight assignments using pairwise comparison

Weights to (a) alternative "*k*" with respect to sub-criteria "*j*" of criteria "*i*" ($WA_{i,j,k}$), (b) sub-criteria "*j*" with respect to criteria "*i*" ($WSC_{i,j}$), and (c) criteria "*i*" with respect to goal (WC_i) were assigned through pairwise comparison. Though details about the pairwise comparison for AHP can be found in Saaty [17,18,23], an example to demonstrate the process to assign weights to the seven fuel *alternatives* ($k=1$–7) for *capital cost* (in this case, $j=1$) contributing to the *direct cost* ($i=1$) is presented. Pairwise comparison assigns a weight on a relative scale using judgement or data from a standard scale such as monetary value [17]. The *capital cost*, includes the price of each stove ($k=1$–3, improved cookstove (ICS) for solid fuels, $k=4$ for standard LPG stove, $k=5$