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Household Cooking Fuel Choice and Adoption of Improved Cookstoves in Developing Countries

A Review

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Abstract

Improving access to affordable and reliable energy services for cooking is essential for developing countries in reducing adverse human health and environmental impacts hitherto caused by burning of traditional biomass. This paper reviews empirical studies that analyze choices of fuel and adoption of improved stoves for cooking in countries where biomass is still the predominant cooking fuel. The review highlights the wide range of factors that influence households' cooking fuel choices and adoption of improved stoves, including socioeconomic (access and availability, collection costs and fuel prices, household income, education and awareness), behavioral (food tastes, lifestyle), and cultural and external factors (indoor air pollution, government policies). The paper also summarizes the evidence on the significant adverse health impacts from exposure to indoor smoke, especially among women and young children. In low-income households, perceived health benefits of adopting improved stoves and financial benefits from fuel savings tend to be outweighed by the costs of improved stoves, even after accounting for the opportunity cost of time spent collecting biomass fuel. The paper identifies knowledge and evidence gaps on the success of policies and programs designed to scale up the adoption of improved cookstoves.

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1. Introduction

It is well documented that improving access to affordable and reliable modern forms of energy services is essential, especially for developing countries (DC) in reducing poverty and promoting economic development (Leach, 1992; UNDP, 2005; Modi et al., 2005; WHO, 2006a; UNDP and WHO, 2009; UNIDO, 2009; AGECC, 2010; World Bank, 2011a; Barnes et al., 2011; Ekouevi and Tuntivate, 2012). As of 2011, about 1.26 billion people do not have access to electricity and 2.64 billion people rely on traditional biomass (fuelwood, charcoal, dung and agricultural residues) for cooking mainly in rural areas in developing countries (IEA, 2013a). Under a baseline scenario, IEA (2013a) projects that the number of people without clean cooking facilities could remain almost unchanged in 2030. Household cooking consumes more energy than any other end-use services in low-income developing countries (IEA, 2006; Daioglou et al., 2012).

The widespread cooking practice with solid fuels, such as traditional biomass and coal, can have severe implications for human health, forest/land degradation and climate change. Existing studies, such as Bruce et al. (2000) and WHO (2006a), find that air pollutants, emitted from solid fuels often burned indoors on inefficient cookstoves, is one of biggest challenges to human health in developing countries. Lim et al. (2012), for example, estimated that in 2010, about 3.5 million premature deaths were caused by household air pollution (HAP) resulting primarily from cooking with solid fuels. They also estimated that there were 500,000 deaths from outdoor air pollution caused by household solid fuels use for cooking in developing Asia and Sub-Saharan Africa (SSA) in the same year.

Recognizing the importance of access to modern affordable energy services in developing countries, the United Nations launched the Sustainable Energy for All (SE4ALL) initiative. with three objectives: i) ensuring universal access to modern energy services, ii) doubling the global rate of improvement in energy efficiency and iii) doubling the share of renewable energy in the global energy mix by 2030 (UN, 2013). This initiative has also attracted world-wide attention on issues related to clean cooking fuels.[2] A separate global alliance, known as Global Alliance for Clean Cookstoves (GACC), has been also 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 the Africa Clean Cooking Energy Solutions to promote enterprise-based, large-scale dissemination and adoption of clean cooking solutions and the East Asia and Pacific region's Clean Stove Initiative (CSI) to scale up access to advanced cooking stoves for rural poor households through country-specific technical assistance and a regional knowledge-sharing and cooperation forum. Besides these global initiatives, there are several initiatives to promote clean cooking. For example, in India, the government has launched National Biomass Cookstoves Program in 2009 to provide 160 million ICS to households currently using solid fuels (Venkataraman et al., 2010).

A key knowledge gap that has emerged in developing these regional efforts to scale up adoption of ICS involves the economics of household cooking energy uses. There have been few recent assessments of the economic rationale for carrying out supply and demand-side interventions such as adopting cleaner cooking technologies and fuels, and implementing community-based fuelwood management practices. More needs to be done to assess costs and benefits of household energy interventions using the latest information. In particular, new developments such as commercial availability of advanced cookstoves and eligibility of ICS projects for carbon mitigation funds – should be considered in the economic analysis as potential beneficial interventions. The objective of this report is to review the literature on the household choice for cooking fuels and economic assessments of household cooking energy transitions. In particular, this report highlights the factors influencing household cooking fuel choice and the challenges faced by empirical studies in estimating opportunity costs of biomass fuel collection.[3]

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[2] IEA (2012) estimated that nearly US$1 trillion in cumulative investment is needed to achieve SE4ALL by 2030. More specifically, a study by Global Energy Assessment (GEA) estimated that US$30 to 41 billion in annual investment is needed to achieve universal access to modern energy services by 2030 (GEA, 2012).

[3] We use ScienceDirect, Google Scholar, 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 articles including both published and unpublished articles.

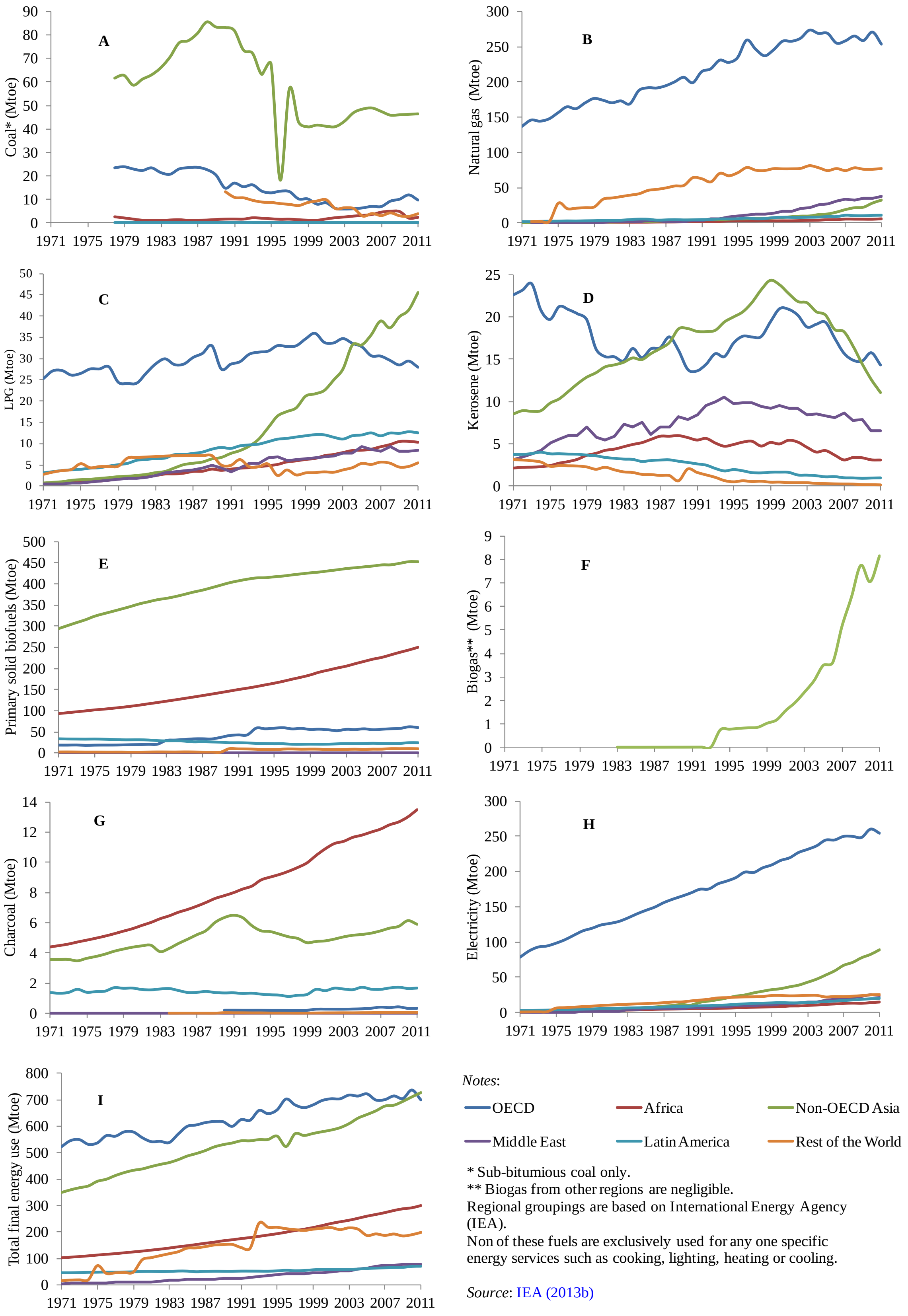
2. Household Energy Consumption Pattern in Developing Countries

While cooking energy is the main focus of this paper, a brief discussion on household energy use patterns in developing countries is provided below. In 2011, household final energy use in developing countries (i.e., non-OECD countries) is 1374 Mtoe, about two-thirds of global residential sector final energy demand (Fig. 1I). Although declining modestly in the last two decades, the share of solid fuels (traditional biomass and coal) in total residential sector final energy demand in developing countries remains significant, in the range of 75% in 1990 to 60% in 2011. These solid fuels are often the primary source of household energy for cooking in rural areas of developing countries. In contrast, the share of "modern liquid and gaseous fuels" (kerosene, LPG, biogas and natural gas) in total residential sector final energy demand in developing countries is increasing steadily from 15% in 1990 to 20% in 2011. Households in developing countries generally use solid fuels, biogas and LPG for cooking and these fuels represent a large share of total energy requirements. Kerosene is mainly used for cooking and lighting, and natural gas is mainly used for cooking and heating but they represent a small share of total household energy consumption. Electricity is mainly used for lighting and electrical and electronic appliances rather than for cooking. In contrast to developing countries, the share of modern fuels in total residential sector final energy demand is increasing steadily from 68% in 1990 to 79% in 2011 in OECD countries.

Region-wide there are wide variations in the level of consumption and the types of fuels used by households (Fig. 1). Although households in developing countries use a combination of fuels for various energy services, for simplicity, we limit our focus on main cooking fuels (solid fuels, biogas, LPG and kerosene) during 1990-2011. Between 1990 and 2011, residential global biomass consumption increased by 173 Mtoe, an average of 1.2% per year (Fig. 1E). However, quantity of biomass use and growth rates by region varied greatly. For example, non-OECD Asia and Africa dominated global residential biomass use. Over the past two decades, these two regions together consumed roughly 88% of global biomass. However, the quantity and growth rates are not equal across non-OECD Asia and Africa. In non-OECD Asia, biomass grew only by an average 0.8% per year between 1990 and 2011, and its share in total biomass declined from 65% in 1990 to 59% 2011. In contrast, biomass consumption in Africa grew strongly by an average 2.6% per year over the same period, and its share in total biomass increased from 23% in 1990 to 31% in 2011.

Non-OECD Asia, mainly China and India, dominates the global residential coal consumption, accounting for 74% of global residential coal consumption in 2011 (Fig. 1A). However, coal consumption in this region is declining in absolute terms, from 83 Mtoe in 1990 to 46 Mtoe in 2011, at an average of 2.7% per year. Between, 1990 and 2011, residential coal consumption decreased in all regions except Africa. Although small in absolute value, residential coal consumption in Africa grew by an average of 2% per year between 1990 and 2011. Charcoal, produced from forest resources, is commonly used for cooking mainly in Africa, non-OECD Asia and Latin America (Fig. 1G). In 2011, almost all global residential charcoal consumption is concentrated in these three regions, with Africa leading the total (63%), followed by non-OECD Asia (28%) and Latin America (8%). Between 1990 and 2011, charcoal consumption in non-OECD Asia declined slightly by an average of 0.4% per year, while it grew by 2.6% per year in Africa and by1% in Latin America.

Almost all global residential biogas consumption is concentrated in non-OECD Asia. Over the past decade (1994-2011), biogas consumption in this region grew by an unprecedented 35% per year (Fig. 1F). Biogas use in non-OECD Asia, produced from the anaerobic digestion of manure, is mainly concentrated in rural areas. Household consumption of kerosene varied widely across the regions. In 2011, OECD consumed the most (40%) of global residential kerosene consumption, followed by non-OECD Asia (31%), Middle East (18%), Africa (9%) and Latin America (3%). However, between 1990 and 2011, the growth of residential kerosene consumption in all developing regions declined, from high (4.8% per year) in Latin America to low (0.9% per year) in Middle East (Fig. 1D). Over the past two decades, households in developing regions show sharp increase in LPG consumption (Fig. 1C). For example, between 1990 and 2011, residential LPG consumption grew by an average 9.6% per year in non-OECD Asia, 5% in Africa, 3.4% in Middle East and 1.5% in Latin America. Within the developing regions, non-OECD Asia consumed the most of LPG (45 Mtoe), followed by Latin America (13 Mtoe), Africa (10 Mtoe) and Middle East (8 Mtoe) in 2011. Combined, these four regions consumed 70% of global residential LPG consumption in 2011.



Notes:

* Sub-bitumious coal only.
** Biogas from other regions are negligible.
Regional groupings are based on International Energy Agency (IEA).
Non of these fuels are exclusively used for any one specific energy services such as cooking, lighting, heating or cooling.

Source: IEA (2013b)

Fig.1. Region-wide residential sector final energy consumption by energy types.

In developing regions, biomass based energy (bioenergy) for cooking is expected to remain significant in next 30 years. For example, bioenergy demand in building sector is projected to account for 7% of global final energy demand in 2035 (IEA, 2012). Although it includes residential and services sub-sectors, most of building sector bioenergy demand in developing countries comes from household cooking and heating. At the regional level, the demand for building sector bioenergy is projected to reach 371 Mtoe in non-OECD Asia, followed by Africa (321 Mtoe) and the rest (45 Mtoe) in 2035 (Fig. 2). If combined, bioenergy for buildings in Non-OECD Asia and Africa is projected to account for 82% of global demand in 2035. However, between now and 2035, non-OECD Asia's share in global buildings bioenergy demand is projected to decrease from 56% to 44%, while it is projected to increase from 31% to 38% in Africa.

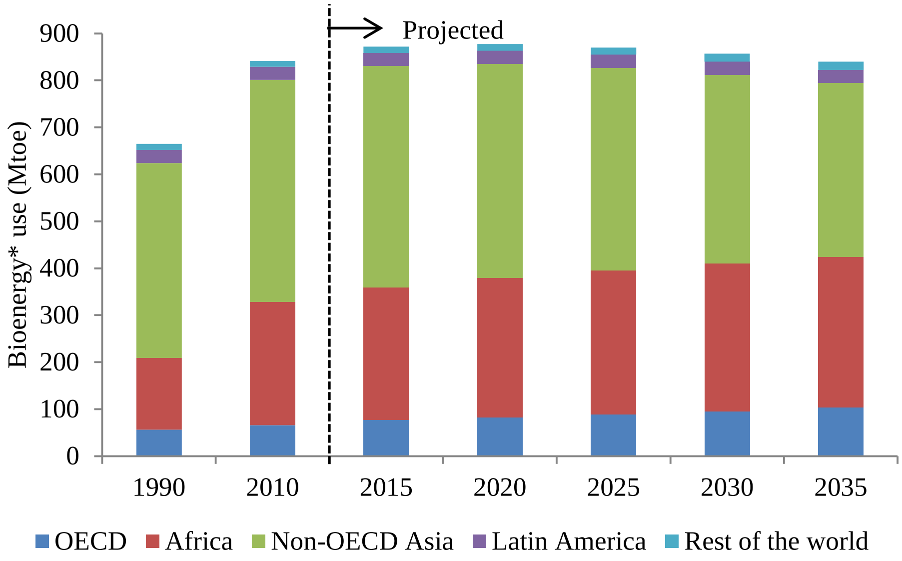


Fig. 2. Historical and projected bioenergy demand for buildings under new policy scenario.
Note: * Bioenergy refers to biomass based energy including biogas. *Source*: IEA (2012).

Based on the bottom-up model projections in selected developing countries, Daioglou et al. (2012) find that cooking consumes most of household energy demand dominated by traditional fuels, especially in rural areas. They also find that demand for cooking fuels is projected to fall mainly due to fuel switching towards modern fuels and increase in autonomous cooking efficiency improvement. Although the proportion of households relying mainly on solid fuels for cooking has decreased world-wide, from 62% in 1980 to 41% in 2010, the absolute number of persons using solid fuels is increasing, particularly in Africa and Asia (Bonjour et al., 2013). In Central America, Wang et al. (2013) finds that biomass, mainly fuelwood, accounted for 34% of total final energy consumption in 2008. About 20 million people use fuelwood for cooking in the region, of which roughly 86% of people live in three countries (Guatemala, Honduras and Nicaragua) and the remaining 14% of them live in El Salvador, Costa Rica and Panama.

3. Household Cooking Fuels and Technologies

The development of policies, strategies and programs to achieve universal access to clean cooking fuels requires understanding of how both stove and the cooking fuels are used in practice. This section discusses types of fuels[4] and stoves/technologies used for cooking in developing countries.

3.1. Cooking energy types

Different terminologies and definitions are used in categorizing household cooking energy types (Fig. 3). For example, depending on typical level of energy development, type of fuels used for cooking in households can be 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, gelfuel, plant oils and dimethyl ether). Based on the way these cooking energy types are produced or extracted, they are sometimes termed as "primary" and "secondary". Primary energy is directly obtained from natural resources such as fuelwood, agricultural waste, animal dung, coal, solar and natural gas. Secondary energy types, which come from transformation of primary energy types, include petroleum products (kerosene, LPG, dimethyl ether) from crude oil, ethanol from sugar cane, charcoal and wood pellets from fuelwood, biogas produced from animal dung and agricultural

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[4] In the literature, "fuels" and "energy" are often used interchangeably. In this paper, fuel refers to any material which is used to produce heat or power by burning, and energy refers to heat and power.

waste, electricity[5] produced from combustion of fossil-fuels and from renewable energy sources such as solar, hydro and wind.

Likewise, cooking energy types can be categorized as "renewables" (biomass, solar and biogas) and "non-renewables" (coal, kerosene, LPG, natural gas). Furthermore, there are also wide variations in the level of consumption and the patterns cooking energy use by households based on their levels of urbanization and income. These categorizations, in general, include "rural" and "urban" households, and "low" income and "high" income households. Besides, use of fuels for household cooking is also concentrated in certain countries, e.g., coal in China, charcoal in SSA, dung in India, kerosene in Djibouti and electricity in South Africa (Smith et al., 2012).

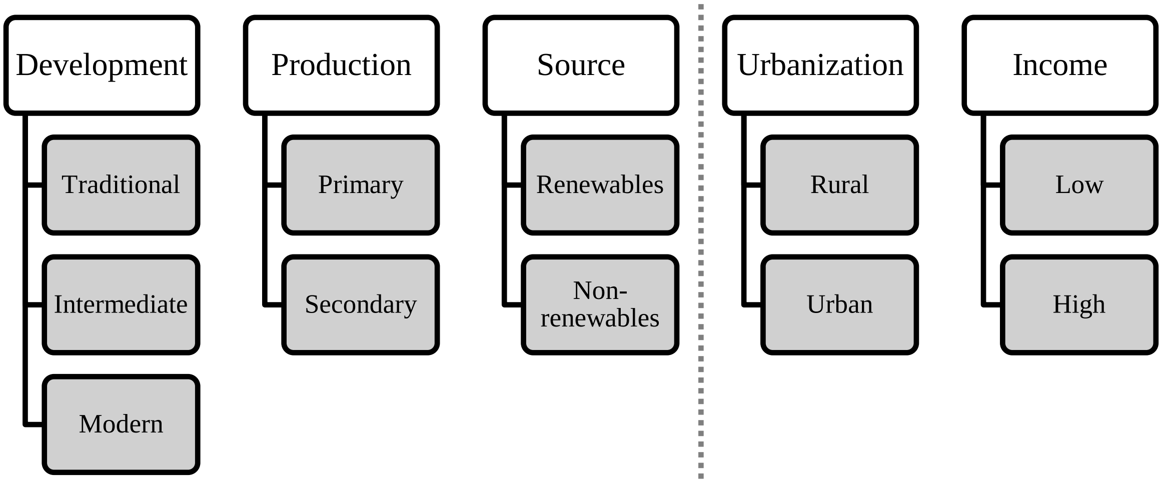

Fig.3. Schematic illustration of categorizing household cooking energy types.
Sources: UN (1982, 2011), IEA (2005, 2012).

3.2. Cookstoves and conversion efficiencies

Several types of cookstoves are used by households and these stoves 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 of developing countries. In contrast, more modern cooking stoves, such as LPG, natural gas and electric, are common in urban areas of both developing and

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[5] Electricity may be produced in a primary (solar, geothermal, hydro, wind) or secondary (fossil-fuel power plants) form. However, electricity used for cooking is considered as a secondary energy types.

developed countries. In recent years, biogas cookstoves are also gaining popularity in rural areas of developing countries.

The conversion efficiency[6] of household cookstoves also varies widely by energy sources. The wide range of cookstove conversion efficiencies reported in the literature is compiled from variety of site-specific circumstances in developing countries (Table 1). Cooking fuels also differ in their energy densities. Modern fuels have high energy content per kg of fuel used, while traditional biomass fuels have low energy content. The use of biomass energy in inefficient or open stoves is considered a traditional way of cooking. On the other hand, natural gas, LPG, kerosene, electricity, and biomass energy used in efficient or less polluting stoves are considered modern ways of cooking. Other examples are also used in the literature, but the general idea is that traditional ways of using energy for cooking typically is inefficient and polluting, whereas the opposite is true of modern energy use for cooking. It is complex but important to understand how and why these different types of energy sources are used for cooking in varieties of cookstoves in different parts of developing countries.

Table 1: Typical conversion efficiency range of household cookstoves[7] by energy sources

Fuel source	Energy content (MJ/kg)	Conversion efficiency range (%)
Traditional (open fire or mud) stoves		
Fuelwood	16	13-18
Crop residue (straw, leaves, grass, maize, wheat)	13.5	9-12
Dung	14.5	12
Charcoal	30	10-22
Improved biomass cookstoves		
Fuelwood	16	23-40
Coconut shell (gasifier)	15.7	33-36
Crop residue (maize, wheat)	13.5	15-19
Charcoal	30	20-35
Biogas	22.8 (MJ/m^3)	50-65
Advance cookstoves		

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[6] The analysis of cooking efficiency is challenging due to variations in individual appliances and the situations where different foods are prepared or different cooking styles are used (see e.g., Hager and Morawicki, 2013). In the literature, cookstoves efficiency, in general, is reported either as cooking, conversion, thermal, appliance or end-use efficiency. They all mean the same.

[7] Different stove terminologies are used in defining cookstoves (World Bank, 2011b; Barnes et al., 2012). It is also difficult to distinguish between "improved" and "advanced" stoves. There are also several classifications of biomass cookstoves (see Kshirsagar and Kalamkar, 2014). In this paper, we refer to biomass based open-fire or mud stoves as "traditional" stoves. "Improved biomass" cookstoves refer to cookstoves that have better fuel efficiency and/or lower emissions than the traditional stoves. "Advanced" cookstoves refer to cookstoves that are freely available in the market and they are based on non-biomass energy sources.

Coal (including coal gas)[a]	17.5	7-47
Kerosene	43	35-55
Liquefied Petroleum Gas (LPG)	45.5	42-70
Natural gas	38 (MJ/m^3)	54-60
Electricity		75

Note: [a] Values reported for coal cookstoves vary from as low as 7% for unprocessed coal (coal power) metal vented stoves to 47% for honeycomb coal briquette improved stoves used in China (Zhang et al. 2000).

Sources: Zhang et al. (2000), Smith et al. (2000), O'Sullivan and Barnes (2007), MacCarty et al. (2008), Berrueta et al. (2008), Jetter and Kariher (2009), WHO (2010), Grieshop et al. (2011), World Bank (2011b), Barnes et al. (2005, 2012), Maes and Verbist (2012), Bansal et al. (2013), Raman et al. (2013) and GACC (2014).

4. Factors Affecting Household Cooking Fuels and Cookstoves Choice

Understanding of key determinants of household cooking energy consumption and cookstoves is important for the design and implementation of effective policies to enhance access to clean cooking. Note that availability and affordability of cooking energy sources and cooking technologies vary widely within and across the countries. In addition, households often use a combination of fuels (fuel stacking) and they do not necessarily switch to more efficient or higher quality fuels for cooking. In the literature, a wide range of factors are mentioned that influence each household's choice of energy types and cookstoves. These include socio-economic, availability of fuels, cultural, environmental, cookstove characteristics and government policies (Leach, 1992; Masera et al., 2000). Although these factors are presented in isolation in the following sections, they are closely interrelated to each other and they are not prioritized on the basis of their relevance.

4.1 Socio-economic factors

A number of studies have shown several socio-economic factors, such as income, education, size and age of the households, time spent at home, and ownership, age and type of dwellings, influence household cooking fuel and cookstove choices. For instance, as per capita income increases, households tend to switch to cleaner and more efficient fuels for cooking; a large number of studies have provided empirical evidence of this.[8] For example, studies by

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[8] See Hosier and Dowd (1987), Leach (1988), Barnes and Qian (1992), Alam et al. (1998), Barnes and Floor (1999), UNDP (2000), Victor et al. (2002), Johansson and Goldemberg (2004), Leiwen and O'Neill (2003), Pachauri (2004), Gupta and Köhlin (2006), Ouedraogo (2006), Wuyuan et al. (2008), Pachauri and Jiang (2008), Barnes et al. (2011) and Lee L. Y-T. (2013).

Bansal et al. (2013) in rural India, Chaudhuri and Pfaff (2003) in Pakistan, Heltberg (2005) in Guatemala and Nlom and Karimov (2014) in northern Cameroon find that household income is one of the main factors in choosing fuels for cooking. While analyzing urban households cooking fuel choice in Ouagadougou, Burkina Faso, Ouedraogo (2006) finds that the fuelwood utilization rate decreases with increasing household income. Similar findings are reported by Arthur et al. (2010) which shows that household wealth determines the transition from biomass to electricity in Mozambique.

However, a few empirical studies present evidence against energy ladder hypothesis --households move towards modern energy sources as their income rises--. For example, Sehjpal et al. (2014) in rural India finds that household income is less significant compared to other social and cultural factors in choosing cleaner fuels. Based on the studies in several developing countries, Arnold et al. (2006) and Cooke et al. (2008) find that income elasticities of fuelwood demand are not significant. Furthermore, studies by Hiemstra-van der Horst and Hovorka (2008) in Botswana, Brouwer and Falcão (2004) in Mozambique and Bhagavan and Giriappa (1995) in India find that fuelwood is chosen by households of all incomes, while studies by Davis (1998) in South Africa, Campbell et al. (2003) in Zimbabwe and Brouwer and Falcão (2004) in Mozambique also find the use of electricity and LPG for cooking in low income households. Mekonnen and Köhlin (2008) argues that the higher income, particularly in urban areas, causes diversification of fuel choice rather than substituting one particular fuel with others through a case study. However, no such evidence is available for rural areas.

Apart from income, several other socio-economic factors also influence household's cooking fuel choices. One important factor is education or awareness. Pundo and Fraser (2006) find that education level of wife significantly influences the probability of switching from fuelwood to charcoal or kerosene in rural Kenya. Similar findings are reported by Heltberg (2004) in eight developing countries and by Suliman (2010) in Sudan. In particular, Pandey and Chaubal (2011) finds that number of educated females between 10 and 50 years of age and average household's level of education had a positive and significant impact on probability of using clean cooking fuels in rural India. In the urban context, studies by Mekonnen and Kohlin (2008) and Gebreegziabher et al. (2012) in Ethiopia and by Farsi et al. (2007) in India came up with similar findings that households with more educated members are more likely to choose cleaner fuels. Based on 2008 Nigerian Demographic and Health Survey data, Oyekale (2012) finds that access to electricity and modern cooking energy sources significantly increased among urban dwellers and educated household heads but declined with resident in rural northern Nigeria. Another factor is fuel pricing. Jain (2010) finds that Indian households continue to depend on traditional and inefficient fuels mainly due to high price of clean and modern fuels. Schlag and Zuzarte (2008) find similar results that high fuel prices made household more likely to use traditional fuels in SSA. In fact, income and price factors complement to each other (Farsi et al. 2007). In addition, based on the data from household surveys in ten developing countries of SSA, South Asia (SA) and Latin America and the Caribbean (LAC) regions, Kojima et al. (2011) finds that increase in level of education and price of alternative cooking fuels, in general, increases use of LPG. However, a study by Zhang and Kotani (2012) in rural Beijing finds that fuel prices did not exhibit substitution effects between cooking fuels (coal and LPG), but an increase in these prices had strong demand effect, i.e., reduces the use of these cooking fuels.

Moreover, most socio-economic factors influence household decision-making together. For instance, Narasimha Rao and Reddy (2007) finds that household expenditure, household size and education all act together in determining fuel choices in rural and urban areas in India. Andadari et al. (2014) finds that the same in Indonesia. Using regression analysis, Peng et al. (2010) finds incomes, fuel prices, demographic characteristics and topography had a significant effects on household's fuel choices in rural China. The study also finds that biomass is often substituted by coal in rural households which contributed to negative impacts on health. However, Jingchao and Koji (2012) finds that changes in prices of coal and LPG, mainly used for cooking, had no substitution effects with other energy sources in rural Beijing areas mainly due to high variations in income level, consumption customs and the availability of energy resources.

Factors such as household size could also influence cooking fuel decision. For example, Nnaji et al. (2012) find that fuelwood is by far the fuel of choice for a majority of households with relatively larger size in rural Nigeria. Liu et al. (2003) and Carr et al. (2005) also find that household size linked to increase in fuelwood consumption because of increased energy demand

and increased laborers available for fuelwood collection. Likewise, Walekhwa et al. (2009) finds that the probability of a household adopting biogas technology in Central and Eastern Uganda increases with decreasing age of head of household, increasing number of cattle owned, increasing household size, male head of household and increasing cost of traditional fuels. In contrast, the study also finds that likelihood of adoption of biogas decreases with increasing remoteness of household location and increasing household land area. There are also several empirical studies that show use of multiple fuels for cooking in support of fuel stacking model.[9]

In general, household cooking fuel choice and adoption of cookstoves are mutually inclusive. In the literature, several studies also focus on identifying wide range of socio-economic factors that influence the adoption of ICS. For instance, Jan (2012) in rural northwest Pakistan and Pine et al. (2011) in Rural Mexico find that education and household income are the most significant factors that determine a household willingness to adopt improved biomass stoves. Based on duration analysis for urban Ethiopia, Beyene and Koch (2013) finds that product price, and household income and wealth are the important determinants of adoption of clean fuel saving technologies. Assessing relative strength of factors in terms of marginal willingness to pay, Takama et al. (2012) finds product-specific factors such as usage cost, stove price, safety and smokiness, significantly affected stove and fuel choices in Addis Ababa, Ethiopia. Using household level panel data, Alem et al. (2013) finds that the price of electricity and fuelwood, and access to credit are the major determinants of adoption of electric cookstoves and cooking fuel transition in urban Ethiopia. Based on the ICS program in rural Mexico, El Tayeb Muneer and Mohamed (2003) find that the adoption rate of ICS is very slow mainly due to lack of knowledge and the educational level of female heads of households in Khartoum, Sudan. Likewise, Lambe and Atteridge (2012) find that despite households' willingness to purchase ICS, the cost of ICS remains the most important factor in decision making in rural Haryana State, India. Using duration analysis in urban Ethiopia, Beyene et al. (2013) find that price of the cookstoves, household income and wealth influence the adoption of biomass ICS ("Mirte" and "Lakech" cookstoves). The study also finds that the availability of substitute electric ("Mitad") and metal cookstoves tends to hinder the adoption of ICS. A review study by

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[9] See Leach (1992), Davis (1998), Karekezi and Majoro (2002), Campbell et al. (2003), Heltberg (2004), Brouwer and Falcao (2004), Martins (2005) and Arnold et al. (2006).

Puzzolo et al. (2013) finds that high household income favors adoption of ICS, while low household income acts as a barrier.

4.2. Behavioral and cultural factors

Behavioral and cultural factors such as household preferences, food tastes, cooking practices and cultural beliefs also influence cooking fuel choice.[10] For example, Masera et al. (2000) finds that people in rural Mexico continue to use fuelwood even when they could afford to use cleaner and modern fuels because cooking "tortillas" on LPG is more time consuming and negatively affects its taste. Likewise, Indian households prefer to use wood cookstoves for baking traditional bread (IEA, 2006). Using 2000 Guatemalan LSMS survey data, Heltberg (2005) argues that traditional cooking practices and food tastes might make people prefer fuelwood, even in situations where fuelwood is as expensive as cleaner alternatives. In another case, Taylor et al. (2011) finds that migrant households in Guatamala often use traditional way of preparing foods despite LPG is available and affordable. Likewise, Narasimha Rao and Reddy (2007) finds that households in rural India with Islamic religion are less likely to use LPG than fuelwood. In Ougadougou, Burkina Faso, Ouedraogo (2006) finds that the frequency of cooking "Tô" − a staple traditional meal made of millet, sorghum or maize − increases the likelihood of using fuelwood. The study also finds that an increased frequency of rice cooking in households reduces the likelihood of using fuelwood.

Many social factors and community interactions also influence the adoption of ICS. For example, Barnes et al. (2012) in Karnataka, India and Person et al. (2012) in rural Kenya, find that the decision to purchase ICS by households was significantly influenced by the experiences of neighbors and relatives who had adopted the stove. Likewise, Miller and Mobarak (2013) and Pine et al. (2011) find that the opinion of leaders within a community also influences the adoption of ICS in rural Bangladesh. Troncoso et al. (2007) find that factors such as the aesthetic appeal and social status gain motivated households in rural Mexico to adopt and use ICS. However, Troncoso et al. (2007, 2011) and Person et al. (2012) also find that lack of suitability of preparing traditional dishes using larger pots and change in cooking habits were associated

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[10] See Masera et al. (2000), Heltberg (2005), Gupta and Köhlin (2006), IEA (2006) and Taylor et al. (2011).

with lower likelihood of ICS adoption. Sesan (2012) finds that the sole distribution of a more efficient technology such as ICS might not be enough to generate a sustainable impact in peri-urban community in western Kenya. The study suggests that it is also crucial to understand local people needs and customs, to incorporate their priorities and perspectives when considering the dissemination of ICS. In China, Indonesia and Sri Lanka, Ramani and Heijndermans (2003) find that time saved due to improvement in access to modern energy served different purposes for men and women. For example, men use this as an opportunity for relaxation and entertainment, while women use this for many purposes such as income generating activities, household chores, spending time with their children and relaxing. Bielecki and Wingenbach (2014) find that households in rural Guatemala values traditional cooking stoves as heat and light sources, and as a social gathering point for families.

4.3. Other external factors

Several other external factors such as availability of fuels, gender, physical environment and government policies also influence household's choice of cooking fuels. For instance, Link et al. (2012) find that increased household's access to organizations and services, e.g., employment, banking, schooling, health care and transportation, in the local community increases the use of alternative fuels in Nepal. Bandyopadhyay and Shyamsundar (2004) find strong linkages between fuelwood consumption and community forest participation in India and household participation has a significant positive impact on fuelwood consumption. Examining fuelwood use in five rural villages in the Bushbuckridge region of South Africa, Madubansi and Shackleton (2007) find that improvement in access to electricity had little impact on fuelwood consumption. Wang et al. (2012) find that off-farm employment and agricultural specialization are the primary driving force of household fuelwood substitution in rural Southeast China. The study finds that fuelwood substitution also led to unexpected progress in hilly ecosystem restoration, particularly in mitigation of soil erosion and forest degradation mainly due to increasing opportunity costs of fuelwood collection, increases in household income, and decreases in household energy consumption for cooking, feeding and heating. In Pakistan, Bacon et al. (2010) find that greater proportion of rural households use LPG than their urban counterparts at all income levels because of the availability of natural gas in urban areas. They also find that high income households in developing countries did not abandon biomass use for many reasons including cost, lack of supply reliability and availability of modern fuels, and cooking practices and cultural preferences. There are also the cases where households switch back to traditional biomass even after adopting modern energy sources due to changes in several factors including price of fuels, reliability and availability of fuel supply, lifestyles and tastes. Using data from the Ghana LSMS survey, Akpalu et al. (2011) find strong evidence that the most preferred fuel is LPG, followed by charcoal, with kerosene the least preferred. Moreover, the study finds spatial differentiation in the type of fuel use with LPG primarily in the coastal zone, fuelwood in the savannah zone and kerosene in the savannah and forest zones. As part of the CSI study, ASTAE (2013a) finds significant progress in incentivizing Indonesian households to switch from kerosene to LPG for cooking needs through the government's inter-fuel substitution program.

Gender could be another factor. For example, Narasimha Rao and Reddy (2007) show that households headed by women generally opt for modern fuels than those headed by men. Women generally play a major role in household cooking decision-making activities. Based on the household survey of access and transitions to cleaner cooking fuels in Sri Lanka, Wickramasinghe (2011) finds that women are more likely to switch to cleaner fuels if they are employed in activities outside of the home. Miller and Mobarak (2013) find that women in rural Bangladesh, who bear disproportionate cooking costs, have stronger preference for ICS but they lack the authority to make the purchase.

In Nepal, Amacher et al. (1993, 1996) find that economic or organizational changes away from subsistence agriculture lead to adoption of ICS and its use reduced the household fuelwood consumption. Based on the survey of 2% households that use ICS in Nepal, Nepal et al. (2011) find that these households are more likely to use same amount or even more fuelwood than the households that use traditional mud or open-fire stoves. Although further investigation is suggested, the study finds that the rebound effect (lower shadow price), keeping their stove running for longer times to warm the house and cooking more frequently might be the main reason for more fuelwood consumption with ICS using households. A review study by Rehfuess et al. (2014) finds that many ICS programs had specific design problems that led to stove modifications by users limiting stove effectiveness and promoting to use traditional stoves. The study also reports that cookstove portability is also important where households switch between outdoor and indoor cooking in different seasons. In addition to perceived health benefit, time savings and other factors (gender, education and prior experience with clean stoves), a study in rural India by Bhojvaid et al. (2014) finds that social factor such as perceived actions of neighbors is also important in promoting new ICS. In the absence of formal marketing, Ramirez et al. (2014) find that men in Western Honduras play leading role in diffusion of ICS over long distances, while women principally communicate over short distances. Urmee and Gyamfi (2014) find that participation of local users and artisans in establishing a self-sustaining industry is important for the success of ICS program. Although there is heterogeneity in preference, Jeuland et al. (2013) find that households in Uttarakhand, India, on average, have a strong preference for traditional stoves and have greater willingness to pay for the smoke emissions reduction feature of ICS than for reduced fuel requirements and increased convenience, e.g., number of cooking surfaces, However, Hanna et al. (2012) find that there was no evidence of improvements in health and change in fuel consumption due to adoption of ICS in rural Orissa, India. The study cites failure to use stoves regularly and appropriately, and lack of necessary investments in maintaining ICS by households as the main reasons.

Despite benefits of improving health and time savings, preserving forests and ecosystems, and mitigating global climate change, adoption of ICS and use of clean and modern cooking fuels by households have been remarkably slow (Bailis et al., 2009; Barnes et al., 2012). There are number of major barriers associated with adoption of ICS and fuel choice in developing countries. Ekouevi and Tuntivate (2012), Simon et al. (2012) and Adler (2010) summarize details on barriers for achieving development benefits in ICS projects in developing countries. Some of these barriers include costs of LPG, lack of communication between manufactures and consumers, markets and lack of supplementary financial provisions such as micro-finance programs or grants for households and entrepreneurs, inadequate local support and rigid stove design capabilities. Despite economic, health, social and environmental benefits of ICS, Kshisager and Kalamkar (2014) compiled several barriers to dissemination and adoption of ICS from available literature and they are categorized as institutional, economic and financial, policy, social and behavioral, technical, and information and interaction barriers. Also, trust, social acceptance and the process of domestication of new technologies considering users' priorities and problems are important in the adoption of technologies (Fouquet and Pearson, 2012). Barriers specific to wide spread adoption of ICS include absence of internationally-recognized ICS standards and lack of testing capabilities, lack of information on health benefit of ICS and fuel interventions, and high initial cost of ICS (GACC, 2011). Apart from direct investments in energy access, Barnes et al. (2010) emphasize indirect investments including adequate generation and transmission for rural electrification, availability of LPG, in developing and implementing programs that can effectively address the barriers to assisting household to move toward better fuels and appliances. Based on the findings of CSI study in Indonesia, ASTAE (2013a) suggests strategies, such as centralized leadership, cross-sector cooperation and creation of sustainable market, to scale up the use of clean biomass stoves. The study finds the commercial market for ICS is quite limited in the country.

5. Household Cooking Energy, Health and Environment

Incomplete combustion of household cooking fuels, mainly solid fuels in developing countries, emits substantial quantities of harmful air pollutants and contaminants. These include toxic air compounds, such as carbon monoxide (CO), polyaromatic hydrocarbons (PAHs), benzene and formaldehyde, and toxic contaminants such as ash, sulfur and mercury (Smith et al., 2012). There is mounting evidence that exposure to these toxic air pollutants and contaminants have adverse impacts on human health. Furthermore, CO_2 emissions and black carbon emitted from household cooking fuels also threaten human health through change in global climate.

5.1. Cooking and human health

The problems related to solid fuels as an energy source for cooking has been an issue of concern for more than three decades. Although the amount and type of fuels used and the time of exposure to emission of toxic products vary, in general, they have adverse impacts on human health including child pneumonia, chronic obstructive pulmonary disease (COPD) and lung cancer (WHO, 2002; Smith et al., 2004; Dherani et al., 2008). Mainly women and young children are at risk, particularly in SSA and SA regions (UNDP and WHO, 2009). Based on the WHO health statistics, pneumonia is responsible for 2 million deaths mostly children and COPD is responsible for 511,000 deaths every year caused by indoor smoke (WHO, 2006a). In the comparative risk assessment (Lim et al., 2012), HAP is the second most important risk factor among those examined for women worldwide. In India alone, approximately 1.04 million premature deaths and 31.4 million disability-adjusted life years (DALYs) are attributed to HAP resulting from solid cooking fuels (Balakrishnan et al., 2014). By 2030, IEA (2010) projects that premature deaths associated with burning biomass indoor will exceed those due to HIV/AIDS.

Three recent meta-analyses (Kurmi et al., 2010; Hu et al., 2010; Po et al., 2011) find that exposure to smoke from burning biomass fuels for cooking and/or heating is associated with increased risk of COPD. There are also evidence of impacts from exposure to HAP such as child cognitive function, low birth weight, cervical cancer, adverse pregnancy outcomes, asthma, and tuberculosis (Velema et al., 2002; Pokhrel et al., 2010; Pope et al., 2010; Hosgood III et al., 2011; Dix-Cooper et al., 2012; Sumpter and Chandramohan, 2013; Trevor et al., 2013; Wong et al, 2013). For example, Epstein et al. (2013) finds that compared to infants born in homes using LPG, those born in biomass and coal dependent households are more likely to be born low birth weight. The study also finds that mean birth weights of infants born in homes using solid fuels (biomass and coal) and kerosene are significantly lower than mean birth weights in households using LPG. Adetona et al. (2013) find that women in Trujillo, Peru who cooked exclusively with fuelwood or kerosene had higher exposure to PAH compare to women who cooked with LPG or coal briquette. A review study by Abdullahi (2013) finds that Chinese cooking lead to a much greater contribution of PAHs to particulate organic matter relative to western-style fast food cooking. Studies in India and Nepal reveal that non-smoking women exposed to biomass smoke have death rates from chronic respiratory disease comparable to those of heavy smokers who are males (Modi et al., 2005). Based on household survey, Lakshmi et al. (2013) find that biomass and kerosene fuels are associated with stillbirth among married women aged 15-49, representing about 12% of stillbirths in India. Parikh (2011) finds substantial physical burden and health impacts on women due to traditional cooking fuels in Indian households. Silwal and McKay (2013) find that cooking with solid fuels worsens lung capacity in Indonesia. However, Wickramasinghe (2011) finds that women in Sri Lanka were more concern about the collection, transportation and processing of biomass fuels than the direct impact of burning biomass fuels.

5.2. Cooking and black carbon

In recent years, black carbon (BC)[11] has received wide attention because of its impact on global climate change and human health. Several studies have also emerged indicating incomplete combustion of traditional biomass and fossil fuels for residential uses as the important source of BC. At the global and regional levels, BC is considered as short-lived but important climate forcers that has significant influence on the climate system for climate change (UNEP and WMO, 2011). However, the sign and magnitude of the net climate influence (warming or cooling) from BC emissions is not fully known at present and further research and quantitative assessment are needed to reduce these uncertainties (EPA, 2012). Based on the review of health effects of BC, WHO (2012) reports that sufficient evidence suggest association of BC concentrations with short term changes in health including cardiovascular mortality. At the local level, BC emissions vary considerably by region and sector due to variation in local practices and the types of fuels and technologies used in different regions and sectors. Based on scientific studies, Ramanathan and Carmichael (2008) and Gustafsson et al. (2009) find that, in general, developing countries in the tropics and Asia are generally recognized as dominant source regions. These studies also find that about 40% of BC originates from burning fossil fuels, 40% is from open biomass burning, and 20% is from the burning of biofuels. However, all of Asia, including China and India, accounts for 40% to 60% of global BC emissions (Bond et al., 2004; Zhang et al., 2009), while biomass combustion for cooking comprises about 26% of BC emissions globally (Bond, 2009). Besides, BC emissions are also transboundary in nature. Kopacz et al. (2011) explain how prevailing wind patterns draw BC emissions in considerable quantities from Africa and the Middle East to Tibetan Plateau especially during dry months when biomass burning activities are most prevalent. At the national level, Venkataraman et al. (2010) estimate that fossil fuel, open burning and residential biofuel combustion combined account for 25%, 33% and 42% of BC emissions in India, respectively. The study also estimates that switching to improved stoves in India could reduce the country's total greenhouse gas (GHG) emissions by 4%. Through project *Surya*, one of the few improved cookstove programs with BC

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[11] Black carbon (BC) is the most strongly light-absorbing component of particulate matter (PM), and is formed by the incomplete combustion of fossil fuels, biofuels, and biomass. The short atmospheric lifetime of BC (days to weeks) and the mechanisms by which it affects climate distinguish it from long-lived GHG like CO_2. See Venkataraman et al. (2005), UNEP and WMO (2011) and EPA (2012) for details on BC.

mitigation as its primary objective in India, the first real-time BC concentration measurements from cookstoves carried out revealing significant amount of BC emissions (Kar et al., 2012). In China, Cao et al. (2006) estimate that 1500 Gg (giga gram) of BC emissions in 2000 mainly due to the burning of coal and biofuels. Based on an assessment of benefit cost ratios of reducing BC emissions, Kandlikar et al. (2009) estimate that for every dollar spent switching to an improved stove, the benefit is between \$100 and \$880 of CO_2e and that improved stoves have a cost-effectiveness of about \$4 per ton CO_2e.

5.3. Cooking, deforestation and climate change

In the 1970s and 1980s, deforestation due to unsustainable extraction of biomass used for cooking is considered a major environmental concern particularly in developing countries. Over the past two decades, more extensive analysis has demonstrated that biomass, mainly fuelwood, used for cooking is not the major cause of deforestation worldwide, though there may be few cases in specific parts of the world (McGranahan, 1991; Arnold et al., 2003). For example, EAC (2006) finds that heavy dependence on biomass contributed to annual deforestation rate of 3-4% in Kenya, 2% in Tanzania and 2% in Uganda. Forest research in the Chalaco District in Peru, as well as in adjacent areas, indicates that fuelwood collection in preparation for the rainy season is strongly related to cutting down trees from cloud forest areas (Córdoba-Aguilar, 1992; Ektvedt, 2011). The study also indicates that in cloud forests with high gradients (where agriculture is hardly feasible) fuelwood extraction may constitute the main cause of forest degradation and deforestation (Córdoba-Aguilar, 1992; Sánchez and Grados, 2007). However, by examining relationships among urbanization, household energy source and forest cover in India, DeFries and Pandey (2010) find that fuelwood demand may lead to local degradation but not large-scale deforestation. The study also finds that at the state level, increases in percent forest cover are positively associated with percent of total households that are urban but not related to changes in fuelwood demand. There is also growing concern of charcoal use for cooking and its environmental consequences including deforestation in many SSA countries (Mwampamba, 2007; Chidumayo and Gumbo, 2013). Unlike traditional wood-based charcoal, cooking with "green charcoal" -- charcoal cooking briquettes made from charred agricultural waste-- is helping to reduce deforestation in Haiti (USAID, 2014).

In addition to negative health impact from smoke inhalation, burning cooking fuels, even when burned completely, emit CO_2, methane and ozone precursors which are the primary source of GHG emissions. The health impact of climate change have also been extensively reviewed (IPCC, 2007; McMichael, 2012, Smith et al., 2012). Recently, Abdullashi et al. (2013) review typical styles of cooking reported in the literature and finds that different cooking styles emit different profiles of compounds influenced by factors such as cooking processes and ingredients. However, Ohimain (2012) finds that use of ethanol for cooking by replacing solid fuels in Nigeria may not reduce GHG emissions citing common argument of food versus fuel conflict. Chaudhuri and Pfaff (2003) find that relationship between air quality and household income is U-shaped implying that increases in income initially leads to deterioration in air quality, but later lead to increased air quality. Based on SEI (2013) report, the global potential for GHG emission reductions from ICS projects around the world is estimated at 1 Gt of CO_2 per year.

6. Economics of Fuel and Technology Choices for Household Cooking

A large number of empirical studies identify different costs and benefits associated with household's choice of cooking fuels and the ICS (Table 2). For example, from the viewpoint of users (demand-side), benefits include health benefit through reduction in indoor air pollutant emissions, economic benefit through time saved collecting fuels, and fuel and fuel cost savings, and other benefits such as aesthetic gains and improve social standings. While costs include cookestove-, fuel-, stove maintenance- and other- costs. Likewise, from the viewpoint of suppliers (supply-side), including INGOs and the government, benefits include environmental benefit such as preservation of forest reserves, GHG and black carbon emissions reduction, economic benefit through market development and other benefits such as job creation and local skill development, while costs include market intervention costs such as subsidies, fuel cost and program cost. The following section presents findings of selected studies from the literature.[12]

Table 2: Benefits and costs adopting ICS and modern fuel choice

	Demand-side (user)	Supply-side
Benefits	Health	Environment

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[12] For a list of empirical studies associated with these issues by types of intervention, methodology and geographical coverage, see Appendix A.

	- Morbidity	- Local (preservation of forest reserves, better soil fertility)
	- Mortality	- Global (CO_2, CH_4 emissions)
		- Black carbon
	Economic	Economic
	- Time savings	- Profit
	- Fuel/fuel cost savings	- Market development
		- Carbon finance
	Others	Others
	- Cleanliness	- Skill development
	- Aesthetic gains	- Job creation
	- Social status gain	- Community engagement
	- Saving fertilizers (biogas)	
Costs	Cost of ICS	Market intervention
	Fuel cost	- Subsidies
	Maintenance cost	- Fuel cost
	Others	- Program costs
		Trainings
		Monitoring and quality control

Many of the studies identify health benefits, especially associated with smoke and safety, and other environmental benefits, from choosing modern fuels and adopting ICS. For example, using cost benefit analysis (CBA), WHO (2006b) finds that it is potentially beneficial for human health as well as for local and global environment to invest in modern fuels and ICS. Using similar CBA framework in Kenya, Sudan and Nepal, Malla et al. (2011) find that there is a direct health benefit from improved cooking system interventions due to reduced treatment costs and in time savings due to fewer days spent ill or having to care for sick child. Habermehl (2007, 2008) finds that environmental benefits including preservation of forest reserves and benefit to CO_2 and CH_4 reduction from ICS program in Uganda and Malawi were significant. However, Madubansi and Shackleton (2007) find that most of the households in the villages of Bushbuckridge region of South Africa, who receive part of the electricity free, still rely heavily on fuelwood for cooking. The study also finds that number of households purchasing fuelwood had increased most likely due to increased fuelwood scarcity in the local areas as reflected by increased fuelwood collection times and changes in fuelwood species preferences. Asaduzzaman et al. (2010) in Bangladesh and Garica-Frapolli et al. (2010) in rural Mexico find that switching to modern cooking fuels and ICS lead to minimizing health risks associated with HAP. However, it is not always the case, as Mobarak et al. (2012) finds that women did not consider indoor air pollution a high priority for adopting ICS.

Economic benefit is another factor associated with adoption of ICS and modern fuels choice. For instance, Garica-Frapolli et al. (2010) find that the ICS intervention in rural Mexico contributed substantial quantity of fuelwood savings, which constituted 53% of overall benefit. In Kenya, Sudan and Nepal, Malla et al. (2011) find that significant economic benefits from cooking system interventions, mainly due to fuel and cooking time savings. Similar findings are reported by Habermehl (2007) in Kampala, Unganda and Habermehl (2008) in Malawi. They find that the economic benefit of the ICS program from fuel savings and reduced cooking time were quite significant. In Maharashtra and Karnataka, India, Thurber et al. (2014) find that the highest rate of adoption of "Oorja" ICS, using pelletized biomass, came from LPG using households mainly because of reduced fuel costs. However, their study also finds that only 9% of households that purchased Oorja ICS were using the stove due to lack of fuel supply. In northern Vietnam, ADB (2009) estimated that households saved roughly US$68 each year using biogas by substituting biomass, coal or kerosene fuels. The report also finds that women in northern Vietnam also saved on avearge1.8 hours a day by using biogas. Christiaensen and Heltberg (2012) find that use of biogas among smallholder farmers in rural China lead to decline in fuelwood and crop residues use for cooking, less time spent by women in collecting fuelwood, improvement in respiratory health and saving in fertilizers. In western Kenya, Djedje (2009) finds that both private and commercial users of ICS were able to reduce the cost of fuels (by using less fuelwood) and time for cooking. The study finds that commercial users of ICS were able to save Euro 1.1 - Euro 6.6 per day. Based on Expenditure and Consumption Survey in Lao People’s Democratic Republic, national average time spent by women collecting fuelwood have fallen from 18 minutes in 2003 to about 12 minutes in 2008 mainly due to shift from fuelwood to charcoal for cooking in urban areas (ASTAE, 2013b). However, time spent by women collecting fuelwood in the villages is significantly higher, in the range of 1-3 hours per day. Although time savings and the opportunity cost of time are important, Jeuland and Pattanayak (2012), however, suggest that the private net benefits of ICS are more likely negative because the ways in which users change behaviors lead to no change or net increases in time spent cooking or preparing fuels resulting reduced health benefits.

In the case of costs associated ICS and modern fuels, WHO (2006b) finds that fuel-, stove- and program- costs are some of the main cooking system intervention costs. For instance, in rural Bangladesh, Asaduzzaman et al. (2010) find that cost of modern fuel and lack of supply contributed limited adoption of ICS. Based on life cycle analysis, Afrane and Ntiamoah (2012) find that fuelwood used in Ghanaian households for cooking has an annual environmental damage cost of US$36497 per household. Through a financial analysis in rural areas in India, Gupta and Ravindranath (1997) show that the ICS using fuelwood is the least cost option and biogas, which is the only quality fuel for rural areas, is the most expensive option. Although unrealistic, EAC (2006) reports that biomass collection time for rural households are as high as 4.5 hours in Kenya, 6 hours in Tanzania and Uganda. Based on Indian household energy survey in 1996, ESMAP (2004) finds that women spent on average 40 minutes for collecting fuels and almost three hours for cooking every day. The study finds that the opportunity costs of poor access to domestic energy have profound effects for all members of the family, particularly women who are the main managers of household biomass energy. On average, women worked for 12 hours of which only 2 hours are spent pursuing paid work indicating high opportunity costs of cooking activities. In rural Ethiopia, households, on average, spent between 11 and 12 hours per week collecting biomass (fuelwood and dung) fuels for cooking (Gwavuya et al., 2012). Female household members between the ages of 18 and 59 are mostly responsible for collecting these fuels. Using the opportunity cost of labor which is estimated through the marginal productivity of own labor in farm activities, the study estimates that on average households lose US$0.06 for each hour spent on collecting fuelwood. This is equivalent to daily rate of US$ 0.47, which is slightly lower than a government's minimum daily wage rate of about US$0.62. Based on the economic evaluation of the ICS program in Uganda during 2005 and 2006, Habermehl (2007) estimates the opportunity cost (shadow wage) of fuelwood collection Euro0.01 per kg. The study assumed that 50% of the time saved by the households used for productive activities with average household income of Euro 0.1 per hour. Heltberg (2005) finds that cooking labor scarcity (i.e., household size) translates into high opportunity costs of fuelwood collection in Guatemala; high share of females in the households is more likely to use multiple fuels, and higher level education increases the opportunity cost of collection time. In a recent study in the same Bushbuckridge region, Matsika et al. (2013) find that 68% of electrified households still use fuelwood as the primary source of energy even as the resource becomes more expensive to use in terms of opportunity costs in collecting and/or purchasing. In Himachal Pradesh, India, Parikh (2011) finds that there is a substantial physical and economic burden in collecting, processing and transporting biomass particularly for women. On average, women walk 30 km each month taking 2.7 hour per trip for fuelwood collection equivalent of 3 to 7 days per month of work days lost. In Central American countries, men on average spend 10 hours per week collecting fuel and women on average spend 4 hours per day cooking (Wang et al., 2013).

7. Financing Clean Cooking

Despite the benefits of fuel switching, use of clean cooking fuels are limited particularly in urban areas of developing countries due mainly to financial barriers. The costs, including both capital and fuel costs, of clean cooking fuels are significantly higher than that of traditional fuels.

Several financing mechanisms designed to mitigate climate change can be leveraged to fund biomass energy projects including the development and deployment of efficient cookstoves (World Bank, 2011b). For example, in 2006 GERES Cambodia is the first project developer in the world to put forward an improved cookstove project to trade on the carbon market. However, Freeman and Zerriffi (2012) find that carbon credits inherently account for climate benefits, but not for health. They suggested that clear objectives of cookstove interventions need to be defined prior to project implementation to insure the maximization of benefits in projects' priority areas. Based on the review of costs of potentially neglected technologies by CDM, including ICS, Kim et al. (2013) suggest that many of these technologies could be cost effective for developing countries if the carbon mitigation benefit is accounted.

Subsidies are the main financial mechanisms to promote use of modern cooking fuels, particularly, LPG, in developing countries. The same is true for biogas and ICS, but these are mainly used by low income households whereas LPG is the choice of cooking fuel for high and middle income urban/peri-urban households. Subsidies to LPG would obviously be regressive for several reasons: burden to public finance, incentive for inefficient and over consumption and misplaced to the income groups who could afford without it. For example, Arze del Granado et al. (2012) find that fuel subsidies for cooking are a costly approach to protecting the poor households in developing countries due to substantial benefit leakage to higher income households. Their results indicate that the top income quintile captures six times more in subsidies than the bottom. Analyzing household cooking fuel choice in Kolkata, India, Gupta and Köhlin (2006) find that subsidies are less effective to reduce polluting fuels, such as coal and fuelwood, due to weak cross-price elasticities. Empirical evidence suggests that high use of ICS cannot be assumed even when stoves are highly subsidized or given free of charge (Lewis and Pattanayak, 2011). Agurto Adrianzen (2013) finds that only 42% of beneficiary households in the rural villages of Peru are effectively using ICS despite providing subsidies. ADB (2010) suggests specifically targeted pro-poor pricing mechanisms instead of discounts and subsidies to ensure benefits to the poor and avoiding leakages to high income households.

There are, however some arguments in favor of subsidies for clean cooking fuels. While exploring the role of fuel subsidies and micro-financing in enhancing diffusion of modern energy sources in India, Ekholm et al. (2010) find that subsidies could increase labor productivity as the time used for gathering and using fuelwood could be used more profitably. Likewise, Gupta and Ravindranath (1997) find that subsidized kerosene is cheaper option than fuelwood with the traditional stove in rural India implying the potential role of subsidized kerosene to reduce deforestation. The study also finds that in urban areas, subsidized kerosene is the low cost fuel option while fuelwood in the traditional stove is among the most expensive one. Also, Ouedraogo (2006) finds that subsidizing LPG and LPG cookstoves could significantly decrease the utilization rate of fuelwood in urban Ouagadougou, Burkina Faso. Examining how credit access to gas stoves affects fuelwood use in Guatemala, Edwards and Langpap (2005) suggest that access to credit plays a statistically significant role in switching over to a gas stove although the effects are small.

8. Concluding Remarks

A large proportion of households in developing countries still rely heavily on biomass, mostly fuelwood, for cooking, especially in rural areas. Unless major policy interventions are introduced, biomass for cooking is expected to remain significant for years to come. In recent years, however, various stakeholders including governments, non-governmental organizations, and international development agencies are focusing on improving access to affordable and reliable modern forms of energy services for cooking. The SE4ALL and Global Alliance for Clean Cookstoves are a few examples in this direction.

Our review of existing literature finds that wide range of factors, including socio-economic, health, behavioral, cultural, local environment, technologies, policies and access to infrastructure, affect household's cooking fuel choice and adoption of ICS. Although households with higher income and education are more likely to use modern fuels, their decision for cooking fuel choice and adoption of ICS are quite complex and multi-dimensional; deep understanding of the interaction of these factors is necessary for designing government plans, policies and strategies to improve access to modern cooking fuels and adoption of ICS.

Several studies provide evidence of significant negative health impacts caused by indoor air pollution from biomass burning for cooking in developing countries, mainly among women and young children. Existing studies also find that biomass combustion for cooking is a key source of black carbon emissions that has an adverse influence on the climate system.

In low income household decision making, costs associated with cookstoves and the opportunity cost of time spent for collecting biomass, in general, outweighs perceived health benefits by adopting ICS and financial benefits from fuel savings. This suggests that a program or policy to deploy ICS or increasing access to modern fuels, especially in the rural areas, would be successful if it also helps income generation. The study also finds significant limitations in methodologies used for estimating the social costs and benefits of adoption of ICS and fuel choice and notes a need for further research to better understand the adoption of ICS over time.

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Appendix A: List of empirical studies associated with households cooking fuel choice and adoption of ICS

	Reference	Region[a]	Country	Intervention[b]	R/U[c]	Method[d]	Publication[e]
1.	Agurto Adrianzen (2013)	LAC	Peru	ICS	R	Regression analysis	Journal
2.	Akpalu et al (2011)	SSA	Ghana	FC(M)		Regression analysis	Journal
3.	Amacher etal. (1993)	SA	Nepal	FC(M)/ICS	R	Probit	Journal
4.	Amacher etal. (1996)	SA	Nepal	FC(FW)/ICS	R	Probit	Journal
5.	Anozie et al. (2007)	SSA	Nigeria	FC(M)/ICS	R/U		Journal
6.	Arthur et al. (2010)	SSA	Mozambique	FC(M)		Logit	Journal
7.	Asaduzzaman et al. (2010)	SA	Bangladesh	FC(M)	R	Regression analysis	WP
8.	Bansal et al. (2013)	SA	India	FC/ICS	R		Journal
9.	Beyene and Koch (2013)	SSA	Ethiopia	ICS	U	Survival analysis	Journal
10.	Chaudhuri and Pfaff (2003)	SA	Pakistan	FC(M)	R/U	Engel curves, probit	WP
11.	Christiaensen & Heltberg (2012)	EAP	China	FC(B)	R	Regression analysis	WP
13.	Djedje et al. (2009)	SSA	Kenya	ICS	R		Report
14.	EAC (2006)	SSA	Multiple	FC(M)/ICS	R/U		Report
15.	Edwards and Langpap (2005)	LAC	Guatemala	ICS		Maximum likelihood	Journal
16.	Ekholm et al. (2010)	SA	India	FC(M)	R/U	Linear cost optimization	Journal
17.	Epstein et al (2013)	SA	India	FC(M)		Unconditional logistic	Journal
18.	ESMAP (2004)	SA	India	FC(M)	R		Report
19.	Farsi et al. (2007)	SA	India	FC(M)	U	Ordered probit	Journal
20.	Garica-Frapolli et al. (2010)	LAC	Mexico	ICS	R	CBA	Journal
21.	Gebreegziabher et al. (2012)	SSA	Ethiopia	FC(M)/ICS	U	Probit	Journal
22.	Gundimeda and Köhlin (2008)	SA	India	FC(M)		Linear approximate	Journal
23.	Gupta and Köhlin (2006)	SA	India	FC(M)	U	Probit	Journal
24.	Gupta and Ravindranath (1997)	SA	India	ICS	R/U	CBA (financial)	Journal
25.	Gururng and Oh (2013)	SA	Nepal	FC(M)	R		Journal
26.	Gwavuya et al. (2012)	SSA	Ethiopia	FC(M)	R	CBA	Journal
27.	Habermehl (2007)	SSA	Uganda	ICS	R/U	CBA, CEA	Report
28.	Habermehl (2008)	SSA	Malawi	ICS	R/U	CBA	Report
29.	Hanna et al. (2012)	SA	India	ICS	R/U	Regression analysis	WP
30.	Heltberg (2004)	Multiple	Multiple	FC(M)	R/U	Logit	Journal

31.	Heltberg (2005)	LAC	Guatemala	FC(M)	R/U	Multinomial logit	Journal
32.	Hosier and Dowd (1987)	SSA	Zimbabwe	FC(M)		Logit	Journal
33.	Hutton et al. (2007)	Multiple	Multiple	ICS		CBA	Journal
34.	Jack (2006)	LAC	Peru	FC(M)		Probit	Dissertation
35.	Jeuland and Pattanayak (2012)			ICS		CBA	Journal
36.	Jones et al. (2011)	SSA	Benin and Togo	ICS	R	Probit	WP
37.	Kanagawa and Nakata (2007)	SA	India	ICS	R	Energy access model	Journal
38.	Kavi Kumar & Viswanathan (2007)	SA	India	FC(M)		Probit	Journal
39.	Kebede et al. (2002)	SSA	Ethiopia	FC(M)		Regression analysis	Journal
40.	Khandker et al. (2010)	SA	India	FC(M)	R/U	Tobit	WP
41.	Khandker et al. (2012)	SA	India	FC(M)	R	Probit	WP
42.	Kishore and Ramana (2002)	SA	India	ICS	R	CBA (partial)	Journal
43.	Lamarre-Vincent 2011	EAP	Indonesia	FC(M)		No fixed/fixed effects	Thesis
44.	Lewis and Pattanayak (2011)	Multiple	Multiple	FC(M)/ICS	R/U		Journal
45.	Liu et al. (2013)	EAP	China	FC(M)	R	OLS/logistic regression	Journal
46.	Madubansi & Shackleton (2007)	SSA	S. Africa	FC(FW)	R		Journal
47.	Matsika et al. (2013)	SSA	S. Africa	FC(FW)	R	ANOVA	Journal
48.	Mehta and Shahpar (2004)	Multiple	Multiple	FC(M)/ICS		CEA	Journal
49.	Mekonnem and Köhlin (2008)	SSA	Ethiopia	FC(M)	U	Multinominal logit	WP
50.	Muneer and Mohamed (2003)	SSA	Sudan	ICS		Linear regression	Journal
51.	Nepal et al. (2011)	SA	Nepal	ICS	R	Regression analysis	Journal
52.	Nnaji et al. (2012)	SSA	Nigeria	FC(M)	R	Multinominal logit	Journal
53.	Ouedraogo (2006)	SSA	Burkina Faso	FC(M)	U	Multinomial logit	Journal
54.	Oyekale (2012)	SSA	Nigeria	FC(M)	R/U	SUBP	Journal
55.	Pandey and Chaubal (2011)	SA	India	FC(M)	R	Logit model	Journal
56.	Parikh (2011)	SA	India	FC(M)	R		Journal
57.	Pattanayak and Pfaff (2009)			ICS			Journal
58.	Peng et al. (2010)	EAP	China	FC(M)	R	Logit	Journal
59.	Pine et al. (2011)	LAC	Mexico	ICS	R	Multinomial logistic	Journal
60.	Pundo and Fraser (2006)	SSA	Kenya	FC(M)	R	Multinomial logit	Journal
61.	Rao and Reddy (2007)	SA	India	FC(M)	R/U	Multinomial logit	Journal
62.	Reddy (1995)	SA	India	FC(M)	U	Multinomial logit	Journal
63.	Walekhwa et al. (2009)	SSA	Uganda	FC(B)		Binomial logistic	Journal
64.	Wang et al. (2012)	EAP	China	FC(FW)	R		Journal
65.	WHO (2006b)	Global	Various	FC(M)/ICS	R/U	CBA	Report
66.	Yan (2010)	EAP	China	FC(M)		Multinomial logit	WP

Notes: [a] SA (South Asia), SSA (sub-Saharan Africa), LAC (Latin America and the Caribbean) and EAP (East Asia and Pacific). [b] ICS (improved cookstoves), FC (fuel choice), M (multiple fuel), FW (fuelwood) and B (biogas). [c] R (rural) and U (urban). [d] CBA (cost benefit analysis), CEA (cost-effective analysis) an SUBP (Seemingly Unrelated Bivariate Probit). [e] WP is working paper.