Chapter 12

Household Energy Interventions and Health and Finances in Haryana, India: An Extended Cost-Effectiveness Analysis

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INTRODUCTION

Approximately 40 percent of the world's population relies on solid fuels, including wood, dung, grass, crop residues, and coal, for cooking (Bonjour and others 2013). Household air pollution (HAP) arising from this use of solid fuels results in 3 million to 4 million deaths yearly from acute lower respiratory infection (ALRI) in children and chronic obstructive pulmonary disease (COPD), ischemic heart disease (IHD), stroke, and lung cancer in adults. This burden constitutes approximately 5 percent of global mortality, ranking highest among all environmental risk factors contributing to global ill health (Forouzanfar and others 2015; Smith and others 2014).

In India, the reliance on solid fuels and the estimated related burden of disease are pronounced. An estimated 770 million individuals—approximately 70 percent of the total population (Government of India 2011)—living in 160 million households continue to use solid fuels as a primary energy source for cooking (Venkataraman and others 2010). Among all risk factors contributing to ill health in India, exposure to HAP from cooking ranks second for mortality, with approximately 925,000 premature deaths yearly; it ranks third for lost disability-adjusted life years (DALYs), amounting to approximately 25 million lost DALYs per year (Forouzanfar and others 2015).[1] An estimated 4 percent of the deaths occur in children under age five years because of pneumonia, which overall accounts for 12 percent of total child deaths in India.

Attempts to reduce this burden fall into two primary categories: (1) those that seek to make biomass combustion cleaner and more efficient, and (2) those that seek to replace biomass use with liquid fuels or electricity (Foell and others 2011; Smith and Sagar 2015). Private and public sector actors have taken action in India to reduce this large burden of disease. Private sector endeavors include research, development, marketing, and distribution of biomass stoves by large multinational corporations, such as Philips and BP, and smaller Indian and international firms, such as Envirofit, Greenway, First Energy, BioLite, and Prakti. In all cases, the evaluations of the viability of these interventions for long-term use, which would be required to reduce exposures and thus the health burden, have been mixed (Brooks and others 2016; Pillarisetti and others 2014; Sambandam and others 2015).

The government of India has undertaken a number of policy initiatives to address HAP through improved biomass combustion, beginning in the 1980s with a failed National Programme on Improved Chulhas

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(Kishore and Ramana 2002) and continuing in 2010 with a National Biomass Cookstoves Initiative. More recently, two innovative programs—the Give It Up (GIU) and Smokeless Village (SV) campaigns—are seeking to bring clean cooking via liquefied petroleum gas (LPG) to the rural poor (Smith and Sagar 2015). Both GIU, which encourages better-off Indian households to voluntarily give up their LPG subsidies and redirects those subsidies one-for-one to below-poverty-line (BPL) families, and SV, which connects every household in a village to LPG, occur in close collaboration with India's three national oil companies. In mid-2016, Indian Prime Minister Narendra Modi introduced Pradhan Mantri Ujjwala Yojana (Ujjwala), a program to extend the GIU and SV campaigns by making free LPG connections available to all BPL households. This policy will affect approximately 50 million households.[2] These programs have the potential to substantially reduce the mortality and morbidity associated with the use of solid fuels for cooking, if one assumes near-complete transitions to clean fuels (Smith and Sagar 2015).

This chapter describes an extended cost-effectiveness analysis (ECEA) of policies designed to promote uptake of hypothetical HAP control interventions aligned with three national government programs:

- A low-cost, mud chimney stove, as was promoted in the National Programme on Improved Chulhas that operated from about 1983 to 2002 (We evaluate this program under the same current conditions as the other programs.)
- An advanced combustion cookstove, like that being promoted in the current National Biomass Cookstoves Initiative
- A transition to LPG being promoted in the national Give It Up campaign.

Our scenarios simplify complex behavioral issues by assuming full use of all intervention stoves in order to estimate best-case health and welfare benefits of clean cooking transitions. We evaluate the sensitivity of our use assumption in annex 12A. Our goal is to indicate the types of policy-relevant analyses that are possible using ECEA and the magnitude of potential benefits of LPG adoption.

Traditional economic cost-effectiveness analyses, such as that by Mehta and Shahpar (2004), focus on the U.S. dollars spent per death or per DALY averted. ECEA also considers the financial implications of policies across wealth strata of a population (introduced in Verguet, Laxminarayan, and Jamison 2015), in this case, by income quintile. ECEAs assess the consequences of financial or other policies that influence the aggregate uptake of an intervention and its health and financial consequences across income groups. Verguet, Laxminarayan and Jamison (2015), for example, looked at public finance and enhanced borrowing capacity as policies to affect tuberculosis treatment in India. Verguet and others (2015) assessed the consequences of a policy to increase tobacco taxes in China. Including distributional analysis by income quintile enables novel policy evaluations, as well as an evaluation of the GIU campaign.

This ECEA focuses on policies to reduce exposure to HAP in Haryana, India. This state has a population of 20 million, about 55 percent of whom use solid fuels for cooking, although significant heterogeneity exists between both rural and urban areas and between available datasets for analyses. In addition, we benefit from the availability of published continuous exposure-response relationships for HAP-related diseases and a fuel gathering–based time metric, allowing us to quantify the potential earnings gained by use of a stove that improves fuel efficiency.[3]

Review of Economic Analyses of Household Energy Interventions

Existing peer-reviewed literature on the costs, benefits, and cost-effectiveness of HAP interventions is sparse (Jeuland, Pattanayak, and Bluffstone 2015). A limited number of global (Hutton and others 2006; Hutton, Rehfuess, and Tediosi 2007; Jeuland and Pattanayak 2012; Mehta and Shahpar 2004) and geography-specific (Arcenas and others 2010; Aunan and others 2013; Malla and others 2011; Pant 2011) economic evaluations exists. A short review follows.

Mehta and Shahpar (2004) found wide variation in the cost-effectiveness of improved stoves and LPG and propane interventions across the World Health Organization subregions, but their analysis did not consider the cost of illness and treatment or potential non-health benefits of transitioning to cleaner cooking. Hutton and others (2006) and Hutton, Rehfuess, and Tediosi (2007) performed a global cost-benefit analysis of eight scenarios that reduced exposure through a transition to either clean fuels or clean biomass stoves and considered benefits including improved health, decreased emissions of climate-altering pollutants, fewer lost work days, and time savings. They found that both the clean fuel transition and the improved stove transition had favorable cost-benefit ratios of 4.3 and approximately 60, respectively. Unlike Hutton and others (2006) and Mehtha and Shahpar (2004), both of which used regional scale inputs, Jeuland and Pattanayak (2012) modeled costs and benefits from household and societal perspectives for clean fuel and clean stove technologies. They found that transitions away from traditional cooking yield variable results; some interventions have high probabilities of net costs to households and societies. Their modeling indicates that LPG, kerosene, and improved charcoal stoves have the highest probability of net positive benefits at household and societal scales. They note that the findings are sensitive to a number of factors, including emission rates and fuel costs.

Cost-benefit analysis has been applied in a number of geography-specific studies, including in Nepal (Malla and others 2011; Pant 2011), China (Aunan and others 2013), the Western Pacific region (Arcenas and others 2010), and Kenya and Sudan (Malla and others 2011). Malla and others (2011) found that across three separate interventions in Nepal (smoke hood), Kenya (LPG or smoke hoods), and Sudan (LPG), benefits exceeded costs over the 10-year intervention period, although there was significant heterogeneity among study sites. They note, however, that the effect of monetized health benefits was relatively small across all sites, compared to time and fuel savings. In China, Aunan and others (2013) evaluated transitions in no-chimney or chimney stove homes to either second-generation improved cookstoves or community-scale pellet stoves. In all cases, benefit-cost ratios were positive (central estimate range of 3.3–14.7), and the largest ratios occurred by switching away from chimneyless stoves. Only health benefits were monetized. Similarly, Pant (2011) and Arcenas and others (2010) used cost-of-illness and value of a statistical life, respectively, to assess the effect of household energy transitions by using survey data. Pant (2011) modeled the effect of a transition from dung fuel to biogas, noting the health cost per household—driven by medication expenses—to be 61.3 percent higher in dung-burning households than the cost of fuel in biogas households.

Clean Fuel Intervention Costs

Interventions considering either fuels—such as LPG or natural gas—or electricity must contend with both upfront and recurrent costs. In India, before 2015, every cylinder of LPG sold to household customers was subsidized at the point of sale, regardless of the income of the household. In 2015, the government announced that cylinders would be sold at full price to all consumers, but that households would have subsidies transferred directly to their bank accounts—the PAHAL scheme (Tripathi, Sagar, and Smith 2015). Among others goals, this policy sought to prevent small and medium enterprises from being able to buy subsidized fuel intended for households from the black market. Current subsidies are approximately one-fourth of the cost of a cylinder, although they vary with the market price of LPG.

As part of the GIU campaign, in addition to the redistribution of the subsidy to the poor, the corporate social responsibility funds of the three national oil companies were used to cover the upfront costs of the regulator and cylinder deposits—a subsidy of approximately 2,000 rupees (Rs) (approximately US$30) made available to BPL households, an official category that varies somewhat by state. Some states also provide a stove to families receiving the GIU benefit. According to the Ministry of Petroleum (2016), 10 million middle-income households had given up their LPG subsidy as of May 1, 2016 (Smith and Sagar 2015). Ujjwalla extends this by providing the same subsidy to all BPL households through use of a new allotment of about US$1.2 billion of Indian government funds (*Times of India* 2016).

Estimation of Health Benefits of Clean Cooking

Understanding improved health attributable to a HAP-reducing intervention, such as a transition to LPG, relies on complex exposure science and behavioral processes. The relationship between exposure to HAP and health is nonlinear and is described through a set of integrated-exposure response (IER) (Burnett and others 2014) curves that link exposure to particulate matter with an effective diameter of less than 2.5 micrometers ($PM_{2.5}$, a key component of combustion-generated air pollution) with a number of health endpoints. IERs currently exist for ALRI, IHD, stroke, lung cancer, and COPD. The IERs integrate exposure data from a range of $PM_{2.5}$ sources, including HAP, active tobacco smoking, secondhand tobacco smoke, and ambient air pollution.

The continuous nature of the exposure-response relationships allows modeling of the potential health benefits of a reduction in exposure to $PM_{2.5}$ attributable to a specific intervention by disease type (Pillarisetti, Mehta, and Smith 2016). However, quantifying exposure reductions is challenging and relies on either expensive and intrusive monitoring of individuals or sophisticated modeling of pollution levels and time-activity patterns. Exposure reductions are complicated by issues of compliance or *stove stacking*, the phenomenon of continuing to use the traditional cooking technology even though a new technology or fuel has come into the household (Brooks and others 2016; Johnson and Chiang 2015; Pillarisetti and others 2014; Ruiz-Mercado and others 2011; Sambandam and others 2015; Smith and others 2015). However, this situation is not unusual in health interventions, where provision of a healthier technology needs to be followed by policies to encourage long-term use and elimination of the unhealthy behavior (for example, with condoms, bednets, and latrines). In a sense, then, the analyses here represent an efficacy approach—the best that could be achieved for each intervention.

To address these issues and others, we have developed (1) an online tool that uses the IERs and relevant background data to estimate the potential effect of an intervention known as the Household Air Pollution Intervention Tool (HAPIT) (Pillarisetti, Mehta, and Smith 2016) and (2) standard protocols to use HAPIT to estimate averted ill health (Smith and others 2014).

METHODS

Estimation of Reductions in Morbidity and Mortality Resulting from HAP Interventions

This chapter uses a modified version of HAPIT (based on the version described in Pillarisetti, Mehta, and Smith [2016] but modified to facilitate evaluation of multiple scenarios at a subnational scale) to estimate the averted deaths and DALYs attributable to an intervention over a five-year period. Briefly, HAPIT uses national background health data and the methods and databases developed as part of the Comparative Risk Assessment (Lim and others 2012), a component of the Global Burden of Disease Study 2010 (GBD 2010) (Lozano and others 2012), to determine pre- and post-intervention population attributable fractions. The burden of disease averted can then be determined by multiplying the background disease-specific burden by the difference in population attributable fractions. Notably, therefore, HAPIT incorporates exposure-response functions for five separate diseases associated with air pollution in recent international assessments based on synthesizing results from multiple individual epidemiological studies in a number of countries. It estimates the effect of interventions based on the background conditions of each of the diseases in the country considered (in this case, India). Pillarisetti, Mehta, and Smith (2016) provide a detailed explanation of HAPIT and its underlying calculations.

Background disease data for Haryana were not readily accessible. Instead, underlying disease burden data for India from the GBD 2010 were scaled by the proportion of the population living in Haryana. To estimate background disease characteristics by income quintile (table 12.1) in Haryana, we distributed premature deaths for children and adults and DALYs according to the fraction of all solid fuel–using households in Haryana residing in a specific income quintile, as determined through analysis of the Indian Human Development Survey (IHDS) 2005–06 (Barik and Desai 2014; Desai, Vanneman, and National Council of Applied Economic Research 2005). The uncertainty in the background disease estimates provided by the Institute for Health Metrics and Evaluation in the Global Burden of Disease Study 2010 is used to bound estimates of averted DALYs and deaths attributable to an intervention.

We also evaluated two additional modes of distributing background disease (annex 12A). In the first, disease data were split on the basis of the overall percentage of Haryana's population in each quintile, calculated by multiplying the number of households per quintile by the number of people per household. In the second, we assumed (1) that all quintiles had equal populations and age distributions and (2) that solid fuel use (SFU) linearly decreased as wealth increased, beginning at 90 percent in quintile (Q) 1 and ending at 60 percent SFU in Q5.

Evaluation of the Consequences of Policy

We evaluate the effect of policies leading to 100 percent penetration and adoption of three interventions—a simple mud chimney stove; a fan-assisted, forced-draft semi-gasifier, also known as a blower stove; and an expansion of LPG—on exposure to $PM_{2.5}$ and subsequent ill health in Haryana, India (table 12.2). Although each scenario is grounded in either past or ongoing policy initiatives (discussed in the introduction), we focus on a simulation of potential benefits of these policies under aspirational conditions. We did, however, assess the sensitivity of our findings to the assumption of full adoption (annex 12A) by modeling a scenario with high adoption of chimney stoves (90 percent) and moderate adoption of blower stoves (65 percent) and LPG stoves (50 percent).

Simple mud chimney stoves cost approximately US$10 (Dutta and others 2007), while blower stoves cost approximately US$60. We assume that chimney stoves have low maintenance costs and work for one year and then provide no benefit, which is consistent with surveys in India. Similarly, blower stoves have low yearly maintenance costs, but they need to be replaced once every three years. The transition to LPG incurs a number of costs, including the cost of the LPG stove (approximately US$20), and the connection fee, security deposit, and administrative costs for the first cylinder (approximately US$30). Cylinder refills cost approximately US$8.70 per cylinder unsubsidized and US$6.60 per cylinder subsidized. Families use approximately nine cylinders per year, on average, across India. Total costs to the government are described in table 12.5 later in this chapter.

Using exposure models developed with data from India, we assume the pre-intervention exposure to $PM_{2.5}$ for adults is 337 micrograms per cubic meter ($\mu g/m^3$)

Table 12.1 Background Disease Burden in India and in Haryana, India, by Income Quintile

	ALRI[a]		COPD[b]		IHD[b]		Lung Cancer[b]		Stroke[b]			
	Deaths	DALYs (thousands)	Deaths	DALYs (thousands)	Deaths	DALYs (thousands)	Deaths	DALYs (thousands)	Deaths	DALYs (thousands)	Solid fuel use (%)	Population (millions)
India	200,000	17,000	910,000	26,000	1,100,000	26,000	83,000	2,100	610,000	12,000	63	1,000
Haryana	4,600	400	21,000	600	26,000	600	1,900	50	14,000	280	55[2]	20
Q1 (Poorest)	1,000	90	4,600	130	5,700	130	420	10	3,100	60	89	
Q2	1,000	90	4,800	140	6,000	140	440	10	3,200	65	90	
Q3	1,000	90	4,600	130	5,700	130	420	10	3,100	60	88	4
Q4	780	70	3,600	100	4,400	100	320	10	2,400	50	66	
Q5 (Wealthiest)	730	60	3,400	95	4,200	100	310	10	2,200	45	62	

Sources: Global Burden of Disease Study 2010, India country profile (IHME 2015) (disease burden data); IHDS 2005–06 (Desai, Vanneman, and National Council of Applied Economic Research 2005) (population data); Census of India 2011 (Government of India 2011) (solid fuel use).

Note: ALRI = acute lower respiratory infection; COPD = chronic obstructive pulmonary disease; DALYs = disability-adjusted life years; IHD = ischemic heart disease; Q = quintile.

a. ALRI in children under age five years. Apportioned by the percentage of all solid fuel–using households in each quintile.

b. Chronic outcomes in adults.

Table 12.2 Potential Interventions in Haryana, India

Intervention	Description	Target population	Existing coverage,[a] % (quintile)	Proposed coverage[b] (%)	Exposure reduction (%)	Reduction in biomass fuel use (%)
Chimney stove	A simple mud-brick chimney stove with two potholes	3.4×10^6 households in Haryana 2.6×10^6 households using unclean fuels[c]	11 (Q1), 10 (Q2), 12 (Q3), 24 (Q4), 28 (Q5)	100	50	15
Blower stove	A single pothole semi-gasifier stove			100	63	42
LPG	Fuel stored as liquid under slight pressure, burned as a gas			100	90	100

Sources: IHDS 2005–06 (Desai, Vanneman, and National Council of Applied Economic Research 2015) (chimney stove, blower stove, and LPG); Census of India 2011 (Government of India 2011) (chimney stove); Bailis and others 2007 (chimney stove); Sambandam and others 2015 (blower stove).

Note: LPG = liquefied petroleum gas.

a. Coverage equals the percentage of households in Haryana currently using an equivalent or better technology. For LPG, this includes households using LPG, electricity, or biogas but does not indicate exclusive use of these clean cooking technologies.

b. This comprises the total population (that does not currently have an equivalent or better cooking technology) to cover by a specific intervention.

c. Unclean fuels include the following Census of India 2011 categories: firewood, crop residue, and cowdung cake; coal, lignite, and charcoal; and kerosene. Eighty-five percent of these households are rural.

and 150 μg/m^3 for children (Balakrishnan and others 2013; Northcross and others 2010; Pillarisetti, Mehta, and Smith 2016; Smith and others 2014). We scale the central estimate of exposure by the respective exposure reduction (table 12.2) attributable to a given intervention. For this analysis, we estimate intervention costs and benefits across five years, child health gains accrue instantly at the start of each year, and adult health gains are weighted using the U.S. Environmental Protection Agency cessation lag (U.S. EPA 2004) model. For simplicity, averted deaths and DALYs are reported in total. For all evaluated interventions, we consider deployments only in households using biomass fuels in traditional cookstoves.

Household Expenditures

We assume households take responsibility for replacing stoves after their useful lifetime has passed. For this analysis, households replace a blower stove once during the five years of the evaluation, a useful lifetime for this class of interventions consistent with evidence from the literature (Pillarisetti and others 2014; Sambandam and others 2015). We assume that a gas stove needs no replacement during the five years of this assessment and that households do not replace their chimney stove after the first year, consistent with findings from the National Programme on Improved Chulhas (Venkataraman and others 2010).

We also assume that the averted ill health attributable to this publicly financed intervention results in lower household medical expenditures. Expenditures averted are based on the probability of seeking care for acute and chronic conditions and the combined inpatient and outpatient costs of such visits, including drugs, hospital visits, and transportation to and from clinics. To calculate the expenditure averted by complete adoption of an intervention, we scale the cost of hospital or doctor visits and related expenditures by the relative reduction in DALYs attributable to an intervention separately for acute (ALRI) and chronic (COPD, IHD, stroke, and lung cancer) conditions. For example, for a hypothetical intervention that reduces DALYs associated with chronic diseases by 10 percent, we assume a 10 percent reduction in health care–related expenditure on chronic diseases.

Treatment-seeking behaviors and associated costs are derived from IHDS (Desai, Vanneman, and National Council of Applied Economic Research 2005) and IHDS summary documents (Barik and Desai 2014). Approximately 94 percent of households across India seek treatment for short-term illnesses, defined as fever, cough, and diarrhea. This figure is consistent with Haryana data extracted from IHDS databases and is applied equally for all quintiles. Similarly, we apply national treatment-seeking percentages by quintile to the chronic illnesses of concern. Treatment-seeking behaviors and associated costs[4] by quintile are described in table 12.3.

Additionally, we translate the increase in fuel efficiency attributable to an intervention into weekly time savings by multiplying the increase in fuel

Table 12.3 Treatment-Seeking Behaviors and Associated Costs

Disease	Behavior and cost	Q1	Q2	Q3	Q4	Q5
Acute diseases (ALRI)	Treatment (%)	94	94	94	94	94
	Median cost (US$)	17	14	10	18	12
Chronic diseases (IHD, COPD, lung cancer, stroke)	Treatment (%)	88	86	90	94	95
	Median cost (US$)	19	20	22	24	38

Sources: Data extracted from IHDS data (Desai, Vanneman, and National Council of Applied Economic Research 2005) and summary documents (Barik and Desai 2014).
Note: ALRI = acute lower respiratory infection; COPD = chronic obstructive pulmonary disease; IHD = ischemic heart disease; Q = quintile.

Table 12.4 Intervention Financial Parameters per Unit

	Government			Household			
Intervention	Stove (US$)	One-time costs, US$ (quintile)[a]	Yearly costs, US$ (quintile)[b]	Stove (US$)	One-time costs, US$ (quintile)	Yearly costs, US$ (quintile)[b]	Time savings, hours per year (quintile)
Chimney	10	5	n.a.	n.a.	n.a.	1	25 (Q1), 19 (Q2), 20 (Q3), 15 (Q4), 14 (Q5)
Blower	60	10	n.a.	n.a.	60	5	72 (Q1), 53 (Q2), 56 (Q3), 41 (Q4), 40 (Q5)
LPG status quo	0	0	33	20	30 (Q1), 30 (Q2), 30 (Q3), 30 (Q4), 30 (Q5)	46 (Q1), 46 (Q2), 46 (Q3), 46 (Q4), 46 (Q5)	170 (Q1), 126 (Q2), 134 (Q3), 97 (Q4), 96 (Q5)
LPG–GIU[c]	0	30 (Q1), 30 (Q2), 0 (Q3), 0 (Q4), 0 (Q5)	33 (Q1), 33 (Q2), 0 (Q3), 0 (Q4), 0 (Q5)	20	0 (Q1), 0 (Q2), 30 (Q3), 30 (Q4), 30 (Q5)[d]	46 (Q1), 46 (Q2), 80 (Q3), 80 (Q4), 80 (Q5)	

Note: GIU = Give It Up; LPG = liquefied petroleum gas; n.a. = not applicable; Q = quintile.
a. For LPG scenarios, one-time costs are the LPG connection costs. Current prices are available at IndianOil Corporation, https://indane.co.in/connection_tarrifs.php; US$1.00 = 68.13 rupees (Rs). For biomass stoves, one-time costs represent the cost of implementation.
b. For LPG scenarios, yearly costs are the cost of the fuel subsidy to the government and the cost of the fuel to the households. The analysis assumes that houses use nine cylinders per year at an unsubsidized cost of US$8.80 (Rs 600.00) per cylinder; that Haryana has 3.35 million homes; and that the per cylinder subsidy is approximately US$3.70 (Rs 250.00). For biomass stoves, yearly costs are stove maintenance costs borne by the household.
c. India's national oil companies cover connection costs for 60 percent of households; connection costs to the household apply only for the upper three quintiles.
d. The subsidy provided to existing LPG users is redirected to the lower-income quintiles.

efficiency relative to the base case scenario by the time spent collecting fuel. We place a monetary value on this gained time using the Mahatma Gandhi National Rural Employment Guarantee Act's guaranteed wage of Rs 251 (US$$3.70) per day, for up to 100 days, in Haryana.[5,6] Accordingly, a household's yearly total averted expenditure as the result of an intervention is the sum of the wage earned during time previously spent collecting fuel and the avoided health expenditure, minus any cost to the household of the intervention (for example, stove maintenance or replacement or fuel costs):

$$Averted\ expenditure = \left(\frac{Time\ savings(hrs)}{8\ hrs/day} \times Wage\right) + Averted\ medical\ expenditure - Intervention\ cost$$

Government Costs

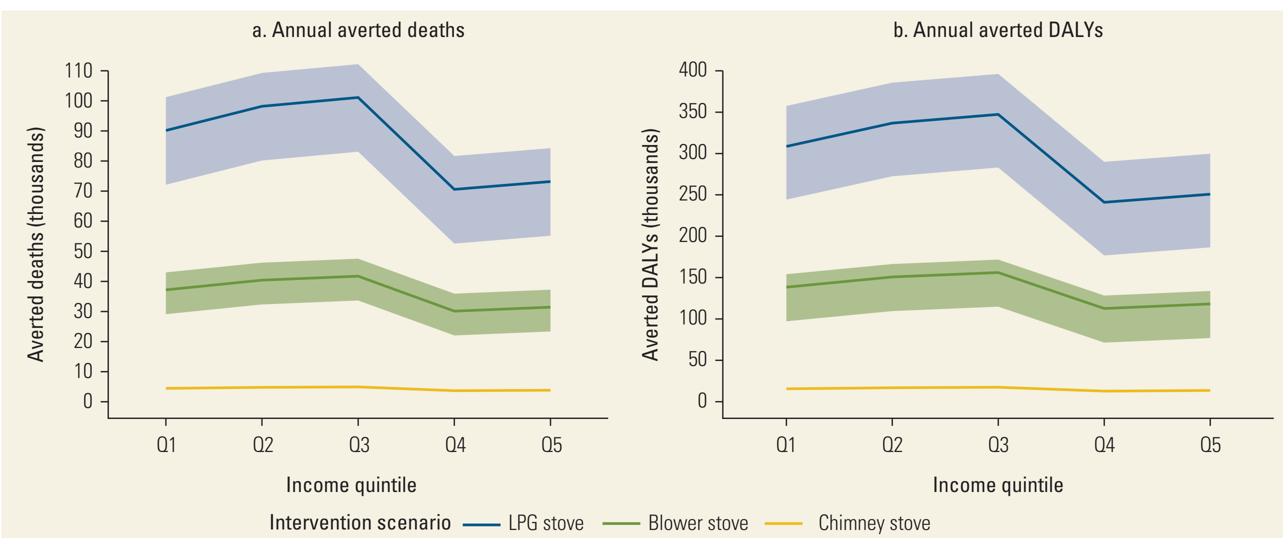
The government incurs costs from providing the intervention. The provision cost of chimney and blower stoves includes the upfront cost of the intervention and a one-time cost of deployment. For the LPG intervention, we consider a policy pathway mimicking the ongoing Give It Up campaign. In this scenario, subsidies are provided to all solid fuel–using households in only the lower two income quintiles (Q1 and Q2 in tables and figures); the subsidy given to existing LPG users in the upper three income quintiles is redirected to the lower two quintiles. Because subsidies are being retargeted, the net cost to the government is zero; the upper-income quintiles absorb the additional costs. However, we assume the connection costs borne by the corporate social responsibility funds from oil companies for the lower two income quintiles could be used elsewhere by these companies, which are owned largely by the government, and thus represent a cost to the government. All households pay for their own LPG stove and for their LPG fuel. This analysis assumes that houses use nine cylinders per year at an unsubsidized cost of US$8.80 (Rs 600.00) per cylinder and that the per cylinder subsidy is approximately US$3.70 (Rs 250.00). Table 12.4 summarizes the per unit private and public intervention costs.

All analyses were carried out using R 3.1 statistical software (R Foundation 2015); plots were generated using the ggplot2 system (Wickham 2009).

RESULTS

Under the assumptions of the analysis, the intervention pathways described result in reductions in ill health attributable to using solid fuel for cooking. The scale of those reductions varies both among interventions and among quintiles; all interventions show higher reductions in ill health in the poorest three quintiles (figure 12.1 and table 12.5). The costs to the government of the five-year programs vary widely among interventions: the chimney stove intervention costs approximately US$39 million, and the blower stove intervention costs approximately US$180 million. At these prices, a life saved by the chimney stove costs the government approximately US$20,000 and the cost of an averted DALY is US$520, whereas a life saved by the blower stove costs US$10,000 and an averted DALY costs US$275. Complete replacement of traditional stoves in solid fuel–using households in Haryana results

Figure 12.1 Averted Deaths and DALYs for Three Classes of Interventions in Haryana, India, by Income Quintile



Note: DALYs = disability-adjusted life years; LPG = liquefied petroleum gas; Q = quintile. Shaded areas account for uncertainty in background disease conditions and indicate the minimum and maximum avoidable burden. The relatively constant shape of the lines for each scenario is a byproduct of high solid fuel use across all income quintiles (range 60 percent to 90 percent) and the increasing number of people per household with increasing income, despite an approximately equal number of homes in each quintile.

Table 12.5 Five-Year Government Intervention Costs, Costs to Households, Household Expenditures Averted, and Deaths and DALYs Averted for Chimney Stove, Blower Stove, and LPG Intervention Pathways

	Q1 *N* = 669,000 SFU = 595,000	Q2 *N* = 670,000 SFU = 604,000	Q3 *N* = 671,000 SFU = 592,000	Q4 *N* = 671,000 SFU = 445,000	Q5 *N* = 670,000 SFU = 418,000
Chimney stove					
Government costs	8,900,000	9,100,000	8,900,000	6,700,000	6,300,000
Household maintenance costs	3,000,000	3,000,000	3,000,000	2,200,000	2,000,000
Household expenditures averted	6,700,000	4,900,000	5,100,000	2,800,000	2,600,000
Deaths averted	420	450	470	340	350
DALYs averted	16,000	17,000	18,000	13,000	14,000
Blower stove					
Government costs	42,000,000	42,000,000	41,000,000	31,000,000	29,000,000
Household maintenance and stove replacement costs	50,000,000	51,000,000	50,000,000	38,000,000	36,000,000
Household expenditures averted	52,000,000	27,000,000	31,000,000	8,300,000	8,500,000
Deaths averted	3,700	4,100	4,200	3,000	3,200
DALYs averted	140,000	150,000	160,000	110,000	120,000
LPG–GIU pathway					
Government costs	18,000,000	18,000,000	0	0	0
Fuel cost to households	150,000,000	150,000,000	270,000,000	200,000,000	190,000,000
Household expenditures averted	95,000,000	36,000,000	–72,000,000	–91,000,000	–84,000,000
Deaths averted	9,100	9,900	10,000	7,000	7,300
DALYs averted	310,000	340,000	350,000	240,000	250,000

Note: DALYs = disability-adjusted life years; GIU = Give It Up; LPG = liquefied petroleum gas; Q = quintile; SFU = solid fuel use. Fuel cost to households includes the up-front, one-time stove costs and recurrent maintenance and fuel costs. Household expenditures averted are the sum of the hourly wages accrued and the medical costs averted minus the cost to the households. For the LPG-GIU pathway, subsidy retargeting has different implications for solid fuel users versus current LPG users. Solid fuel users assume the additional full cost of unsubsidized LPG, while current LPG users assume only the difference between the full, unsubsidized LPG cost and the subsidized cost.

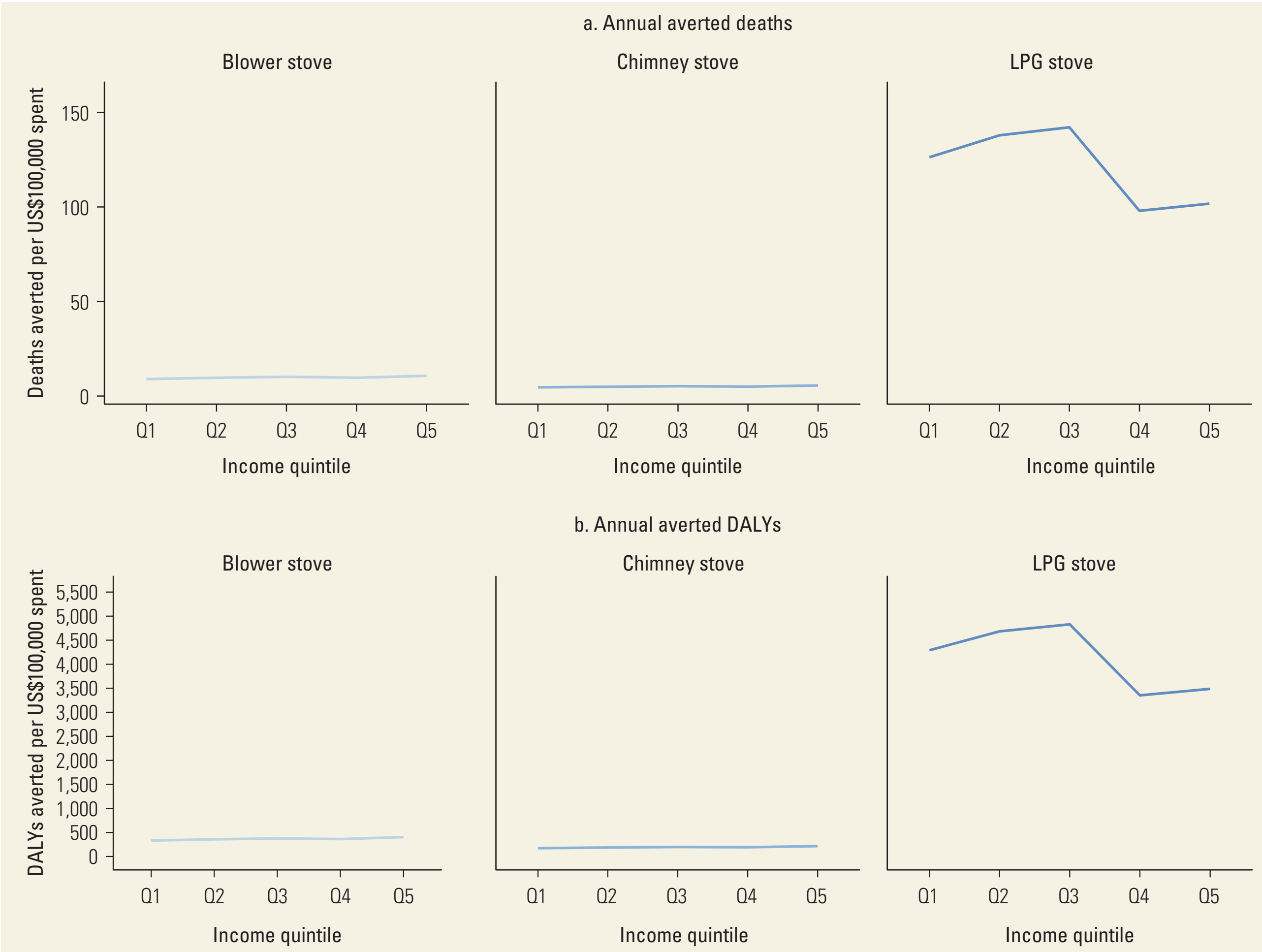
in 2,000 averted deaths and 77,000 averted DALYs for the chimney stove and 18,100 averted deaths and 676,000 averted DALYs for the blower stove.

The LPG pathway, in which the government pays for connection charges from the allocation of corporate social responsibility funds, costs approximately US$36 million, or approximately US$11 per home when averaged across all homes or US$30 per home when averaged across only the lower two income quintiles. This policy pathway assumes that all higher-income households (n ~ 2,000,000) give up their subsidy and that the reclaimed subsidy can be targeted to solid fuel–using households (n ~ 1,340,000) in the lower-income quintiles, effectively not altering the cost to the government. Under this scheme, an averted death costs the government US$825 and an averted DALY costs US$25. Over the five-year evaluation period, 1,484,000 DALYs and 44,000 deaths are averted.

The LPG stove averts the most deaths and DALYs across all income quintiles, per US$100,000 spent (figure 12.2). The figure panels for the LPG intervention evenly split the costs between all income quintiles, though the only additional expenditure by the government is for the bottom two quintiles.

Figure 12.3 depicts the trends in expenditures averted by households by quintile. Notably, households in the poor quintiles avoid more private expenditure than do households in the upper quintiles. This finding is most pronounced for the blower and LPG stoves. The described LPG intervention, in which the richest households receive no subsidy for fuel, simulates the GIU campaign and results in a net cost to these households, which must pay the full, unsubsidized price for their fuel and their one-time connection costs. The national oil companies cover connection costs for poor households, which also receive subsidized fuel.

Figure 12.2 Averted Deaths and DALYs per US$1 Million Spent for Three Classes of Interventions in Haryana, India, over Five-Year Intervention Lifetime, by Income Quintile



Note: DALYs = disability-adjusted life years; LPG = liquefied petroleum gas; Q = quintile. Panels represent intervention classes. For the LPG scenario, gas subsidies given up by income quintiles 4 and 5 result in no expense to the government for the intervention in these quintiles; the subsidy is retargeted evenly to income quintiles 1, 2, and 3.

DISCUSSION

We present results from ECEAs of policies designed to achieve high uptake of three hypothetical classes of HAP interventions in Haryana, India. The classes of interventions presented match historical modes of household energy programs, first attempted with chimney stoves, then with blower-assisted biomass stoves, and, most recently, with a transition to truly clean cooking using LPG. By evaluating multiple types of interventions, we are able to compare cheap, poorly performing chimney stoves with intermediate (blower) and modern (LPG) options.

Our approach is novel in several ways:

- It seems to be the first ECEA to date evaluating household energy policies.
- It takes into account the earning potential of individuals who save time by transitioning to more efficient stoves, which require less fuel and less time spent collecting fuel.
- It uses a continuous exposure-response function to estimate health benefits of interventions with different exposure reduction potentials.
- It evaluates a current LPG policy pathway that mimics the ongoing retargeting of LPG fuel subsidies.

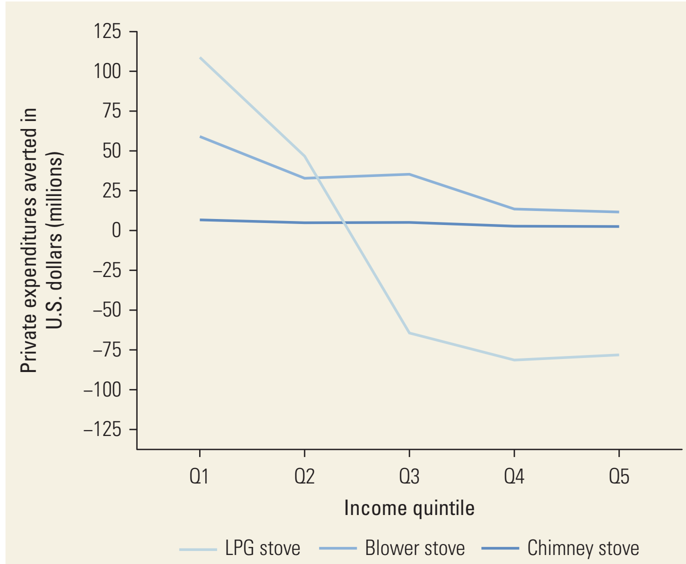
By considering earnings and medical expenses averted as a result of these interventions, we hope to present a more rigorous and multidimensional set of options for policy makers to evaluate and consider as they seek to reduce the significant health burden associated with exposure to smoke arising from use of solid fuel combustion for cooking. Unlike many other ECEAs, we present both averted deaths and averted DALYs, a combined metric of both morbidity and mortality.

Our findings indicate that from the perspective of avoiding ill health, the evaluated LPG scenario outperforms attempts to make biomass combustion clean, although it imposes an additional fuel cost on households. Our findings show, however, that the added cost of subsidized fuel—at least for the poorest income quintiles—is more than covered by the monetary values of saved time and avoided healthcare. This striking finding, however, is heavily influenced by the assumption that use of time previously spent collecting fuel is repurposed for productive economic return, which may not be true in these settings. The income quintile–based consequences of these policy pathways are complicated by the underlying distributions of SFU and disease burden. Using those distributional consequences alone to make policy decisions would favor less effective interventions and ignore the significant health burden remaining from adoption of such technology. In contrast, the financial protection provided by the LPG policy pathways benefits the poor, who receive subsidized fuel, free LPG connections, and reduced health care costs and who stand to gain the most in wages. This inverse relationship between those quintiles that receive an advantage from health benefits versus financial benefits is not uncommon to ECEA (Pecenka and others 2015); it reveals the methodology's ability to highlight multiple policy-relevant facets masked by traditional cost-effectiveness analysis. It also indicates an area of ongoing concern. Public financing of interventions such as those that are targeted to quintiles and that are modeled to benefit the most may have unintended consequences.

Strikingly, retargeting the subsidy—as is happening in India under the Give It Up campaign—significantly increases the cost-effectiveness of interventions targeting the poorest income quintiles. This finding suggests that such an approach—especially when considered in light of the considerable financial risk protection afforded by targeting the lower-income quintiles—may be a way to quickly and efficiently move resources to those most vulnerable to both the health and the financial effects of SFU for cooking.

Despite these clear distributional benefits, less profound difference exists among quintiles than originally anticipated, which explains the relatively constant values across quintiles seen in figures 12.1, 12.2, and 12.3. We believe this is due in part to relatively high SFU numbers across all quintiles and an increasing number of people per household as wealth increases, resulting in a skewed distribution of background disease rates.

Figure 12.3 Averted Private Expenditure for Each Class of Intervention over the Proposed Five-Year Intervention Lifetime



Note: LPG = liquefied petroleum gas; Q = quintile. Negative values indicate net costs to households. However, the upper quintiles are voluntarily giving up their subsidy in the GIU campaign. Annex 12A, figure 7 shows the per household costs and savings by income quintile and intervention scenario.

We conducted a sensitivity analysis to evaluate the effect of a hypothetical scenario with an equal number of people per quintile and linearly decreasing SFU as wealth increases. Under these conditions, the effects of all three scenarios were most profound for the poorer income quintiles.

Our analysis has a number of limitations. First, we present only a small number of potential household energy intervention scenarios under ideal use scenarios, none of which considers an additional benefit in the form of reducing the herd or the neighborhood effect; that is, by swapping out entire communities, wider gains in exposure reduction could occur. We assume that households transition fully to the cleaner technology in all three cases and do not revert to older technologies even partially. We address this shortcoming in part by evaluating the effects of adoption rates less than 100 percent and the effects of variation in exposure that may represent suboptimal intervention performance or use of both old and new interventions. We find that the overall trends in our findings are robust to these types of changes (annex 12A). We chose this framing to indicate the potential effects of statewide adoption and use of LPG, realizing that such a transition will take time and must contend with issues of stove stacking. We acknowledge that such a framing does not contend with issues of the perceived costs of fuel versus potential health savings and wage gains, which may be viewed independently by household decision makers.

Second, our study uses older IHDS data from 2005–06. Newer data—either from IHDS itself or from other national surveys—may provide more up-to-date numbers on the penetration of LPG in Haryana and on treatment-seeking behaviors and related costs. We also recognize that our mapping of BPL households to IHDS income quintiles 1 and 2 may not match the current reality. However, to our knowledge, unlike other surveys, IDHS has the benefit of providing a single source from which to gather almost all parameters needed for this analysis, thereby preventing potentially problematic comparison among surveys with different sampling frames. Similarly, we use national data on treatment-seeking behavior for Haryana; data from IHDS at the state level were unrealistically homogenous across income quintiles.

Our quantification of the monetary value of time savings does not account for behavioral aspects related to job-seeking behavior or any potential rebound effects of adoption of cleaner cooking technologies. We acknowledge that small daily or weekly time savings may not be large enough and (1) that a search for a job via the Mahatma Gandhi National Rural Employment Guarantee Act is warranted, (2) that employment opportunities exist for the modeled time savings, or (3) that household members who experience time savings might engage in employment versus other household or leisure-related activities. We assume that people will successfully seek employment in the national program and that the time saved by shifting away from biomass can be utilized productively—findings that may not hold and warrant further investigation. Our approach does offer an empirical money metric of time savings based on an ongoing program in Haryana and India at large. Thus, it is based on a documented rural wage rate.

We assume universal adoption of the cleaner cooking technology in Haryana for the main scenarios described in this chapter. This assumption is highly optimistic because older, more polluting stoves are often not abandoned immediately when a cleaner one of any kind is adopted; studies have shown that even the best modern biomass stoves often do not perform well over time in reducing pollution exposures. However, LPG is essentially always clean. We bound our chimney stove scenario by assuming that it breaks down after one year and is not rebuilt, which has often occurred with the inexpensive models widely deployed in India. An alternative approach would be to build in regular replacement of these stoves, or perhaps to move to the much more expensive and robust chimney stoves that have been successfully used in other countries and subregions. For example, in China and Mexico and in Central America, chimney stoves that function for a decade or more are not uncommon, but costs are at least 15 times greater.

Because of the need to purchase fuel, the financial conditions of the biomass and LPG scenarios are fundamentally different, but we attempt to explore them here in the same analysis. In doing so, we evaluated the current LPG subsidy system as a given and took only the extra costs of LPG connections in the GIU campaign as the cost of the LPG expansion, thereby assuming that the shift of subsidy from the middle class to the poor did not itself incur any change in government expenditures; that is, there were no transactional costs to the government. The framing in a different country without any current LPG subsidy, however, might be quite different. Although the funds for connections currently come from the required social responsibility funds of the national oil companies, we assign these as government expenditures because they could have been used for other purposes. Finally, in the absence of information, we assumed no operational costs to the government to design, promote, manage, and evaluate the large-scale disseminations that would be needed in all three scenarios.

Solid fuel–using households in upper income quintiles (Q3, Q4, and Q5) absorb a significant fuel costs in our modeled LPG intervention, as they move from no LPG to full-price LPG. The large number of solid fuel–using households in the wealthier income quintiles suggests that future subsidies and LPG-promoting programs may wish to address these households using a sliding subsidy, as suggested by Tripathi, Sagar, and Smith (2015). Ongoing LPG programs in India do not currently have a provision to target these households.

Future analyses of this type should investigate alternate methods of apportioning underlying data from national data to state-level data and into disease quintiles. Furthermore, although partitioning by SFU is reasonable in our example, it may mask behavioral patterns related to solid fuel use that we did not anticipate and differences between quintiles that impact disease distributions.

Beyond methodological and data limitations, we assume the status quo remains constant with respect to international LPG prices and related subsidies. This assumption ensures analytic tractability, but it may not hold, given the volatility in oil prices globally. India is undergoing a rapid, policy-driven transformation that is dramatically increasing access to LPG for communities previously reliant on solid fuels. Although these ongoing changes may alter the calculus behind the results, they highlight the need for being able to perform multifaceted analyses that consider more than simply basic cost-effectiveness to estimate the potential effects of large programs—precisely the type of evaluation facilitated by ECEA.

CONCLUSIONS

Exposure to HAP from solid cookfuel, mainly as biomass, causes an estimated 925,000 deaths yearly in India today. The number of people most affected—700 million to 800 million—has not declined in 30 years, despite considerable economic development and the growth of clean fuel use for the middle class. Other approaches are clearly needed to address this health hazard.

Three types of national policies have been initiated to address the health, social, and environmental effects of inefficient household biomass use. In the 1980s and 1990s, households relied on inexpensive stoves made locally with simple materials but without much improvement in smoke emissions, although often including a chimney. Around 2010, a new program was initiated that promised to develop and promote biomass stoves that produced far less pollution emissions, but usually this program did not incorporate chimneys. Starting in 2014, the national GIU campaign began to greatly expand access to a clean modern fuel, LPG, for BPL families by using innovative financing and promotional modalities. Newer initiatives—including the Smokeless Village program and the recently announced Ujjwala program—continue this trend of making clean cooking available widely across India. This chapter has evaluated each of the approaches separately for their cost-effectiveness in hypothetical deployments in the same northern Indian state, Haryana. We believe these types of modeling exercises are instructive and help target further, field-based studies evaluating the effect of programs.

Lowering household exposures to air pollution can decrease both health and financial burdens not only by reducing medical costs, but also by averting household expenditures or avoiding lost wage earnings. The scale of the reduction—and the amount of disease burden left untouched by each of them—varies widely among the three intervention options, however, although cost-effectiveness varies less widely. More modest reductions from chimney stoves, for example, are to some extent matched by more modest costs.

The innovative policy of Ujjwala, extending out of the GIU campaign, starts by retargeting existing LPG subsidies away from the middle class to the poor. This approach can result in highly cost-effective health improvements in the poorest quintiles of the population. It is accompanied by some shift of costs to the middle class, but, notably, by their agreement and without a net increase in government expenditures. By being the cleanest of the options examined, LPG also has the potential to achieve the greatest health benefits. Compared to the other two fuels, LPG also benefits from a familiar long-lived cooking technology that has a well-established repair and refill system in place in the region, although it requires reliable extension to additional populations.

To be effective, however, any intervention program must focus not only on providing access to the intervention but also on enhancing use over the long term, including continuing to pay for subsidized fuel and repair and replacement of the stoves. Only when use of the traditional polluting biomass stoves is greatly reduced over time and replaced by LPG or another equally clean alternative will full health benefits be secured.

ANNEX

The annex to this chapter is as follows. It is available at http://www.dcp-3.org/environment.

- Annex 12A. Supporting Information

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NOTES

World Bank Income Classifications as of July 2014 are as follows, based on estimates of gross national income (GNI) per capita for 2013:

- Low-income countries (LICs) = US$1,045 or less
- Middle-income countries (MICs) are subdivided:
  a) lower-middle-income = US$1,046 to US$4,125
  b) upper-middle-income (UMICs) = US$4,126 to US$12,745
- High-income countries (HICs) = US$12,746 or more.

1. We use the DALY that was first widely deployed in the GBD 2010. It is not adjusted by age weighting or discounting. It cannot be directly compared to previous versions that did so.
2. Policy measures to increase access to LPG among the rural poor in India are advancing rapidly. The programs mentioned in this chapter are up to date as of July 2016.
3. Our analysis does not include any assessment of outdoor air pollution and the reduction in emissions from the household sector, which account for an estimated 25–50 percent of ambient small particle exposures in India (Chafe and others 2014; Lelieveld and others 2015).
4. We use IHDS questions about cough and fever in the past month as a proxy for ALRI. The total number of households reporting this proxy for ALRI per quintile is multiplied by 12 to obtain the number of cases per quintile per year and then divided by the total number

of households in the quintile to determine the number of cases per household per year. The per case cost estimate is multiplied by the number of cases per household by quintile to determine the yearly cost.

5. See http://www.haryanarural.gov.in/guidelines/MGNREGS/1025MGNREGS_wage_notification_2015_16.pdf.
6. See http://www.haryanarural.gov.in/detail-nrega.htm#bnote.

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