Clean Cooking: Why is Adoption Slow Despite Large Health and Environmental Benefits?

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ABSTRACT

More than one-third of the world's population, mainly the low-income group, still rely on traditional biomass fuels for household cooking. The indoor air pollution from household cooking is one of the main drivers of child mortality in developing countries. It also causes deforestation and emissions of black carbon. A large number of studies show that the benefits of clean cooking, including health and environmental benefits and value of time savings from fuelwood collection, are much higher than the cost of adoption of clean cooking. Over the last four decades, several programs and initiatives have been launched by governments and non-governmental organizations in many developing countries with the help of multilateral and bilateral donor agencies to adopt clean cooking. Two common options adopted are improved-cookstoves and cleaner fuels. However, the adoption of clean cooking has been very slow. This paper discusses the main factors responsible for the slow adoption of clean cooking. We present an extensive review of empirical literature for this purpose. We find that lack of information or awareness, low household income or affordability, and human behavior and social factors are the main barriers to expedite the adoption of clean cooking in developing countries. Finally, we offer some innovative approaches to promote clean cooking policies and programs.

Keywords: Clean cooking, technology adoption, household energy

https://doi.org/10.5547/2160-5890.10.1.gtim

1. INTRODUCTION

About three billion people or 43% of the global population still rely on traditional biomass, for their daily cooking needs (WHO 2016). Currently, traditional biomass such as fuelwood, animal dung, and agriculture residues accounts for 35% of the global household energy consumption (Table 1). The share is highest in Africa (86%) followed by developing Asia (49%). The situation is much worse in low-income population, more than 90% of which depend on traditional biomass for cooking and home heating (WHO 2017).

Household cooking consumes more energy than any other end-use services (e.g., lighting, heating, cooling and refrigeration) in the residential sector in low-income countries even if all other fuels are included (Daioglou, Ruijven, and Vuuren 2012). The widespread use of traditional biomass for cooking can have severe implications for human health through indoor

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TABLE 1
Share of biomass-based fuels (mainly traditional biomass) in total household energy demand (%).

	1990	2016
Developing Asia	76	49
Of which: China	69	25
India	86	70
Africa	90	86
Rest of world	10	10
World	42	35

Source: IEA (2018).

air pollution and the natural environment through deforestation. Burning of biomass releases greenhouse gases (GHGs) and black carbon,[1] thereby contributes to climate change.

The World Health Organization (WHO) estimated that 4.3 million premature deaths in 2012 caused by exposure to household air pollution (HAP) from cooking with solid fuels (WHO 2017). These premature deaths translate into the direct economic impact of US$400 billion or 0.5% of global GDP in the same year (MGI 2014). In particular, women and children are facing the highest health risks from exposure to HAP, accounting for 60% of all deaths attributed to such pollution (WHO 2017). The common health risks associated with HAP include risk of respiratory illnesses, including childhood pneumonia and chronic obstructive pulmonary disease (COPD), lung cancers, and cardiovascular diseases.

Burning of biomass for household cooking is one of the major sources of deforestation in the developing world. An early study by the East African Community Secretariat reports that heavy dependence on biomass for energy supply contributed to an annual deforestation rate of 3-4 % in Kenya, 2% in Tanzania and 2% in Uganda (EAC 2006). Similarly, fuelwood extraction is the main cause of forest degradation and deforestation in Peru (Sánchez and Grados 2007). It is estimated that if half of the world's households that rely on fuelwood for their cooking need, shift away from fuelwood to other clean cooking fuels by 2030, it would save from 16% to 40% of current global forest cover (WLPGA 2018).

Fuelwood consumption for cooking contributes to climate change through multiple channels. First, it is the direct source of CO_2 emissions because it is mainly collected from unsustainable natural forests. Second, it causes regional and global warming through emissions of black carbon. Third, it reduces the carbon sinks of forests and soils through deforestation and forest degradation.

Since the extensive use of traditional biomass for cooking is the source of the severe health impacts and considerable environmental and climate change impacts, promotion of clean cooking is one of the main elements of energy policies in developing countries. It is also one of the main agendas of the United Nations' sustainable development goals (SDG), which seek to ensure access to 100% of the global population to clean fuels and technology by 2030 (UN 2015). The economics of clean cooking is very sound as the benefits, including health and environmental benefits, is much higher than the total costs of its implementation (Jeuland

1. Black carbons are emitted from incomplete combustion of solid fuels, particularly the traditional biomass. They are considered as short-lived but important climate forcers that have a significant influence on the earth's climatic system and contribute to global climate change (UNEP and WMO 2011). Solid fuels (traditional biomass and coal) used for cooking or heating in homes is estimated to contribute 25% of global black carbon emissions (Bond et al. 2013).

et al. 2018; Gwavuya et al. 2012; Jeuland and Pattanayak 2012; García-Frapolli et al. 2010; Habermehl 2007, 2008; Smith and Haigler 2008). Several efforts have been made to promote clean cooking around the world over the last 40 years. As of 2010, there were more than 100 national programs on clean cookstoves (World Bank 2015).[2] Heavy subsidies are being provided to scale-up improved clean cookstoves and switching to clean fuels, such as LPG and electricity (Malla and Timilsina 2014). Yet, the adoption of clean cooking is very slow and not that many programs or projects for improved cookstoves delivered the expected results (Lewis and Patttanayak 2012; Puzzolo et al. 2016).

Based on the rich literature, this paper investigates why adoption of clean cooking is so slow despite the huge economic, health and environmental benefits, and despite so much of efforts to promote it by national governments and international organizations. We review studies that empirically demonstrate the importance of various factors affecting households' adoption of clean and improved cooking. We find that lack of information or awareness, low income or affordability, and behavioral and social factors are the main factors behind the slow adoption of clean cooking. Other important factors include lack of supply infrastructure and higher costs. Understanding of these factors, some of which are country-specific, is important to increase the adoption of clean cooking by households which are heavily dependent on traditional biomass and inefficient cookstoves for cooking. Further, any local or national policies that address awareness of clean cooking, understand its social values, enhance local employment targeted for women in poor households, create community ownership, and support sustained use of clean cooking, should be promoted. The insights coming from this review is expected to contribute to designing future policies and programs to promote clean cooking in developing countries.

2. HOUSEHOLD COOKING TYPOLOGY

Multiple criteria are used to categorize energy types for cooking. Depending on the level of energy development, cooking fuels are categorized as "traditional" (animal dung, agricultural residues and fuelwood), "intermediate" (wood pellets, charcoal, briquettes, lignite, coal and kerosene) and "modern" (solar, LPG, biogas, natural gas, electricity). They are categorized as "primary" and "secondary" depending on their production/extraction process. The primary energy for cooking is that obtained directly from resources (e.g., fuelwood, agricultural residues and animal dung). Secondary energy is derived from primary energy through physical or chemical transformation (e.g., electricity from biomass-fired power plants, ethanol from sugar cane, charcoal and wood pellets from fuelwood, biogas produced from animal dung and agricultural waste). Cooking fuels are also categorized as "renewables" (biomass from sustainable forests and biogas) and "non-renewables" (biomass from unsustainable forests, LPG and natural gas). Note that available statistical databases count all biomass energy under "renewable en-

2. Global efforts to promote clean cooking continues. A global alliance, known as Global Alliance for Clean Cookstoves (GACC), has been initiated under a global partnership of public and private sectors to foster the adoption of clean cookstoves and fuels in 100 million households by 2020 (GACC 2011). The World Bank has recently launched a number of regional clean cooking initiatives such as (i) the Africa Clean Cooking Energy Solutions, a market transformation program that promotes enterprise-based, large-scale dissemination and adoption of clean cooking solutions in Sub-Saharan Africa and (ii) the East Asia and Pacific region's Clean Stove Initiative which aims to scale up access to advanced cookstoves for rural poor households through country-specific technical assistance and a regional knowledge-sharing and cooperation forum. Besides these global initiatives, there are several large-scale national initiatives to promote clean cooking, particularly in China and India (Venkataraman et al. 2010; World Bank 2013).

ergy" category. Biomass-derived from unsustainable forests cannot be interpreted as renewable. There are also wide variations in the level of consumption and the patterns of cooking energy use by households based on their levels of urbanization and income. These categorizations include "rural" and "urban" households, and "low" income and "high" income households. Based on its level of impact on human health, cooking energy types are also categorized as "polluting" and "clean" fuels. The former category includes solid fuels (biomass and coal) and kerosene, and the latter includes biogas, LPG, natural gas and electricity.

Households use several types of cookstoves which are often associated with specific energy types. For example, traditional (3-stones), simple non-traditional (e.g., clay pot-style or simple ceramic liners), chimney, rocket, charcoal, and gasifier stoves use solid fuels which are common in rural areas in developing countries. In contrast, modern cookstoves such as LPG, natural gas and electric stoves, are common in urban areas. In recent years, biogas cookstoves are also gaining popularity in rural areas in developing countries.

The energy conversion or thermal efficiency of cookstoves vary by stove types. Traditional cookstoves (e.g., open mud stoves burning fuelwood, crop residue, and charcoal) have a low efficiency varying between 9% to 22%.; Thermal efficiency of improved biomass stoves (e.g., improved stoves burning fuelwood, crop residues, charcoal and biogas) varies between 20% to 65%; and thermal efficiency of advanced cookstoves (i.e., cookstoves burning LPG, natural gas, electricity) reaches up to 75% (Malla and Timilsina 2014). Cooking fuels also differ in their energy densities or heat values. Modern fuels have high energy content per kg of fuel used, while traditional biomass fuels have low energy content.

3. CLEAN COOKING ECONOMICS AND WELFARE

A large number of empirical studies assess both costs and benefits of switching to modern fuels for cooking (e.g., LPG and biogas) or switching to efficient stoves using fuelwood and charcoal (improved cookstoves or 'ICS') (see, for example, Jeuland et al. 2018; Troncoso and da Silva 2017; Nerini et al. 2017; Gwavuya et al. 2012; Jeuland and Pattanayak 2012; Malla et al. 2011; García-Frapolli et al. 2010; Habermehl 2007, 2008; Mehta and Shahpar 2004). Table 2 presents selected studies along with their methodologies and key findings. These studies vary in terms of coverage and valuation of the costs and benefits associated with switching to clean cooking.[3] In general, the costs include the capital cost of a stove and ventilation system, program expenses associated with clean cooking initiatives if switching to ICS is carried out through such initiatives (instead of automatic market-driven approach), regular operation and maintenance (O&M) costs, and fuel costs. The benefits of clean cooking include time savings (both cooking and fuel collection), fuel savings due to efficiency improvements, health benefits mainly due to reduction of indoor air pollution, local environmental benefits through reduction of local air pollutants such as particulate matters and volatile organic compounds, and climate change benefits (i.e., reduction of GHG and black carbon emissions).

The economics of clean cooking reported in the existing studies varies due to differences in the coverage and valuation of these costs and benefits. For example, some studies (e.g.,

3. While systematic reviews are desirable, they require a considerable investment in time and human resources. For the purpose of this review study, we use simple approach that are context and organization specific and require less time and resources. We use ScienceDirect, Google Scholar, Scopus, JSTOR and ISI Web of Science databases, and individual websites of several international organizations (World Bank, UN, UNDP, UNEP, UNICEF, WHO, GTZ, IEA/OECD, ADB, EPA, SEI, EPA, USAID) for searching relevant published and non-indexed articles.

TABLE 2
Selected studies evaluating the economics of clean cooking.

Study	Methodology	Key Findings	Strength of the study	Limitation of the study
Gwavuya et al. (2012) Ethiopia	A multistage stratified sampling method was used to obtain study areas (villages) and systematic random sampling was used to select study households within a village Benefits included: fuelwood savings, increased fertilizer quality, time savings in fuel collection	Due to low shadow prices of own collected energy sources, biogas needs a heavy subsidy to replace traditional fuels (firewood and dung) Results are sensitive to the values assigned to slurry and shadow wage	It follows the survey technique to determine the values of associated variables; Estimates shadow wages (opportunity cost of labor in the absence of wage rate	Not all costs and benefits, such as benefits from indoor air pollution, benefits of leisure (recreation and comforts) are included
García-Frapolli et al. (2010) Mexico	Standard benefit-cost analysis including both direct and external costs and benefits related to the *Patsaris* improved cookstoves program implemented in rural Mexico Benefits considered: fuel savings, time savings, income generation, health benefits, reduction of local and global emissions	The benefit to cost ratio is very high, 9 to 11 for discount rates when the economic lives of the stoves are 14 years	Detailed data obtained through monitoring studies carried out in the study area for several years The analysis includes all possible indirect benefits	Selection of some variables, such as shadow wage, is ad-hoc Benefits pose a risk of overestimation due to the uncertain values of external benefits and use of the market price of fuelwood instead of the value of time savings based on the shadow wage rate Not enough sensitivity analysis
Malla et al. (2011) Nepal, Kenya, and Sudan	Uses WHO guidelines for CBA of household energy interventions (Hutton et al. 2006) Benefits considered: health benefits, fuel savings, time savings in both cooking as well as fuelwood collection	The benefit to cost ratios, at 10% discount rate, are 1.4, 2.5 and 21.4 in Nepal, Sudan, and Kenya respectively; corresponding IRRs are 19%, 62% and 429%.	Data collection through survey approach Both direct and indirect costs and benefits are included	Values of cooking time savings are overestimated, especially in Kenya, where the value of cooking time savings is much higher than the value of time savings from fuelwood collection No sensitivity analysis despite the fact that estimation of indirect benefits are highly uncertain

(continued)

TABLE 2
Selected studies evaluating the economics of clean cooking *(continued)*.

Study	Methodology	Key Findings	Strength of the study	Limitation of the study
Jeuland and Pattanayak (2012)	Compares the net costs of traditional wood-burning stoves to six alternatives: a) improved wood stoves, b) unimproved charcoal stoves; c) improved charcoal stoves, d) kerosene stoves, e) LPG stoves, and f) electric stoves. Uses Monte Carlo simulations of the net benefits for the various stove options Benefits included: fuel savings and climate change mitigation	Switching from traditional wood stoves to improved wood and charcoal stoves, and kerosene and LPG stoves would be economically attractive from the private perspective (even if environmental benefits are not accounted for); the benefits are higher with kerosene and LPG stoves compared to improved wood or charcoal stoves.	Monte Carlo simulations allow a large number of sensitivities on parameters values that are often uncertain and influence the economics of clean cooking.	Does not include benefits from time savings in the kitchen as well as fuelwood collection. It also does not account for potential health benefits. Although large sensitivities through Monte Carlo simulation are carried out, results cannot be applied for any particular country or location
Habermehl (2008) Malawi	Comparison of net costs of an efficient rocket stove with that of traditional wood stoves Benefits included: fuel savings, reduction in deforestation and climate change mitigation	The benefits to costs ratio varies from 2.67 to 5.16 for 10 years' program and with a carbon price of US$7 per ton of CO_2.	Data were collected from different user groups to cover the maximum diversity in values of various parameters (size of cookstoves, fuel efficiency, prices, etc.); Includes the costs of program implementation as the efficient cookstoves were implemented through donor-funded programs (costs of staff salary, other costs)	It does not include health benefits of clean cooking; the firewood savings were valued with the trade price for fuelwood, which could overestimates the value of time savings especially for those households, which have very low opportunity costs for their time. The discount rate is relatively low (3%)
Habermehl (2007) Uganda	An economic evaluation of dissemination of ICS with traditional fuelwood and charcoal stoves	An investment of €1 yields a return of €25, considering all economic benefits (fuel saving, cooking time, health, forest resources, soil fertility, emissions); whereas investment of €1 gives a return of €13, taking only the benefits due to fuel savings into account.	The economic evaluation assessed the economic benefits for the households using the improved stoves and the economic benefits derived from health and environmental impacts.	The discount rate is relatively high (10%)

(continued)

TABLE 2
Selected studies evaluating the economics of clean cooking *(continued)*.

Study	Methodology	Key Findings	Strength of the study	Limitation of the study
Bensch et al. (2015) Burkina Faso	Comparison of *Roumde* biomass ICS with traditional cookstoves	Despite the economic benefit of adopting *Roumde* ICS (cost US$ 4-7) is very high (annual return of 300% even with a very high-interest rate of 60%), the adoption rate is very low (10%) mainly due to upfront cost (liquidity constraint) of ICS.	Affordability problems play a key role in the adoption of ICS and subsidies to bring down the price or financing schemes should be considered to overcome household's liquidity constraints.	Includes only private monetary returns and excludes social benefits (positive health and relief in workload) based on qualitative findings.
Nerini et al. (2017) Kenya	Comparison of traditional cookstoves with improved and advanced cookstoves based on a levelized cost of cooking a meal (LCCM)	While LCCM is lower (15-25%) with improved biomass cookstoves, the LCCM is much higher (up to 8 times) with advanced cookstoves (LPG and electricity) mainly due to fuel costs.	Despite the higher costs of advanced cookstoves, targeted subsidies for advanced stove and fuel technologies are recommended to transition to clean cooking solutions.	Despite health and environmental benefits, only private benefits from the users' perspective are considered.
Usmani et al. (2017) Cambodia	Evaluating whether economic incentives enhance continued use of ICS	Households respond to capital-cost subsidies by adopting ICS at significantly higher rates and by using it more frequently and for longer periods, however, their effect appears to diminish over time.	Greater variation in levels of economic incentives for disseminating clean cooking technologies in low-income households is needed to better understand their net social benefits.	Households in low and medium income communities do appear to have over reported stove use possibly to obtain use-based economics incentives.
Mehta and Shahpar (2004)	Comparison of ICS and advanced cookstoves based on generalized cost-effectiveness analysis	ICS are much more cost-effective than the advanced cookstoves because advanced cookstoves require an additional cost of more expensive cleaner fuels and cooking technology.	Interventions may not appear to be cost-effective if it includes health benefits and exclude non-health benefits, such as social and environmental benefits.	This analysis only addresses benefits from averted illness but ignores treatment costs.

(continued)

TABLE 2
Selected studies evaluating the economics of clean cooking *(continued)*.

Study	Methodology	Key Findings	Strength of the study	Limitation of the study
Troncoso and da Silva (2017) LAC	Exploratory analysis of transitioning from solid fuels to LPG	Price is the single most important adoption factor for the uptake of advance cookstoves in LAC, even surpassing cultural barriers in some cases in Ecuador and Bolivia. Also, LPG subsidy benefited high-income households	Subsidy policies should include mechanisms to target non-LPG users.	Lack of information on the price and percentage of LPG fuel subsidy in each LAC countries per year that is necessary to relate the decline in solid fuels with LPG fuel subsidies.
Jeuland et al. (2018)	Based on the costs and benefits of adoption of ICS distinguished by stove type and fuel.	Households may not typically benefit privately from switching to cleaner cooking technologies even if health and time savings gain are fully internalized.	Net benefits are positive when the environmental benefits, that includes reduced CO_2 and BC, are included in the accounting. Targeted fuel and stove subsidies are suggested.	One concern is that of site or technology selection bias. Second, valuation of local loss of forest cover, stove maintenance or promotion program costs and not covered.
Larsen (2018) India	Based on benefit-cost ratios (BCRs) of HAP control interventions.	For significant health benefits, community-focused programs that promote ICS together with sustained use of LPG is important.	BCRs are largest for promotion of ICS, followed by the promotion of LPG cookstoves and reduction in LPG subsidy.	The quantified benefits of health effects from the intervention programs are not study area (Rajasthan, India) specific.

García-Frapolli et al. 2010; Hutton et al. 2006) cover most of the possible indirect benefits from clean cooking (i.e., value of saved time from biomass fuel gathering, value of reduction in health costs through the reduction of indoor air pollution, value of GHG mitigation), others consider only part of these benefits. While Jeuland and Pattanayak 2012 consider only the GHG mitigation benefits, Gwavuya et al. 2011 and Habermehl 2008 consider most benefits but the health benefits. In terms of costs, some studies (e.g., Habermehl 2007, 2008; Larsen 2018) also include the costs of program implementation as the efficient cookstoves were implemented through donor-funded programs (costs of staff salary, other costs); this is not the case in most other studies.

Existing literature on the economics of clean cooking also report significant economic benefits from switching over to clean cooking (Table 2). For example, while evaluating the economics of an improved clean cooking program in rural Mexico using detailed data obtained through monitoring of the program between 2003 and 2008, García-Frapolli et al. (2010) estimate that every one dollar investment on clean cooking would generate net benefits of 9 to 11 dollars through savings of fuel and time (including fuel collection time) and reducing health impacts of traditional biomass-based cooking. A cost-benefit analysis based on a guidance developed by the WHO, Hutton et al. (2006) and Malla et al. (2011) show that the benefits of clean cooking (that would result from fuel savings, time savings, and in-door air pollution reduction) are 1.4, 2.5 and 21.4 times higher as compared to the implementation costs in Nepal, Sudan and Kenya, respectively. While estimating the net costs of adopting efficient clean cookstove (rocket stove) instead of traditional wood stoves in Malawi, Habermehl (2008) finds that the benefits, including fuel savings, time savings, reduction of deforestation and climate change mitigation, would be 2.67 to 5.16 higher as compared to the investment to the program, including the costs of implementation of the program (e.g., costs of staff salary, office overheads). Likewise, based on the economic evaluation of dissemination of ICS in Uganda, Habermehl (2007) estimates that the investment of €1 yields a return of €25 by considering all economic benefits, such as fuel saving, cooking time, health, soil fertility and emissions, whereas the investment of €1 yield a return of €13 even if only fuel savings are taken into consideration. WHO (2006) reports that if US$ 13 billion were invested annually to halve the number of people globally using solid fuels with traditional stoves for cooking by 2015, by providing them with access to LPG or improved biomass stoves, it would produce a payback of US$ 91 to $104 billion per year, an equivalent of annual benefit-cost ratio (BCR) of 7 or higher. In the report, the benefits included health care cost savings, avoided lost work time, reduced environmental degradation and deforestation, time savings, and the economic welfare gain from reduced risk of premature death. If only improved cookstoves were made available to half of those burning biomass and coal in traditional cookstoves, it would produce a net benefit of US$ 34 billion a year.

In some cases, a combination of different intervention programs in reducing household air pollution (HAP) from cooking with traditional biomass is also important. For example, a recent study on benefits and costs of HAP control intervention programs in India (Larsen 2018) finds that BCRs are largest (5.5 – 10.3) for the promotion of ICS, followed by the free provision of LPG for poor households (2.8 – 4.9) and a 50% reduction of subsidies to LPG fuel (0.4 – 0.6). Benefits of ICS and LPG cookstove programs included the value health improvements, time savings from biomass fuel collection and preparation, reduced cooking time resulting from ICS and LPG cookstoves, and reduced CO_2 emissions, while the benefit of LPG subsidy intervention program included reduced LPG fuel cost savings and welfare gain from reduced economic deadweight loss. However, the health benefits associated with the ICS program is only half of the health benefits associated with the LPG cookstoves program. Combining these intervention programs, switching from traditional inefficient cookstoves to ICS and LPG cookstoves, make substantial health benefits. Using systematic analysis, Jeuland et al. (2018) find that net benefits are positive from switching to cleaner cooking technologies when environmental benefits, that include reduced climate forcing related emissions (CO_2 and black carbon), are included. Some studies show that clean cooking would be economically attractive even if the indirect benefits, such as health benefits, environmental benefits, the value of time savings (biomass collection and cooking), are not taken into account. Using a Monte Carlo simulation technique, Jeuland and Pattanayak (2012) show that switching from traditional inefficient fuelwood stoves to improved wood and charcoal stoves, and kerosene and LPG stoves would be economically attractive. They find that the benefits are higher with kerosene and LPG stoves compared to improved wood or charcoal stoves. Based on a cost-effective analysis of households switching from coal to advanced biomass gasifier stoves in rural China, Smith and Haigler (2008) find that the health and climate benefits of improved stoves are about $300, of which 69% is associated with health benefits, and the BCR is 6.

Note that not all improved biomass cookstoves over traditional cookstoves have both climate and health-related benefits. For example, Sota et al. (2018) find that replacing traditional cookstoves with locally made improved rocket stove (*Noflaye Jegg*) in rural Senegal contributed to a significant reduction of fine particulate matter and CO concentrations, but increased indoor BC concentrations.

One of the key welfare benefits of access to clean cooking fuel is the reduced hardship for women and children from fetching fuelwood. For example, in Himachal Pradesh, India, Parikh (2011) finds that on average, women walk 30 km each month taking 2.7 hours per trip for fuelwood collection; the equivalent of 3 to 7 days per month not available for other uses. In rural Rajasthan, India, households make 16 trips per month for fuelwood collection and spend three hours per trip, thus spending about 50 hours a month just to collect fuelwood for cooking (Laxmi et al. 2003). In some mountain areas of Nepal, girls are kept out from schools because they need to go into natural forests to collect fuelwood. Because collecting and transporting fuelwood involves walking long distances in difficult terrain and carrying backloads (in hilly areas) or head-loads (in plains areas), it results in health degradation and injuries.

4. ADOPTION OF CLEAN COOKING

Despite the economic, environmental and health benefits and the persistent efforts by the governments and international organizations for promoting clean cooking programs over the last four decades, the rate of adoption of clean cooking is still very slow. Demand for traditional biomass by households continues to rise in absolute values in developing countries despite its proportion in total final energy consumption has decreased over time. For example, residential biomass consumption increased from 154 Mtoe in 1990 to 285 Mtoe in 2016 in Africa, while it increased from 205 Mtoe in 1990 to 259 Mtoe in 2016 in Developing Asia excluding China (IEA 2018). A wide range of factors and barriers could be attributed to the slow adoption of clean cooking. A study by Otte (2013) classifies these factors into six groups: (1) economic factors (price of clean cooking appliances and fuels, household income), (2) social factors (level of education, gender of heads of households), (3) cultural factors (cooking practice/habit, food characteristics, such as taste, texture) (4) environmental or resource factors (availability of cooking fuel alternatives, supply infrastructure), (5) political or policy factors (existence of clean cooking policies and programs, fiscal incentives to clean fuels) and (6) technical factors (technical performance of cooking appliances, user-friendliness). Reviewing 57 studies including 14 qualitative, 16 quantitative, and 27 case studies, Rehfuess et al. (2014) identify 31 factors that influence access to clean cooking. They grouped these factors in seven categories: (i) fuel and technology characteristics (e.g., matching of stove design with kitchen design, efficiency, operational characteristics), (ii) Household and setting characteristics (e.g., socioeconomic status, household income, level of education, gender of household head), (iii) knowledge and perception, (iv) financial, tax and subsidy, (v) market development, (vi) regulation, legislation, and standards and (vii) programmatic and policy mechanisms. However, this classification does not seem to be correct as it possesses redundancy and it is unnecessarily complicated. The key factors responsible for lack of access to clean cooking can be broadly regrouped into two categories: (i) demand-side factors and (ii) supply-side factors. Demand-side factors include low adoption of clean cooking technologies because households could not afford or they do not want to afford it because they are either unaware of its benefits (information barrier) or they are ignorant to those benefits. On the other hand, supply-side factors mainly refer to lack of supply infrastructure and higher costs of clean cooking. Demand-side factors can be further divided into two categories: (i) affordability factor and (ii) behavioral factor. The former represents the fact that households cannot afford clean cookstoves and fuels even if they are interested to switchover to clean cooking, the latter factor implies that households discount the value of clean cooking for a variety of reasons, such as unaware of the implications of indoor air pollution and cultural inertia (e.g., food taste).

In the literature, a large number of empirical studies are also available that examine factors affecting the adoption of clean cooking. Some studies evaluate and synthesize the findings of the empirical studies. For example, Lewis and Pattanayak (2012) conduct a systematic review of 146 empirical analyses from 32 papers focused on 22 developing countries to identify factors that influence the adoption of clean cooking technologies. They find evidence of a systematic and theoretically consistent relationship between adoption of clean cooking technologies and fuels and socioeconomic variables, such as household income, education, and social marginalization and location (urban vs. rural). We summarize key findings and the methodology used from selected empirical articles of key factors and their role in the slow adoption of clean cooking in developing countries (Table 3).

4.1 Availability of clean cooking fuels and technology—the supply-side factors

One natural factor for lower adoption of clean cooking is the lack of supply of clean cooking technologies or fuels. For a large segment of households around the world, lack of supply infrastructure is the main factor constraining the access to clean cooking. This barrier is more relevant, particularly to modern fuels for clean cooking (e.g., LPG and electricity) than improved biomass cookstoves. A simple example is that even if a household can afford electricity for cooking, it cannot use electric stoves if electricity supply does not exist. However, the availability of supply infrastructure for clean cooking fuels is a necessary but not a sufficient condition for switching to clean cooking. Using household survey data from eight developing countries (i.e., Brazil, Ghana, Guatemala, India, Nepal, Nicaragua, South Africa and Vietnam) to examine household fuel choice for cooking, Heltberg (2004) finds that access to electricity enhances the probability of households to switchover to clean fuel (here electricity) for cooking. With a sample survey of 500 households in Harare, Zimbabwe, Chambwera and

TABLE 3
Selected studies investigating clean cooking adoption barriers.

Study	Methodology and Data	Key Findings
Jeuland et al. (2014) Uttar Pradesh and Uttarakhanda states of India	Discrete choice and conjoint method; data collected through a sample survey of 2,120 households in 66 Census-delineated villages	Analysis of data on household energy choices, especially stove ownership, shows that ICS (nearly all LPG stoves) are owned by only about 20% of Wealthy, educated and small family size households are more likely to adopt clean cooking, however, on average, survey respondents were not willing to pay more to clean cookstoves than what they for a traditional cookstoves. Additional intervention (e.g., social marketing or price reductions) are needed to stimulate demand for clean cookstoves.
Jan (2012) Northwest Pakistan	Regression analysis; primary data collected from 100 randomly selected households in two villages of rural northwest Pakistan.	Education and household income are the most significant factors to influence household willingness to adopt improved cookstoves.
Burwen and Levine (2012) Ghana	Randomized-controlled trial	Clean cookstove technologies (design) and programs that are locally adaptive are important factors in promoting clean cooking.
Takama et al. (2012) Addis Ababa, Ethiopia	A choice experiment with 200 households in Addis Ababa using a stated preference survey combined with a discrete choice model to evaluate the strength of the product-specific factors in influencing fuel/stove choice.	Low-wealth households are more sensitive to stove price and usage costs than middle and high-wealth households; The high and middle-wealth groups are more willing to pay than the low-wealth group for reductions in indoor air pollution and increase in safety.
Gebreegziabher et al. (2012)	Discrete choice models; cross-sectional dataset from a stratified sample of 350 urban households from the year 2003.	Education and income are the most important factors to enhance a household's use of electric cookstoves; Providing credit access for purchasing clean cookstoves is a recommendation policy intervention.
Pandey and Chaubal (2011)	Logistic regression and multinomial logistic regression models; household data from the 61st round of National Sample Survey conducted from July 2004 to June 2005 that covered 79,298 rural households in 7,999 villages across the country.	Household income, household education and female education play a very important role in household's choice of clean cooking fuel; Land size, family size and belonging to socially deprived classes negatively impacted the adoption of clean cooking.
Walekhwa et al. (2009) Uganda	Employing a logistic regression model on data collected from a survey of 220 households in six districts in Central and Eastern Uganda	Factors positively influencing biogas adoption are younger/male head of household, increased farm income or number of cattle owned, larger household size and increasing cost of traditional fuels;
Rehfuess et al. (2009) Benin, Kenya, and Ethiopia	Bayesian hierarchical and spatial modeling applied to demographic and health survey data	Wealth and the educational attainment of women and men is the main determinant of clean cooking in all three countries; Fuel choice is more driven by supply-driven factors as compared to demand-driven factors

(continued)

TABLE 3
Selected studies investigating clean cooking adoption barriers *(continued)*.

Study	Methodology and Data	Key Findings
Farsi et al. (2007) India	Ordered a discrete choice model for fuel choices for cooking in urban Indian households; 1999–2000 cross-section data from India's household expenditure survey Round 55 conducted by India's National Sample Survey Organization;	Household income is the main factors that retard households from using cleaner fuels; Adoption decision for LPG is highly sensitive to its price; Socio-demographic factors, such as education and gender of the household head, are also influencing household's fuel choice.
Ouedraogo (2006) Ouagadougou, Burkina Faso	Multinomial logit model applied on household data collected through a sample survey of 1008 households in urban areas	Household income is the main determinant of cooking fuel choice in urban households; fuelwood utilization rate decreases with increasing household income.
Karimu et al. (2017) Ghana	Parametric and semi-parametric probit model for estimating the preference of clean fuel (LPG) in Ghana Ghana living standards surveys (GLSS 2005/06 and GLASS 2012/13)	Education, income, household characteristics, access to urban infrastructure and urban location are consistently important factors choosing LPG for cooking; Subsidy on LPG in addition to the tax on biomass fuels (fuelwood and charcoal) is likely to promote switching to LPG provided that initial cost constraints (cost of LPG cylinder and stove) are reduced significantly; In urban areas where fuelwood is purchased, cooking technologies that are cost-effective and that are designed to meet the taste and cultural preferences of people is likely to be successful for switchover to clean fuels.
Chen et al. (2016) Rural Sichuan, China	Alternative-specific conditional logit model using the revealed and stated preferences method to examine household energy choice behavior; Household survey based on a sample size of 556 households conducted from August 2013 to February 2014	Energy-specific determinants of choosing clean cooking fuels include low price, higher safety, and lower indoor pollution; Household-specific determinants of choosing clean cooking fuel (electricity) include income, higher level of education of decision maker and location of households (adoption of clean cooking is higher in plain areas than in hill and mountain areas)
Baquie and Urpelainen (2017) Rural India	An analytical approach using a linear probability model to explain subjective satisfaction with clean cooking based on 8568 rural households in six states in India	Households value easy access to market to purchase fuelwood; other factors include reduction in smoke, speed of cooking and quality of meals much more than difficulty, cost and safety factors.
Wolf et al. (2017) Rural Peru	Logistic multi-variable regression method to examine measures of clean cookstove adoption based on 1200 households in 2014 in rural Andean regions in Peru;	Education, age and civil status of female, household wealth and size, technical knowledge (O&M) and subsidy schemes are key to enhance adoption of ICS.
Vulturius and Wanjiru (2017) Kenya	Social network analysis to examine the promotion adoption of ICS using behavioral change techniques based on 40 individuals in Kenya;	Suppliers' knowledge about ICS in terms of how they market and offer support to their users, e.g., directly targeting specific user group (women's self-help groups and teachers), after-sale support and using loan payment visits by users to be offered technical support, show increase adoption of ICS.

(continued)

TABLE 3

Selected studies investigating clean cooking adoption barriers *(continued)*.

Study	Methodology and Data	Key Findings
MacCarty and Bryden (2017) Mali	An integrated systems model for village energy services to analyze the potential costs and impacts of energy technology strategies in Mali with a population of 770;	Despite environmental, health and social benefits of adoption of ICS, motivation to adopt these biomass cookstoves by households is limited mainly because fuel savings do not offset the purchase of cost these cookstoves. Also, the quality of life of households who adopted ICS have slightly reduced the quality of life because they are less convenient and require a change in cooking practice.
Das et al. (2018) Rural India	A hypothetical cooking energy system analysis based on the availability of cooking fuels and cookstoves of 178 households in rural Assam, India;	Households using improved cookstoves prefer fuelwood over charcoal as a choice of cooking fuels because time spent on collecting fuelwood and producing charcoal is much higher than simply collecting and using fuelwood directly for cooking.
Hou et al. (2018) China	Multinomial logit regression method to examine household's cooking fuel choice in 25 provinces and nearly 16000 households in China;	Transitioning from solid fuels to clean fuels is influenced more by household assets than by household income and that households choose gas over electricity for cooking when switching from biomass or coal. Also, households that have easy access to water resource and a short time to nearest market use gas and electricity for cooking.
Paudel et al. (2018) Afghanistan	Multinomial logit model to analyze household cooking fuel use pattern based on 21,835 Afghan households.	Low income and education levels together with supply constraints contribute to households' reluctance to switch from biomass to cleaner cooking fuels such as LPG, in rural Afghanistan.
Calzada and Sanz (2018) Peru	A matching technique to evaluate the Peruvian government's 2012 FISE program in 11 provinces with 221,390 inhabitants.	The FISE program favored the adoption of the LPG cookstoves and its use reduced negative health impacts, but the selection of beneficiaries and the creation of a national network of suppliers for the delivery of LPG cylinders are the two main challenges faced during the implementation of the program.

Folmer (2007) find that as electricity access increases, the shares of firewood and kerosene in the total household energy expenditure decreases thereby implying switching of households to electricity for cooking when electricity supply is available. The same could hold true for LPG, especially in urban areas. In the absence of a reliable supply chain, households do not switch to LPG for cooking even if they can afford for it. Lack of understanding of non-technical factors for promoting clean cooking technologies, such as design of cookstoves considering local cultural practices, availability of livestock for biogas, proximity to road, market and clean cookstoves distribution and repair centers, and interaction and communication between users and promoters, hinder dissemination and implementation of clean cooking solutions in poor communities (Kumar and Igdalsky 2019).

Tasciotti (2017) finds that electrified household members in Malawi are more likely to experience malaria than non-electrified household members mainly because malaria vectors are attracted by electric lights and outdoor lighting available after the sunset changes people's habits and increases their exposure to those vectors. However, introducing innovative improved cookstoves may also change the cooking behavior of the households. For example, Wilson et al. (2018) find that rural households in India who do not have access to electricity are willing to prepare fuel and adopt trial-based USB-enabled improved cookstoves despite it is much smaller in size and more cumbersome in operation that traditional cookstoves.

Adoption of clean cooking may also be very slow even if there are no supply-side constraints. In the following Sections (4.2 - 4.5) we present the main demand-side factors that influence the adoption of clean cooking.

4.2 Lack of information and awareness behind the slow adoption of clean cooking

Lack of information is a key factor behind the slow adoption of clean cooking. Most empirical studies included in Lewis and Pattanayak (2012) review show strong relationships between the adoption of clean cooking and education level of household adults. This evidence implies that the knowledge barrier (i.e., the capacity for understanding the benefits of clean cooking and consciousness about their health) is a primary factor influencing the adoption of clean cooking. Some other studies not included in Lewis and Pattanayak's review also find a strong relationship between the level of education and adoption of clean cooking (see e.g., Paudel et al. 2018; Jan 2012; Pandey and Chaubal 2011).

Paudel et al. (2018) find that low income and education levels together with supply constraints contribute to households' reluctance to switch from biomass to cleaner cooking fuels such as LPG, in rural Afghanistan. Using regression analysis on primary data collected from 100 randomly selected households in two villages of rural northwest Pakistan, Jan (2012) finds that level of education is one of the most significant factors that influence household's willingness to adopt improved biomass stoves. Similarly, employing a logit model on a large database consisting of more than 400 thousand observations from India, Pandey and Chaubal (2011) find that household decision to switch to clean cooking is mainly driven by the level of household education, especially female (who are normally responsible for cooking). These findings again imply that information or awareness of the negative consequences of traditional biomass cooking is crucial to switch over to clean cooking.

4.3 Income level or affordability

Even if households are aware of the adverse impacts of cooking using inefficient cookstoves or using dirty fuels, they may not be able to switch to clean cooking due to lack of income or affordability. This is evident from a large number of empirical studies (see e.g., Paudel et al. 2018; Hou et al. 2018; Jan 2012; Beyene and Koch 2013; Gebreegziabher et al. 2012). These studies find that income level of households has a strong relationship with adoption of clean cooking. Higher upfront investment cost needed for clean cooking is one of many reasons for the slow adoption of clean cooking. Even if clean cooking fuels (e.g., LPG) are heavily subsidized, their large-scale adoption is still lacking in many low-income countries. This is because subsidized clean cooking fuels are still expensive as compared to freely available fuelwood. A LPG subsidy would not help substituting traditional biomass normally used by low-income households, because these households cannot afford LPG even if it is highly subsidized. Instead, high-income households reap the LPG subsidy benefits intended for low-income households (Granado et al. 2012). Further, in some cases, prices of modern fuels and LPG cylinder are too high such that households are either unable to pay for it or they are not willing to pay for it. Because of this, they continue to use solid biomass or kerosene for cooking even though their knowledge of negative health impacts associated with smoke from burning biomass. They tend to heavily discount the air quality benefit of clean cooking. Using data from a household survey in Guatemala, Edwards and Langpap (2005) show that high start-up costs together with lack of access to credit discourage households to switch to clean fuels (here LPG) for cooking. To upscale the use of LPG for clean cooking solutions in Northern Ghana, Dalaba et al. (2018) highlighted accelerating LPG cylinder recirculation by addressing safety concerns, providing access to credit through public-private partnership and targeted LPG subsidies for poor households. Based on the cookstove program in Mexico's Central Highlands, Bailis et al. (2009) suggest that instead of direct subsidies on clean cooking solutions, provisions that spread investment costs over time would be more effective to promote clean cooking. Using a choice experiment with 200 households in Addis Ababa, the capital city of Ethiopia, using a stated preference survey combined with a discrete choice model to evaluate the strength of the product-specific factors in influencing fuel/stove choice, Takama et al. (2012) find that low-income households are more sensitive to stove price than middle and high-income households. Further, the low-income households are also more sensitive to usage cost than the middle and high-income households.

Household income is another important factor that influences the adoption of clean cooking. For example, Jan (2012) finds that household income is one of the most significant factors influencing household adoption of improved biomass stoves in rural Pakistan. Using the duration data to examine the timing of the adoption of improved biomass cookstoves in urban Ethiopia, Beyene and Koch (2013) find that high-income households adopt cleaner cookstoves more quickly than the low-income households. Likewise, in another empirical study in Ethiopia based on 350 urban households, Gebreegziabher et al. (2012) find that household income is the main determinant of switching to electricity for cooking. In India, employing a logit model on a large database generated through household surveys, Pandey and Chaubal (2011) find that households who possess 'Below Poverty Line or BPL' ration card are not positively linked to the use of clean fuel for cooking. This is because only poor households, who are below the poverty line, are eligible to receive the ration card. In another study for urban India, which examines household fuel choices employing an ordered discrete choice model on 1999–2000 cross-section data, Farsi et al. (2007) find that household income is the main factors that retard households from using cleaner fuels. Employing a multinomial logit model on household data collected through a sample survey of 1008 households in urban areas of Ouagadougou, the capital city of Burkina Faso, Ouedraogo (2006) also finds that household income is the main determinant of cooking fuel choice in urban households. Analyzing household energy consumption data from national sample surveys conducted during the period 1983–2000 across 16 major states in India, Viswanathan and Kavi Kumar (2005) conclude that affordability is the dominant factor in choosing clean fuels for cooking. Findings from these and many other studies (Table 3) clearly indicate that affordability is one of the main factors to influence the adoption of clean cooking. Further, in China, Hou et al. (2018) find that transitioning from solid fuels to clean fuels is influenced more by household assets than by household income and that households choose gas over electricity for cooking when switching from biomass or coal. They also find that areas where households have easy access to water resource and a short time to nearest market use gas and electricity for cooking.

4.4 Behavioral factors to slow clean cooking adoption

While the low-income level or lack of affordability is cited as one of the main barriers to the adoption of clean cooking by many studies, higher income or affordability does not necessarily enhance the adoption of clean cooking. The energy ladder hypothesis, which suggests that households increasingly switch to clean fuels for cooking as their income rises (see e.g., Hosier and Dowd 1987; Heltberg 2005; Lee 2013), is not universally true in the case of clean cooking adoption. For example, Sehjpal et al. (2014) find that household income is less significant compared to other social and cultural factors in choosing cleaner fuels in rural India. Cooke, Köhlin and Hyde (2008) also find that income elasticities of fuelwood demand are not significant in several developing countries. Studies by Hiemstra-van der Horst and Hovorka (2008) in Botswana and Brouwer and Falcão (2004) in Mozambique show that fuelwood was chosen by households almost equally by all income households. Mekonnen and Köhlin (2008) find higher household income in urban areas of Ethiopia causes diversification of fuel choice rather than substituting one particular fuel with others. Other factors, such as behavioral factors and social/cultural factors are more responsible for the slow adoption of clean cooking. For example, Masera, Saatkamp, and Kammen (2000) find people in rural Mexico continued to use fuelwood even when they could afford to use cleaner and modern fuels because cooking "tortillas" on LPG was more time consuming and negatively affects its taste. Further, Heltberg (2005) finds traditional cooking practices and food tastes made people prefer fuelwood, even in situations where fuelwood was as expensive as cleaner alternatives. In another case, Taylor et al. (2011) find migrant households in Guatemala often use the traditional way of preparing foods despite LPG was available and affordable. In rural India, Narasimha and Reddy (2007) find households with Islamic religion are less likely to use LPG than fuelwood. In rural Northeast India, Das et al. (2018) find that households using ICS prefer fuelwood over relatively cleaner charcoal as a choice of cooking fuels because time spent for collecting fuelwood and producing charcoal is much higher than simply collecting and using fuelwood directly for cooking.

Several other studies (e.g., Jan 2012; Lewis and Pattanayak 2012; Schlag and Zuzarte 2008) further highlight the behavioral factors to slow the adoption of clean cooking. Some studies (e.g., Burwen and Levine 2012; Jeuland et al. 2014) provide empirical evidence of how behavioral factors pose an obstacle to the adoption of clean cooking. Using a randomized controlled trial of improved cookstoves in Ghana, Burwen and Levine (2012) find that half of the households participated in their experiment were found not to utilizing the improved cookstoves after a few months of their free distribution. This finding implies that households tend to discount the health benefits of improved indoor air quality. A similar finding is also reported in Jeuland et al. (2014) while investigating the barriers to adoption of clean cookstoves applying a discrete choice and conjoint method on data collected through a relatively large sample (2,120 households living in 66 Census-delineated villages) in two Northern Indian states (Uttar Pradesh and Uttarakhand). They find that households' willingness to pay for clean cookstoves is not more than the costs of traditional inefficient stoves they have been using so far. This means they are not willing to pay an additional price for the benefits coming from clean cooking. This implies that households do not take indoor air pollution seriously because they are either do not know the health risks of indoor air pollution or they are ignorant to such risk (heavily discount the risks).

4.5 Other factors

Some other factors that influence the adoption of clean cooking are also highlighted in the literature. These factors include social factors (e.g., gender and age of household heads or decision makers), cultural or religious factors, and technical factors (Vulturius and Wanjiru 2017; Karimu et al. 2016; Baquie and Urpelainen 2017). Khandelwal et al. (2017) argue that rural Indian women are deeply attached to their traditional cooking practices and less motivated to shift to improved cookstoves. Employing a logistic regression model on data collected from a survey of 220 households in Central and Eastern Uganda, Walekhwa et al. (2009) find that households with younger generation heads are more likely to adopt biogas than those with older heads. The study also finds that the number of cattle owned and household size are also important factors to influence the adoption of biogas in Uganda. Miller and Mobarak (2013) find that women-headed households are more likely to adopt clean cooking than men headed. Technological factors also pose obstacles to the adoption of clean cooking. Rehfuess et al. (2014) report that specific stove design criteria that do not allow users to modify it limits the adoption of improved cookstoves. Lack of trust (or social acceptance) is another factor for households not adopting improved cookstoves (Fouquet and Pearson 2012). Saxena and Bhattacharya (2018) find that Indian households belonging to the three major disadvantaged groups based on cast, tribe, and religion are systematically discriminated against the access to cleaner fuels such as LPG and electricity compared to other groups, because these marginalized social groups mainly reside either in the isolated areas or in remote areas due to social isolation. Further, they find that LPG subsidy likely benefited mainly the non-poor sections of the society due to lack supply infrastructure of LPG to the socially marginalized households. Households are often not motivated towards clean cooking initiatives because a system that values convenience, cleanliness, and saved time is lacking (Wikramasinghe 2012).

5. POLICY MESSAGES AND CONCLUDING REMARKS

Households' reliance on traditional biomass for cooking in developing country is a significant and growing problem. Despite the global efforts of promoting clean cooking over the last four decades in response to severe health and considerable environmental impacts of burning biomass fuels for household cooking, the adoption of clean cooking is still sluggish. Existing literature on clean cooking adoption empirically attributed the slow rate of adoption in developing countries to various supply- and demand- side factors. Key supply-side factors include lack of infrastructure associated with supply of modern fuels and clean cookstoves, and lack of technological innovation of clean cookstoves that are locally adaptive. Other important factors hindering a broader adoption of clean cooking is households' limited ability to pay for clean cooking solutions that include higher costs of clean fuels and cookstoves. On the demand-side, key factors include households' limited access to information and awareness, limited household income or affordability, and behavioral factors. Cultural inertia also played a big role in the adoption of clean and improved cooking solutions. Further, households are often not motivated towards clean cooking solutions because a system that values convenience, cleanliness and cooking time saved is lacking.

A policy to increase the awareness of clean cooking (e.g., technology options and the multiple benefits of clean cooking facilities, particularly related to health, gender, social and time savings) and create an environment to appreciate the social values (e.g., cleanness, comfort, and leisure) of clean cooking would certainly help increase the adoption of clean cooking. Equally important is the policy that encourages strong and effective awareness campaigns of clean cooking that involves women and children. As long as households have zero opportunity costs (i.e., they have free time in the absence of any productive activities), they will go to natural forests or public lands to collect fuelwood and dungs, no matter how cheaper the clean cooking alternatives would be. Thus, policies that enhance local employment and increase the income of poor households is critical for the success of clean cooking programs. Also, making the segmentation of households in terms of their income and differentiation of policy instruments across the different income group is important for scaling up of clean cooking solutions.

Any policies to make clean cooking affordable for low-income households is also important. However, there could be a long debate on how to make clean cooking affordable. Various types of subsidies are being used as policy instruments. However, existing subsidy schemes benefitted rich households who could get clean cooking access anyway than the poor households who could not get access in the absence of such subsidies. Therefore, reformulation of existing subsidy programs with carefully designed to channel the benefits to targeted low-income households is needed. Further, instead of direct subsidies on clean cooking solutions, provisions that spread investment costs over time would be more effective to promote clean cooking. Carbon financing, where clean cooking projects receive carbon price, carbon mitigation grants and soft loans, could be channelized to pay for targeted subsidies.

Behavioral factors, such as lack of motivation and ignorance towards the benefits of clean cooking might have played a role in the failure of many clean cooking initiatives in the past. Therefore, prioritizing social marketing to address these behavioral barriers is important as well. Creating ownership through the engagement of local stakeholders could also be helpful. Involving local entrepreneurs for manufacturing and marketing of clean cookstoves is critical for sustainable adoption. Donor-driven improved cookstove programs would not sustain long after donor supports expires if the local capacity for repair and maintenance is not built and proper incentives are not created for local markets. Enhancing the engagement of women in clean cooking adoption decision is crucial for the success of an adoption program or policy. Increased private sector participation together with creating a space for market-driven implementation of clean cooking would be a way for sustainable adoption of clean cooking in developing countries.

Also important is further research on in-depth analysis of key barriers, particularly behavioral barriers, and come up with innovative solutions to reduce these barriers. Rigorous empirical studies are needed to evaluate existing clean cooking programs to draw useful lessons for new programs.

ACKNOWLEDGMENTS

The authors are grateful to Venkata R. Putty, Alain Ouedraogo, Mike Toman and Randall Bluffstone for their constructive comments. The authors acknowledge financial support from the World Bank's Research Department and Energy Sector Management Assistance Program (ESMAP). The authors are also thankful to three anonymous reviewers for their helpful comments and suggestions. The authors are responsible for any remaining errors.

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