BENEFIT-COST ANALYSIS

# INDOOR AIR POLLUTION

## Benefits and Costs of Household Air Pollution Control Interventions in RAJASTHAN


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RAJASTHAN PRIORITIES
AN INDIA CONSENSUS PRIORITIZATION PROJECT

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# Academic Abstract

This paper evaluates the benefits and costs of three interventions affecting household air pollution caused by the use of solid fuels for cooking. Benefits and costs are presented as a ratio of annualized benefits and annualized costs (benefit-cost ratios) over the expected useful life of each intervention.

Benefit-cost ratios (BCRs) are found to be the largest for promotion of improved biomass cookstoves (5.5-10.3) followed by free provison of LPG connection to poor households (2.8-4.9). A 50% reduction of subsidies to LPG fuel has a BCR of less than one (0.4-0.6).

These BCRs reflect health effects of the interventions estimated using a value of statistical life (VSL) for averted deaths as a high bound and years of life lost (YLL) to premature mortality valued at 3 times GDP per capita as a low bound. Avoided illness is valued at 3 times GDP capita per "year lived with disability" (YLD). Monetary values of time savings are estimated at 50% of wage rates. Discount rates are in the range of 3-8%. BCRs with averted years of life lost to premature mortality (YLL) valued at 3 times GDP per capita is about one-third lower (or higher in the case of LPG subsidy reduction) than BCRs with premature mortality valued using VSL. The quality of evidence associated with the estimated benefits and costs of the interventions range from "medium" to "medium-strong".

While the BCRs for promotion of improved biomass cookstoves are more than twice as large as for free provison of LPG connection for poor households, the health benefits of an improved cookstove is roughly half of the health benefits of using LPG as primary cooking fuel. Thus in order to make a substantial dent in the huge health effects of solid fuels used for cooking in Rajasthan, predominant and sustained use of LPG or other clean cooking solutions need to be achieved. However, improved biomass cookstoves can serve as an intermediate arrangement.

An important dimension is also that the use of solid biomass cooking fuels by one household affects surrounding households. Smoke is vented out of one household for so to enter the dwellings of others and also pollute the ambient outdoor air. There are therefore benefits from stove promotion programs being community focused with the aim of achieving

“unimproved stove free” and eventually “solid biomass free” communities along the lines of community lead sanitation programs and “open defecation free” communities.

# Policy Abstract

## The Problem

Nearly 2.6 million people died globally in 2016 from harmful exposure to PM2.5 emissions from household use of solid fuels such as wood, coal, charcoal, and agricultural residues for cooking according to estimates by the Global Burden of Disease 2016 (GBD 2016) Project. This makes household air pollution (HAP) one of the leading health risk factors in developing countries.

About 65,000 people died from HAP in Rajasthan in 2016 according to GBD 2016 and estimate in this paper.

About 68% of the population in Rajasthan relied on solid fuels for cooking in 2015-16 according to the National Family Health Survey IV (IIPS, 2017) compared to about 40% globally. While 20% of urban households used solid fuels, as many as 85% of rural households did so.

About 32% of households used modern cooking fuels in 2015-16 (IIPS, 2017), mainly LPG, up from about 21% in 2005-06 (IIPS, 2008), with substantial growth both in urban and rural areas.

Very few of the households using solid fuels in Rajastahn have adopted improved biomass cookstoves with more efficient, cleaner burning and less pollution (Nielsen India, 2016). Judging from exposure studies in India and around the world, household members' average exposures to PM2.5 may be on the order of 100-200 $\mu g/m^3$ among households cooking with solid biomass fuels, depending on cooking location in the household environment (Larsen, 2017). These exposure levels are 5-20 times the WHO's outdoor annual air quality guideline (AQG) of 10 µg/m3, and cause serious health effects including heart disease, stroke, lung cancer and respiratory diseases.

Three interventions are evaluated in this paper in terms of their benefits and costs:

1) Promotion of improved biomass cookstoves.
2) Free provison of LPG connection to poor households.

3) A 50% reduction of subsidies to LPG fuel.

Benefits and costs are presented as a ratio of annualized benefits and annualized costs (benefit-cost ratios (BCRs)) over the expected useful life of each intervention.

It should be noted that a comparison of benefits and costs of these three interventions does not imply that the interventions are mutually exclusive. However, a ranking of the interventions in terms of high to low benefit-cost ratios (BCRs) provide valuable information as to setting priorities when facing limited resources.

## Intervention 1: Improved biomass cookstoves

### Overview

Improved biomass cookstoves are designed to be more energy efficient and to generate less smoke than traditional cookstoves or cooking over open fire. Such stoves therefore have the potential to reduce harmful PM2.5 emissions over the life to the stove.

### Implementation Considerations

The success of improved cookstove promotion programs – i.e., high household adoption rates, sustained use of the cookstoves, and proper functioning of the stoves - depend on factors such as household acceptability of the characteristics of the stoves being promoted, stove financing arrangements, household perceptions of benefits of the cookstoves, and program follow-up in terms of monitoring and promotion of sustained use of the stoves as well as proper stove maintenance and repair.

### Costs and Benefits

Costs and benefits are estimated based on an assumed household intervention adoption rate of 30% and a sustained user rate of 65%.

#### Costs

Costs include initial cost of stove, cost of stove maintenance over its useful life, and program promotion cost.

#### Benefits

The quantified benefits of the intervention are the value of health improvements, time savings from reduced biomass fuel collection and preparation (or biomass fuel purchases) resulting from the higher energy efficiency of the stoves, reduced cooking time resulting from the improved cookstove, and reduced $CO_2$ emissions.

## Intervention 2: Free provision of LPG connections to poor households

### Overview

One impediment to adoption of LPG for cooking is the initial cost of LPG cylinders and auxiliary equipment. A government program therefore provides LPG connection equipment to households below the poverty line (BPL) free of charge in order to encourage households to switch from solid fuels to LPG.

### Implementation Considerations

LPG connection equipment can often be a major obstacle for households to adopt LPG for cooking. However, the cost of an LPG stove with multiple burners is as high as and the cost of LPG fuel per year is several times higher than the connection equipment cost.

### Costs and Benefits

Cost and benefits are estimated based on the assumption that 35% of households receiving the intervention will adopt LPG as primary cooking fuel.

#### Costs

The main household cost of using LPG for cooking is the cost of LPG fuel. This is followed by the LPG stove and connection equipment (latter provided for free by the government program). Stove maintenance cost is a minor outlay compared to the other costs.

#### Benefits

The quantified benefits of the intervention are the value of health improvements, time savings from reduced biomass fuel collection and preparation (or biomass fuel purchases), reduced cooking time resulting from the LPG cookstove, and reduced net $CO_2$ emissions.

## Intervention 3: 50% reduction of subsidies to LPG fuel

### Overview

LPG fuel retail prices in India are substantially below the market price, as determined by world prices and transportation and distribution cost. LPG retail prices have been increased in the past year, but so has world prices of LPG. The subsidy therefore amounted to about 25% of market price or non-subsidized price as of April 2018.[1]

### Implementation Considerations

Retail price subsidies to LPG have implications for government finances. Reduction of subsidies have, however, negative implications especially for poorer households. An implementation consideration is therefore to identify designs that protect poorer households while allowing better off households pay market prices.

### Costs and Benefits

#### Costs

Costs of LPG subsidy reduction are many. Some households will switch back to cooking with solid fuels and thus face the health effects of these fuels as well as sustain increased use of time from biomass fuel collection and cooking. Net $CO_2$ emissios will also increase. These households will also need to purchase a biomass stove.

#### Benefits

The main benefit of a subsidy reduction is LPG fuel cost savings among households that no longer will cook with LPG. A second benefit is the welfare gain (or reduced "deadweight loss") from a supply and demand for LPG fuel at retail prices closer to market prices.

## BCR Table

Benefit-cost ratios (BCRs) are found to be the largest for promotion of improved biomass cookstoves, followed by free provision of LPG connection to poor households. A 50% reduction of subsidies to LPG fuel has a BCR of less than one.

The quality of evidence associated with the estimated benefits and costs of the interventions range from "medium" to "medium-strong".

Table 1. Summary of the benefits and costs and interventions (Rs million annualized)

| | Interventions | Benefit | Cost | BCR | Quality of Evidence |
|---|---|---|---|---|---|
| 1 | Promotion of improved biomass cookstoves | 29,385 | 3,041 | 9.7 | Medium |
| 2 | Free provision of LPG connection to poor households | 68,566 | 14,499 | 4.7 | Medium-Strong |
| 3 | 50% reduction of subsidies to LPG fuel | 9,963 | 24,142 | 0.41 | Medium-Strong |

Notes: All figures assume a 5% discount rate, and use VSL for valuation of mortality benefits and YLD at 3 times GDP per capita for valuation of morbidity benefits. BCRs using YLL at 3 times GDP per capita for valuation of mortality are +/- 1/3rd of the ones presented here Source: Author.

The BCRs for improved biomass cookstoves estimated in this paper represent "potentials", and depend on the quality, intensity and duration of promotion programs. BCRs also depend very much on pre-intervention PM2.5 personal exposure levels, and the magnitude of PM2.5 reductions achieved by the interventions. This is influenced by multiple factors, such as characteristics of dwellings, cooking location, cooking practices, and activity patterns of household members. These factors can be positively modified by stove promotion programs to enhance the benefits of cleaner cookstoves.

Post-intervention PM2.5 exposure levels are also influenced by the condition of improved cookstoves. Promotion programs need therefore demonstrate and encourage proper use, maintenance and repairs of stoves.

The use of solid biomass cooking fuels by one household affects surrounding households. Smoke is vented out of one household for so to enter the dwellings of others and also pollute the ambient outdoor air. There are therefore benefits from stove promotion programs being community focused with the aim of achieving "unimproved stove free" and eventually "solid biomass free" communities along the lines of community lead sanitation programs and "open defecation free" communities.

# 1. Introduction

## 1.1 Context and interventions

Nearly 2.6 million people died globally in 2016 from harmful exposure to PM2.5 emissions from household use of solid fuels such as wood, coal, charcoal, and agricultural residues for cooking according to estimates by the Global Burden of Disease 2016 (GBD 2016) Project. This makes household air pollution (HAP) one of the leading health risk factors in developing countries.

About 65,000 people died from HAP in Rajasthan in 2016 according to GBD 2016 and estimate in this paper.

Very few of the households using solid fuels in Rajastahn have adopted improved biomass cookstoves with more efficient, cleaner burning and less pollution (Nielsen India, 2016). Judging from exposure studies in India and around the world, household members' average exposures to PM2.5 may be on the order of 100-200 μg/m$^3$ among households cooking with solid biomass fuels, depending on cooking location in the household environment. These exposure levels are 5-20 times the WHO's outdoor annual air quality guideline (AQG) of 10 μg/m3, and cause serious health effects including heart disease, stroke, lung cancer and respiratory diseases.

Three interventions are evaluated in this paper in terms of their benefits and costs:

4) Promotion of improved biomass cookstoves.
5) Free provision of LPG connection to poor households.
6) A 50% reduction of subsidies to LPG fuel.

Benefits and costs are presented as a ratio of annualized benefits and annualized costs (benefit-cost ratios (BCRs)) over the expected useful life of each intervention.

It should be noted that a comparison of benefits and costs of these three interventions does not imply that the interventions are mutually exclusive. However, a ranking of the interventions in terms of high to low benefit-cost ratios (BCRs) provide valuable information as to setting priorities when facing limited resources.

## 1.2 Common data

Many of the data utilized in this paper are common to the three interventions. These data are discussed in this section.

Data on household primary fuels used for cooking, as well as household cooking locations are from the National Family Health Surveys (NFHS) 4 (2015-16) and NFHS 3 (2005-06) These surveys provide state level data for Rajasthan.

Intervention impacts are health effects of expected changes in air pollution and changes in cooking time and time spent on biomass fuel collection and preparation. The methodology for estimating health effects of the interventions are provided in Annex 1.

The baseline health data used for the estimation of health effects are from the Global Burden of Disease 2016 (GBD 2016) for the state of Rajasthan.[2]

Premature mortality is valued using two alternative methods:

(i) Value of statistical life (VSL) at 72 times GDP per capita in Rajasthan, based on methodology developed by the World Bank (2016);
(ii) Years of life lost (YLL) to premature mortality discounted at 3%, 5%, and 8% and valued at 3 times GDP per capita in Rajasthan.

Morbidity or illness is expressed as years lived with disability (YLDs). YLD is years or fraction of a year with illness or injury multiplied by a disability weight. One YLD is valued at 3 times GDP per capita in Rajasthan.

Changes in time required for cooking and biomass fuel collection and preparation is valued at 50% of average female wage rates. Average wage rate are estimated from GDP per capita and labor force participation rates in Rajasthan, and labor income share of GDP for India. Urban and rural wage differentials are estimated from wage differentials reported in the National Sample Survey 68 (NSS 68). Male/female wage differentials are estimated from the NSS 68 and the Labor and Employment Survey 2015-16.

The VSL, the value of YLL and YLD and the value of time over the lifetime of the interventions increase at the rate of projected GDP per capita.

Table 1.1 Basic data for Rajasthan

| | | |
|---|---|---|
| Population, 2017 | 77,124,923 | |
| GDP per capita, 2017 Rs | 95,284 | |
| VSL to GDP per capita ratio | 72 | Method in World Bank and IHME (2016) |
| VSL, 2017 Rs | 6,860,482 | Product of GDP per capita and VSL to GDP per capita ratio |
| Average daily wage rate, 2017 Rs | 469 | Based on GDP per capita in 2017 |
| Average daily wage rate, Urban, 2017 Rs | 738 | Based on urban/rural differentials reported in NSS 68 |
| Average daily wage rate, Rural, 2017 Rs | 369 | Based on urban/rural differentials reported in NSS 68 |

Costs of interventions are unique to each intervention and discussed in the intervention sections.

## 1.3 Literature review

A main literature utilized in this paper pertains to the assessment of health effects of interventions. The methodology for estimating health effects of the interventions are provided in Annex 1. The methodology is based on the Integrated-Exposure Response (IER) function developed by the GBD Project. The function provides relative risks (RR) of five major health outcomes in relation to long-term exposure to PM2.5 air pollution (Forouzanfar et al, 2016). This allows estimation of health effects from changes in PM2.5 exposure levels resulting from the interventions by applying the Potential Impact Fraction (PIF).

The RRs of health outcomes in relation to long-term PM2.5 exposure are based on global evidence. Sufficient research evidence of the magnitude of RRs in Rajasthan or even in India is not available. Thus estimated health effects are only an indication, rather than a precise estimate of the health effects one may expect from the interventions assessed in this paper

The magnitude of health effects of changes in PM2.5 exposure associated with the interventions is also influenced by the quality and access to public health services and medical care. These factors can influence case fatality rates and severity and duration of illness. However, this is reflected in the baseline health data used for estimating the health effects of interventions.

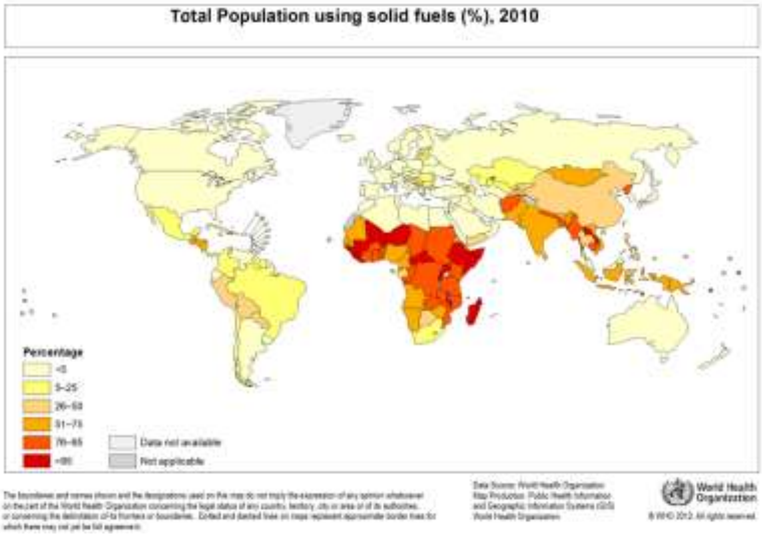
Literature pertaining to adoption and sustained use of improved cookstoves (ICS) is also reviewed, especially the experience of ICS promotion in India. This is discussed in the ICS intervention section.

# 2. Household biomass fuels and health effects

## 2.1 Household use of solid biomass fuels

As many as 41% of households globally relied mainly on solid fuels for cooking in 2010 (Bonjour et al, 2013). Prevalence rates of solid fuel use are particularly high in several countries in Asia and in Sub-Saharan Africa (figure 2.1).

Figure 2.1 Prevalence of solid fuel use, 2010




Source: Presented in Smith et al (2014).

About 68% of the population in Rajasthan relied on solid fuels for cooking in 2015-16 according to the National Family Health Survey IV (IIPS, 2017). While 20% of urban households used solid fuels, as many as 85% of rural households did so.

About 32% of households used modern cooking fuels in 2015-16, mainly LPG, up from about 21% in 2005-06, with substantial growth both in urban and rural areas.

Over two-thirds of households in Rajasthan cooked in their dwelling, 6% cooked in a separate building, and over one-quarter cooked outdoors according to the NFHS III 2005-06 (IIPS, 2008).

## 2.2 Household exposure to PM2.5

Air concentrations of PM2.5 from the use of solid biomass cooking fuels often reach several hundred micrograms per cubic meter (μg/m3) in the kitchen, and well over one hundred micrograms in the living and sleeping environments. These are findings from measurement studies around the world (WHO, 2014).

In households using solid cooking fuels in four states in India, PM2.5 concentrations (24 hours) averaged over 160 $\mu g/m^3$ in the living area and over 600 $\mu g/m^3$ in the kitchen (Balakrishnan et al, 2013). Type of fuel and kitchen, ventilation, geographical location and duration of cooking were found to be significant predictors of PM2.5 concentrations. These predictors were used by the authors to model 24-hours PM2.5 concentrations in kitchens among households that primarily used solid fuels for cooking in all states of India. Average rural and urban kitchen concentrations in Rajasthan were estimated at 532 and 514 $\mu g/m^3$, respectively, or about 20% higher than the nationwide average (Balakrishnan et al 2013).

However, personal exposure is the indicator of importance in terms of health effects of household PM2.5 and 24-hour personal exposures are lower than 24-hour kitchen concentrations. Balakrishnan et al (2012) estimate a nationwide long-term personal exposure in households using solid fuels in India of 338 µg/m3 among women, 285 µg/m3 among children, and 205 µg/m3 among men. This is based on the same study reported in Balakrishnan et al (2013).

Exposure of adult women is used as a reference point in this report for personal exposure in estimating the health effects of HAP, as well as the benefits and costs of interventions in the sections that follow in this report. This is because the person cooking in the household is most often a woman, and the exposure measurement studies are most often in reference to the person cooking using a traditional stove or open fire.

Exposures of adult men and young children are set at 60-85% of adult women's exposure (table 1.1). This is because adult men and young children generally spend less time in the household environment and/or the kitchen than adult women (Smith et al, 2014).

Cooking in the house is used as reference location. Personal exposures from cooking outdoors or in a separate building are set at 60-80% of exposure from cooking in the house (table 2.1). The exposure levels reflect that a portion of biomass smoke from outdoor cooking or cooking in a separate building enters the indoor living and sleeping areas.

Table 2.1. Relative exposure levels by household member and cooking location

| | | Household member (H) | | Location (L) |
|---|---|---|---|---|
| 1 | Adult women | 100% | In house | 100% |
| 2 | Adult men | 60% | Separate building | 80% |
| 3 | Children < 5 years | 85% | Outdoors | 60% |

Source: Estimates by the author.

An average exposure level of 200 μg/m$^3$ is applied to adult women cooking in the house with biomass over open fire or traditional cookstove. This level is lower than the exposure level concluded by Balakrishnan et al (2012). However, this level, with adjustments for men and children (see below), results in estimated annual health effects of household air pollution in Rajasthan that is almost identical to the magnitude of health effects reported by the GBD 2016.[3]

Average exposure levels of adult men and children under five years of age, and in various cooking locations are calculated in relation to the exposure level of adult women cooking in the house by applying the relative exposure factors in table 2.1. So for instance, the exposure level of adult men in a household cooking outdoors with biomass fuels is 200 μg/m$^3$ * H2 * L3 = 200 μg/m$^3$ * 60% * 60% = 72 μg/m$^3$ (table 2.2).

Table 2.2. Long term personal PM2.5 exposure by cooking location in households using traditional biomass cookstoves (μg/m$^3$)

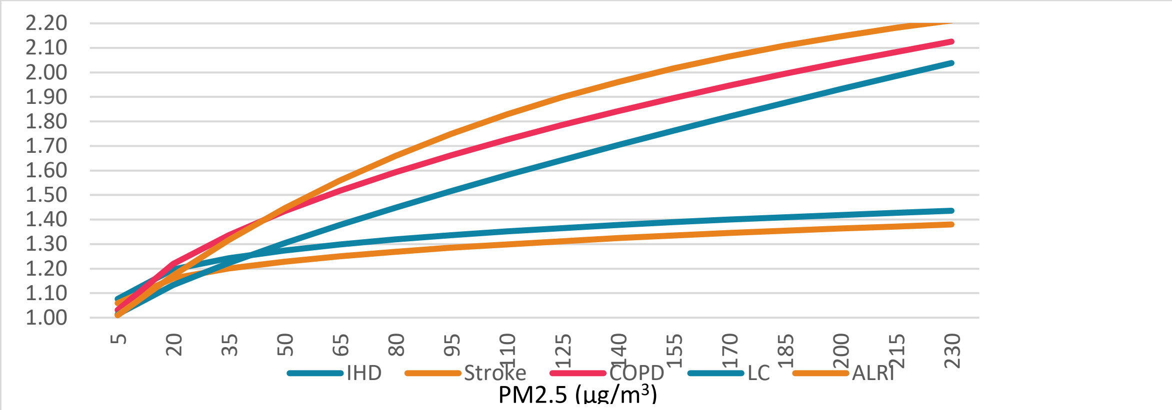
| | Adult women | Adult men | Children < 5 years |
|---|---|---|---|
| In house | 200 | 120 | 170 |
| Separate building | 160 | 96 | 136 |
| Outdoors | 120 | 72 | 102 |

Source: Estimates by the author.

## 2.3 Health effects and cost of household PM2.5

Health effects of long term exposure to PM2.5 in the household environment from the burning of solid fuels include: (i) ischemic heart disease (IHD), (ii) cerebrovascular disease (stroke), (iii) lung cancer (LC), and (iv) chronic obstructive pulmonary disease (COPD) among adult women and men, and (v) acute lower respiratory infections (ALRI) among children and adult women and men. These are all major health effects evidenced by the Global Burden of Disease (GBD) Project (Forouzanfar et al, 2016), and figure 2.2 shows how the risk of these five health effects in terms of mortality increases with increasing levels of PM2.5 exposure.

Figure 2.2. Relative risk of mortality from long term PM2.5 exposure




Note: Age-weighted relative risks. Source: Produced from Forouzanfar et al (2016).

The solid fuel use prevalence rates, PM2.5 exposure levels, and the relative risks of health effects are combined to estimate the health effects of household PM2.5 air pollution from the use of solid fuels. The results show that 18-20% of all IHD and stroke, and 30-40% of all COPD, lung cancer, and ALRI in Rajasthan are from household PM2.5 air pollution.[4] The attributable percentages translate to annual deaths of 65,214 in 2017 (table 2.3).

Table 2.3. Estimated morality attributable to PM2.5 household air pollution in Rajasthan, 2017

| | % of total cause-specific mortality | Annual cases of deaths |
|---|---|---|
| Ischemic heart disease (IHD) | 20% | 14,332 |
| Cerebrovascular disease (stroke) | 18% | 4,365 |
| COPD | 36% | 29,920 |
| Lung cancer | 30% | 1,001 |
| ALRI | 40% | 15,595 |
| **Total** | | **65,214** |

Source: Estimates by the author.

The health effects of HAP can be monetized as a cost to society by using economic valuation methods. In the Rajasthan Priorities Project, the Copenhagen Consensus Center (CCC) applies a value per "disability adjusted life year" (DALY) of 3 times GDP per capita, with DALYs discounted at an annual rate of 3, 5, and 8%. The discounting of DALYs reflects that a death that occurs or is avoided today represents years of life well into the future. Thus the discounting provides the "present value" or the value of these years today.

The midpoint annual cost of PM2.5 household air pollution in Rajasthan is estimated at Rs. 252 billion, equivalent to 3.4% of GDP. The range of cost is Rs. 209-291 billion, equivalent to 2.8 – 4.0% of GDP (table 2.4).

For comparison, World Bank (2016b) proposes the use of "value of statistical life" or VSL for valuation of the welfare cost of premature mortality. This implies an annual cost of Rs. 482 billion, equivalent to 6.6% of GDP.[5] This includes the cost of illness with YLDs valued at 3 tiems GDP per capita.

Table 2.4. Annual cost of PM2.5 household air pollution in Rajasthan, 2017

| Discount rate | DALY=3*GDP/capita (Rs Billion) | DALY=3*GDP/capita (% of GDP) |
|---|---|---|
| 3% | 291 | 4.0% |
| 5% | 252 | 3.4% |
| 8% | 209 | 2.8% |

Source: Estimates by the author.

# 3. Interventions and exposure effects

## 3.1 Interventions

The objective of this paper is to assess benefits and costs of interventions that affect household PM2.5 air pollution from the use of solid fuels for cooking. Specifically, the interventions are promotion program for household adoption and sustained use of improved biomass cookstoves (ICS), free provision of LPG connection to poor households, and a 50% reduction of LPG fuel subsidies. The first two interventions are expected to reduce air pollution while the last intervention is expected to increase air pollution as households will reduce LPG consumption and increase the use of solid fuels.

The interventions are assessed with respect to:

(1) Health benefits of reduced PM2.5 exposure;
(2) Non-health benefits (i.e., fuel savings and cooking time savings);
(3) Stove and fuel costs of interventions;
(4) Stove promotion programs and stove maintenance; and
(5) Comparison of benefits and costs of interventions (i.e., benefit-cost ratios).

Each of the interventions is assessed in three cooking locations:

(1) Cooking in the house;
(2) Cooking in a separate building; and

(3) Cooking outdoors.

Household use of solid fuels has community effects. Smoke from fuel burning enters dwellings of other households as well as contributes to outdoor ambient air pollution. An improved stove with chimney, or simply venting of smoke through a hood from any stove or open fire, may be effective for the household installing these devices, but contributes to increased outdoor ambient pollution and indoor pollution in nearby dwellings. Only "smokeless" fuels and technologies prevent this problem of externalities.

To achieve the maximum benefits per unit of expenditure on household energy and stove interventions, all households would need to participate, and thus achieve a "solid fuel free" community or, alternatively, an "unimproved stove free" community. This concept may be applicable to rural areas where communities consist of a cluster of households and each community is spatially separated from one another, and is similar to an "open defecation free" community in the sanitation sector, often promoted and achieved through community-lead or total sanitation programs.

## 3.2 Post-intervention PM2.5 exposures

The use of improved cookstoves (ICS) for biomass fuel or LPG stoves is expected to reduce household members' exposure to PM2.5 from cooking. Review of personal exposure studies before and after installation of an ICS indicates a median reduction in exposure of greater than 50% (Larsen, 2017). However, studies of exposure reductions are most often measured within relatively short time after the installation of the ICS. Exposure reductions over the life of the ICS is likely to be somewhat less as the quality of the ICS deteriorates over time.

A 40% exposure reduction from an ICS over its lifetime is therefore likely to be more realistic even with good stove maintenance and is applied here to households cooking in the house.[6] Exposure reductions from an ICS for households cooking in a separate building or outdoors may be less than for households cooking in the house. This is because the relative contribution to exposure from pollution originating from other households cooking with solid fuels in the community is larger for households cooking in a separate building or outdoors than for households cooking in the house. Thus exposure reductions of 35% and 25% are applied to households cooking in a separate building and outdoors, respectively.[7]

Table 3.1 summarizes the exposure reductions from ICS. The reductions are relative to the exposure levels using traditional cookstoves (TCS) presented in table 2.2, and are applied to adult women, men and children.

**Table 3.1. Household member exposure reduction from ICS in relation to cooking location**

| | |
|---|---|
| In house | 40% |
| Separate building | 35% |
| Outdoors | 25% |

Source: The author.

Combustion of LPG results in very little PM emissions and is therefore considered relatively clean cooking fuels. Studies have however found that household PM2.5 concentrations among users of LPG often remain as high as 40-60 μg/m$^3$, presumably mainly due to the community pollution from neighboring households using solid fuels. It is therefore stipulated here that exposure levels associated with cooking with LPG are on average 50 μg/m$^3$. This exposure level is applied to adult women and children, and is independent of cooking location. A somewhat lower exposure level of 35 μg/m$^3$ is applied to adult men, as this household member group often spends considerable time away from the immediate community, and presumably in locations with less pollution.

Personal exposure levels in households using LPG may decline to levels below 50 μg/m$^3$. Joon et al (2011) found a 24-hour average PM2.5 exposure for the cook of 25 μg/m$^3$ among rural households using LPG in Haryana, India. Titcombe and Simcik (2011) measured an average PM2.5 personal exposure of 14 μg/m$^3$ in households in the southern highlands of Tanzania cooking indoors with LPG.

Pre- and post-intervention levels of personal exposure to PM2.5 are presented in table 3.2 and reflect the exposure reductions from ICS and levels associated with LPG discussed above. The exposure levels are broad averages and will vary substantially across individual households.

Table 3.2. Household member air pollution exposure by intervention and cooking location (μg/m$^3$)

| | Pre-Intervention | Post-Intervention | |
|---|---|---|---|
| | TCS -Biomass | ICS - Biomass | LPG |
| **Adult female** | | | |
| Outdoors | 120 | 90 | 50 |
| Separate building | 160 | 104 | 50 |
| In house | 200 | 120 | 50 |
| **Adult male** | | | |
| Outdoors | 72 | 54 | 35 |
| Separate building | 96 | 62 | 35 |
| In house | 120 | 72 | 35 |
| **Children** | | | |
| Outdoors | 102 | 77 | 50 |
| Separate building | 136 | 88 | 50 |
| In house | 170 | 102 | 50 |

Note: TCS = Traditional cookstove (open fire or unimproved stove); ICS = Improved Cookstove; LPG = Liquefied Petroleum Gas. Source: The author.

## 3.3 Net carbon emissions

Fuel consumption of 1650 kg per household per year for households cooking with biomass and a traditional cookstove (TCS), and 150 kg per household per year for households cooking with LPG, is applied to estimate the effect of interventions on $CO_2$ emissions.

Biomass fuel consumption is based on Nielsen India (2016), and the relationship between biomass and LPG consumption is calculated based on an energy content of 15 MJ/kg and 45.2 MJ/kg for biomass (fuelwood) and LPG respectively, and stove efficiency of 15% and 55% respectively. This gives an effective energy per kg of LPG that is 11 times higher than per kg of fuelwood. Thus a household would need 11 times more fuelwood (1650 kg) than LPG (150 kg).

Based on the carbon content of the fuels, $CO_2$ emissions from a household using fuelwood and TCS are 3.025 tons per year, and 0.451 tons from a household using LPG. However, most of the fuelwood or biomass supply is renewable and thus biomass regrowth absorbs most of the $CO_2$ emissions. With an assumption that 25% is non-renewable biomass (Singh et al, 2017; Bailis et al, 2015), net $CO_2$ emissions from biomass fuel with TCS is 0.756 tons per household per year (table 3.3).

Table 3.3. $CO_2$ emissions per household per year

| | TCS (wood) | LPG | |
|---|---|---|---|
| Fuel consumption | 1,650 | 150 | Kg per household per year |
| Carbon content | 50% | 82% | |
| Carbon | 825 | 123 | Kg per household per year |
| Gross $CO_2$ emissions | 3.025 | 0.451 | Tons per household per year |
| Net $CO_2$ emissions | 0.756 | 0.451 | Tons per household per year |

Net $CO_2$ intervention savings are presented in table 3.4. Savings are 0.3 tons per household per year an improved biomass cookstove (ICS) such as a Rocket stove (2b – 2a), as result of 40% fuelwood savings from using ICS. Savings are also 0.3 tons for households taking advantage of a free LPG connection and start using LPG instead of a TCS (2c – 2a). LPG subsidy reduction results in a negative net saving (increase) of 0.154 tons per household per year for households switching from LPG back to biomass or fuelwood.

Applying a social price of carbon of US$ 25.3 (3% discount rate), US$ 7.6 (5% discount rate), and US$ 0 (8% discount rate) per ton of $CO_2$ (Tol, 2011), carbon benefits per household per year are the range of Rs. 0-319 for ICS, Rs. 0-495 for free LPG connection, and negative Rs. 0-270 for LPG subsidiy reduction (table 3.4).

Table 3.4. $CO_2$ benefits of intervention

| | TCS (a) | ICS (b) | LPG connection (c) | LPG subsidy reduction (d) | |
|---|---|---|---|---|---|
| (1) Fuelwood savings | | 40% | | | Dalberg (2013) |
| (2) Net CO2 emissions | 0.756 | 0.454 | 0.451 | 0.451 | Tons per household per year |
| (3) Net CO2 intervention savings | | 0.303 | 0.305 | -0.154 | Tons per household per year |
| (4) Sustained use of intervention | | 65% | 100% | 100% | |
| **Carbon benefits (Rs/HH/year)** | | **319** | **495** | **-250** | 3% disount rate |
| | | **96** | **149** | **-75** | 5% disount rate |
| | | **0** | **0** | **0** | 8% disount rate |

# 4. Improved biomass cookstoves

## 4.1 Description of intervention

About 68% of households in Rajasthan used solid biomass fuels (mainly wood) in 2015 according to the NFHS IV 20015-16 (IIPS, 2017). The share in rural areas was 85% and 20% in urban areas.

A survey of over 6,000 households in 20 districts in the state found that practically no households had improved cookstoves (ICS) for biomass burning. All households that used biomass for cooking cooked over open fire/three stone fire or used traditional mudstoves of which a majority was fixed stoves in contrast to portable stoves (Nielsen India, 2016).

Thus the intervention is:

- A program promoting the adoption and sustained use of an improved biomass cookstove (ICS), such as a Rocket stove that burns biomass more efficiently and emits less harmful smoke, and that has two burners.

The intervention stove has two burners so as to minimize household use of their old stoves.

## 4.2 Literature Review

Many improved cookstove programs have suffered from low user rates, poor maintenance, and outright abandonment of the improved cookstove in favor of the old traditional stove. This is particularly the case with programs that are not demand driven, i.e., when stoves are distributed for free or at a highly subsidized rate and whether or not households want the stoves (Hanna et al, 2016).

The success of stove promotion programs – i.e., high household adoption rates, sustained use, proper maintenance and repair of the cookstove, and repeat adoption of an improved stove (or clean fuels) - will depend on factors such as household acceptability of the characteristics of the stoves being promoted, stove financing arrangements, household perceptions of benefits of the cookstoves, and program follow-up in terms of monitoring and promotion of sustained use of the stoves as well as proper stove maintenance and repair (Hanna et al, 2016; Miller and Mobarak, 2015; Mobarak et al, 2012).

Kar and Zerriffi (2015) present a theoretical framework for achieving successful stove promotion programs. The framework is based on "the claim that behavior change is not a discrete event but a process that unfolds over time through a series of six distinct stages." The stages are: i) pre-contemplation; ii) contemplation; iii) preparation; iv) action; v) maintenance; and vi) termination. For a stove promotion programs to be successful they must give due consideration to each of these stages. This includes well-designed behavioral change communication (BCC) strategies, overcoming obstacles to stove adoption (e.g., identify desirable stove technology and design, stove financing, warranty, stove satisfaction guarantees), stove servicing and maintenance follow-up.

Lewis et al (2015) reports the results of a piloting of improved cookstoves in eight villages across three states in India. The piloting tested various aspects of stove marketing related to (i) behavioral change communcation (BCC); (ii) type of stoves; (iii) purchase options (installment payment and stove return option) and rebates for prolonged use; and (iv) access and institutional delivery. All households in the village were given the opportunity to purchase a stove at or close to manufacturer's suggested retail price and interviews were conducted with a subset of households. Stove prices ranged from Rs. 900 to Rs. 2,700. Stove sales varied across villages from 0% to 60%. Sales reached 60% among randomly selected households in the village in which the most intensive marketing and BCC was undertaken and multiple stove options, installment plan, rebates for prolonged use and/or stove return option were offered. Sales were lowest in the villages in which only one type of stove was offered, full upfront payment was required, and rebates and/or stove return option were not offered. All monitored households continued to use their stove through the installment payment period (3-4 months).

The opportunity to assess the sustainability of use of improved cookstoves was limited in the study by Lewis et al. In contrast, Pillarisetti et al (2014) assessed the usage of an advanced cookstove (gasifier stove) in Haryana, India. The use of the stove declined by about 60% over a period of about 1 year, with usage falling fastest in first 100 days and stabilizing after about 225 days. The stove was distributed to households for free and was not demand driven, likely negatively affecting long-term usage. Also, the stove required that biomass fuel be chopped into small pieces, possibly affecting the attractiveness of the stove.

In a study in rural Guatemala of households that had adopted a chimney stove, the stoves were used 90% of the days over a monitoring period of 32 months (Ruiz-Mercado et al, 2013). Factors that contributed to the high usage rate included: i) high initial stove acceptance in the region; ii) familiarity of new users with the stove; iii) frequent follow-up by study/project personnel; and (iv) continued encouragement to use the stove.

The above discussion about success of stove promotion programs is highly relevant for the benefit-cost assessment in this paper. This is because benefits per unit of cost critically depend on stove adoption rates, long-term user rates, and sustained benefits of stoves (through proper maintenance and repairs). For a given promotion program, high adoption rate lowers the cost per household that adopts an improved stove. High long-term user rate and sustained benefits, once a household has acquired a stove, increases the total benefits of the program or benefits per household that acquired a stove.

In light of the above literature review, an initial stove adoption rate of 30%, and a long-term user rate of 65% of initial adoption is applied in the benefit-cost assessment in this paper. The adoption rate is the mid-point in Lewis et al. The long-term user rate is the mid-point of findings in Pillarisetti et al and Ruiz-Mercado et al.

## 4.3 Calculation of Costs and Benefits

### 4.3.1 Costs

Costs of improved cookstove promotion include initial cost of stove, stove maintenance (O&M) cost, and the cost of promotion program. The applied cost of the stove is Rs. 2,600 (or about US$ 40), at the high end of Rocket stoves such as Envirofit, Greenway and Prakti (Dalberg, 2013). Annual O&M is assumed to be 5% of stove cost, or Rs. 130 per year. Program cost is assumed to be Rs. 175 per targeted household. With an assumed stove adoption rate of 30%, this translates to Rs. 583 per household that adopts a stove.

Annualized cost per household is estimated at Rs. 985 (table 4.1) and total annualized cost of intervention is estimated at Rs. 3.0 billion (table 4.2) based on total intervention beneficiaries of 3.1 million households, i.e., households purchasing an ICS (see next section).

Table 4.1. Cost of intervention (Rs per household)

| | Initial cost | Annualized cost |
|---|---|---|
| Cost of stove | 2,600 | 698* |
| O&M (5% of stove cost per year) | | 130 |
| Promotion program cost | 583 | 157 |
| **Total annualized intervention cost** | | **985** |

Note: Annualized cost is calculated using a discount rate of 5%. * Useful life of stove is 4 years.

Table 4.2. Total annualized cost of intervention, Rs million

| | Total |
|---|---|
| Beneficiary households (000) | 3,087 |
| **Total annualized cost, Rs million** | **3,041** |

Note: Discount rate: 5%. Source: Estimates by author.

### 4.3.2 Benefits

#### Health benefits

Health benefits of moving from pre-intervention to post-intervention exposure levels associated with the improved cookstove (ICS) are estimated by using the integrated exposure-response (IER) methodology from the GBD 2015 Project presented in annex 1.

Estimated percentage reduction in health effects among beneficiary households is 22% if the households consistently use the ICS. This is nevertheless less than the anticipated 25-40% reduction in PM2.5 exposure (see table 3.1) due to the non-linearity of the IER functions (see figure 2.2). At a 65% long-term use rate the intervention is expected to avert 2,742 deaths and 5,041 YLDs per year (table 4.3).

Table 4.3. Health benefits of intervention

| | 100% use rate | 65% use rate |
|---|---|---|
| Averted deaths per year | 4,218 | 2,742 |
| Averted YLDs per year | 7,755 | 5,041 |

Source: Estimates by author.

Switching to an improved cookstove (ICS) also has non-health benefits. Main benefits are reduced biomass fuel consumption, whether self-collected or purchased, and reduced cooking time. The magnitude of these benefits will depend on current cooking arrangements, type of improved stove, household cooking patterns, cost of fuels, and household member valuation of time savings.

#### Fuel savings

Common energy conversion efficiencies for unimproved stoves, or cooking over open fire, are in the range of 13-18% for wood and 9-12% for agricultural resides and dung. Reported efficiencies of improved biomass cookstoves are 23-40% for wood and 15-19% for agricultural residues (Malla and Timilsina, 2014). This means that efficiency gains from using an improved stove instead of an unimproved stove or open fire generally exceed 25% and can be more than 100% depending on type of stoves, cooking practices and type of food cooked. Consequently, biomass fuel savings therefore generally exceed 20% and can be nearly 70% using wood.

Dalberg (2013) reports that a Rocket stove (i.e., the intervention stove in this report) provides fuel savings up to about 50%. It is here assumed that average fuel savings are 40%.

Many urban households in Rajasthan purchase some or all of the biomass fuels they use for cooking while the vast majority of rural households collects these fuels themselves (Nielsen India, 2016). It is important to impute a value of the self-collected fuels. A common approach is to impute a value based on the amount of time households spend on fuel collection and preparation.

Households in the state spend on average 23 hours per month on fuel collection and preparation (Nielsen India, 2016). However, time savings from reduction in fuel consumption is likely less than 40% because households may spend the same amount of time on reaching fuel collection locations. For instance, PAC (2014) finds 28% fuel savings from a variety of efficient and no so efficient ICS in South Asia, but only 18% reduction in collection and preparation time. Thus it is assumed here that time savings are 30%, or about 7 hours per month.

The value of time savings can be estimated based average female wages rates, and a value of time equal to 50% of the female wage rate. Thus the estimated annualized value of time savings from reduced fuel consumption is Rs. 1,753 per household per year over the life of the improved cookstove (at 5% discount rate) if the stove user rate is 100% and Rs. 1,139 is the user rate is 65%. A female wage rate is applied as most fuel collection and preparation is carried out by women.

For comparison, the value of fuel savings may be estimated based on the market price of fuelwood. The rural price is reported at Rs. 4.3 per kg in Nielsen India (2016). Average fuel consumption is 1,650 kg per household per year. Thus a 40% fuel saving is worth Rs. 2,838 per rural household per year. However, only a minority of rural households purchase some or all of their fuel. The time value of fuel savings, calculated above, is therefore used as benefit of ICS.

### Cooking time savings

Hutton et al (2006) report that it takes 11-14% less time to boil water with a Rocket stove (improved cookstove) than over open fire. Habermehl (2007) reports that monitoring studies have found that cooking time declined by 1.8 hours per day with the use of a Rocket Lorena stove. One-quarter of this time, or 27 minutes, is considered time savings by Habermehl, as the person cooking often engages in multiple household activities simultaneously. Jeuland and Pattanayak (2012) assume that an improved wood stove saves around 10 minutes per day. Garcia-Frapolli et al (2010) report that cooking time from using the improved Patsari chimney stove in Mexico declined by about 1 hour per household per day. Effectively 15-30 minutes of this time is saved. PAC (2014) reports an average cooking time saving of nearly 15% from the use of an improved biomass cookstove in South Asia.

Average cooking time in Rajasthan in a household using solid fuels and a traditional cookstove is 142 minutes per day (Nielsen India, 2016). This paper applies a cooking time saving of 15% from the use of an ICS, i.e., 21 minutes per day. As for fuel collection and preparation time savings, a value of time equal to 50% of female wage rates are applied to estimate the value of cooking time savings. Annualized value of time savings over the life of the improved cookstove (at 5% discount rate) is Rs. 2,706 per household per year if the stove user rate is 100% and Rs. 1,759 is the user rate is 65%.

### Total benefits

The total annualized value of benefits of the intervention is estimated at Rs. 17 – 30 billion, depending on method used for valuation of deaths averted, i.e., VSL or YLL at 3 times GDP per capita (YLDs are valued at 3 times GDP per capita). The estimate reflects a sustained ICS user rate of 65%. Annualized benefits per household, adjusted by the user rate, are Rs. 6,405 when averted deaths are valued using YLLs valued at 3 times GDP per capita, and Rs. 9,519 when averted deaths are valued using VSL. This includes $CO_2$ emisison benefits presented in section 3.3 (table 4.4).

Table 4.4. Value of benefits of intervention, Rs per household per year

| | VSL+YLD | YLL+YLD |
|---|---|---|
| Health benefits | 6,525 | 3,411 |
| Fuel collection time savings | 1,139 | 1,139 |
| Cooking time savings | 1,759 | 1,759 |
| $CO_2$ emission benefits | 96 | 96 |
| **Total benefits** | **9,519** | **6,405** |

Note: Discount rate: 5%. Source: Estimates by author.

### 4.3.3 Benefit-cost ratios

A comparison of benefits and costs, and benefit-cost ratios (BCRs) are presented in table 4.5, reflecting an ICS user rate of 65%. BCRs are in the range of 9.1-10.3 when averted deaths are valued using VSL and in the range of 5.5-7.5 when averted deaths are valued using YLL at 3 times GDP per capita.

Table 4.5 Benefits and costs of intervention, Rs million per year and BCRs

| | 3% discount rate | | | 5% discount rate | | | 8% discount rate | | |
|---|---|---|---|---|---|---|---|---|---|
| Valuation method | Benefit | Cost | **BCR** | Benefit | Cost | **BCR** | Benefit | Cost | **BCR** |
| VSL+YLD | 30,454 | 2,968 | 10.3 | 29,385 | 3,041 | 9.7 | 28,527 | 3,149 | 9.1 |
| YLL+YLD | 22,322 | 2,968 | 7.5 | 19,773 | 3,041 | 6.5 | 17,398 | 3,149 | 5.5 |

Source: Estimates by author.

## 4.4 Assessment of Quality of Evidence

The dimensions that most importantly affect the estimated benefits and costs of the intervention are presented in table 4.6. Quantified health benefits of the intervention are proportional to the baseline health data. These data are most likely of medium-strong quality. The relative risks (RR) of disease and mortality reductions are based on a large body of global research, but not specifically in Rajasthan. The value of statistical life (VSL) used for valuation of mortality benefits is from a benefit-transfer function developed by the World Bank (World Bank, 2016). The function is based on meta-analysis of VSL studies from mostly high- and medium-income countries and other available evidence of VSL by country income level. The rate of sustained use of the intervention has limited-medium evidence and has material impact on the BCRs. The time savings are based on medium evidence as studies from Rajasthan are limited.

Cost of intervention has medium-strong evidence.

Table 4.6. Quality of evidence

| | Quality of evidence |
|---|---|
| Baseline health data | Medium-Strong |
| Relative risks (RR) for health benefits | Medium-Strong |
| Valuation of mortality | Medium-Strong |
| Sustained user rate of intervention | Limited-Medium |
| Time savings | Medium |
| Cost of intervention | Medium-Strong |
| *Total evidence* | **Medium** |

Source: Author.

# 5. Free provison of LPG connection to poor households

## 5.1 Description of intervention

While over 80% of urban households use clean fuels (mainly LPG) for cooking, only 15% do so in rural areas according to the NFHS IV 2015-16 (IIPS, 2017). Nationwide 24% of rural households use clean cooking fuels. The rates of clean cooking fuel utilization are even lower among the poorer segments of the population.

The government has therefore implemented a program (Pradhan Mantri Ujjwala Yojana (PMUY) launched in 2016) that provides free LPG connections (LPG cylinder and auxiliary equipment) free of charge to households below the poverty line (BPL) to encourage these households to switch from solid fuels to LPG. The budgeted cost to the government is Rs. 1,600 per connection. The households can also get a loan from the oil marketing companies to cover the cost of an LPG stove.[8] A loan can also be obtained for the first LPG filling of the cylinder.[9]

The intervention assessed in this paper, in terms of benefits and costs, is therefore the free provision of LPG connection to poor households.

## 5.2 Intervention response rate

Studies of household adoption of improved cookstoves and clean fuels have identified upfront cost as a major obstacle (Lewis et al, 2015), as discussed under the ICS intervention.

Thus free provision of one of the cost components of cooking with LPG may be expected to induce some households to switch to LPG. However, the LPG stove is also an important cost component. An LPG stove with two burners costs about the same as the connection. Moreover, LPG fuel even at current subsidized prices in India costs several times more per year than the LPG connection.

Important questions are therefore to what extent free provision of LPG connection induces households to switch to LPG, how much of cooking will be done with LPG, and how sustained is the switch to LPG.

A survey undertaken by financial consulting firm Micro Save in 12 districts of Uttar Pradesh, India revealed that nearly all of the beneficiaries of the scheme switched to cooking with LPG as soon as the LPG cylinders were made available.[10]

However, a large number of LPG connection beneficiaries have not come back for refills in many states. The gap between the growth in LPG connections and LPG consumption in 2016-17 confirms the ground-based reporting of PMUY customers not buying refills.[11]

Moreover, a survey from Uttar Pradesh revealed that refilling LPG cylinder was done only four times in the past one year by some beneficiaries (approx. 1/3rd of total energy need for cooking). This was primarily because the beneficiary finds refilling too costly.[12]

Data on annual LPG consumption and LPG connections can shed some light on the adoption rate of LPG, or response rate, among BPL households resulting from free LPG connections. New connections increased by 32.2 million in 2016-17, of which 20 million were PMUY customers that received free connections.[13] Assuming that households with LPG connection in 2015-16 (prior to PMUY program), as well as the new non-PMUY connections in 2016-17, consumed the same amount of LPG (kg/household) in 2016-17 as they did in 2015-16 would imply that the new PMUY connections consumed on average about 55 kg of LPG per year (about 55% of average non-PMUY consumption per household per year). This is an average and one can expect that some households adopted LPG as their primary cooking fuel while others used LPG only for certain cooking needs (or even eventually abanonded the use of LPG).

Estimating the number of PMUY connections that adopt LPG as primary cooking fuel is of main interest because it is these households that will achieve the most substantial health benefits. Use of LPG for let's say only 20-25% of a household's cooking needs would be expected to result in only modest reductions in household members' PM2.5 exposure, and thus very modest health benefits.

Based on reported household consumption of biomass fuel in Rajasthan (Nielsen India, 2016) one can estimate that a household would need about 150 kg of LPG per year to meet its cooking energy needs if it were to use LPG as exclusive or primary cooking fuel. PMUY households that use LPG as a secondary fuel may on average consume 15-30 kg per year, or about one to two cylinders.

If one applies a range of 100-150 kg of LPG consumption for households that use LPG as primary cooking fuel, and a range of 15-30 kg for secondary users, one can estimate that around 21-48% of BPL households receiving free LPG connections adopt LPG as a primary cooking fuel. The mid-point of this range is 35% and is used as the household LPG adoption response rate to free LPG connections in this paper.

## 5.3 Calculation of Costs and Benefits

### 5.3.1 Costs

Costs associated with the intervention are the government provided LPG connection (cylinder and auxiliary equipment), as well as LPG stove, stove maintenance and repair (O&M), and LPG fuel.

The government budgeted cost of LPG connection is Rs. 1,600 per household. This implies an effective cost of Rs. 4,570 per household, assuming that 35% of the households adopt LPG as primary cooking fuel as previously discussed.

Households that receive free LPG connection will also purchase LPG stove. Cost of a two-burner LPG stove is also about Rs. 1,600.[14] However, only 35% of the households (LPG used as primary cooking fuel) will receive sustained and substantial benefits from LPG. Thus the effective cost is again Rs. 4,570 per household.

Annual O&M is assumed to be 5% of stove cost, or Rs. 80 per year. LPG fuel cost among households using LPG as primary fuel is estimated at about Rs. 7,077 per year based on a consumption of 150 kg per year and a price of Rs. 670 per bottle (14.2 kg). This was the average 10 months non-subsidized market price from August 1st 2017 to April 1st 2018 in major markets in India.[15] The market price, and not subsidized price, is used to estimate cost and benefits of interventions because both private and public costs shall be included in the assessment.

Annualized cost per household is estimated at Rs. 8,285 (table 5.1) and total annualized cost of intervention is estimated at Rs. 14.5 billion (table 5.2) based on total intervention beneficiaries of 1.75 million households, i.e., households adopting LPG as primary cooking fuel.

**Table 5.1. Cost of intervention (Rs per household)**

| | Initial cost | Effective cost | Annualized cost |
|---|---|---|---|
| Cost of connection | 1,600 | 4,570 | 564* |
| Cost of stove | 1,600 | 4,570 | 564* |
| O&M (5% of stove cost per year) | | | 80 |
| LPG fuel cost | | | 7,077 |
| **Total annualized intervention cost** | | | **8,285** |

Note: Annualized cost is calculated using a discount rate of 5%. * Useful life is 10 years.

**Table 5.2. Total annualized cost of intervention, Rs million**

| | Total |
|---|---|
| Beneficiary households (000) | 1,750 |
| **Total annualized cost, Rs million** | **14,499** |

Note: Discount rate: 5%. Source: Estimates by author.

### 5.3.2 Benefits

#### Health benefits

Health benefits of moving from pre-intervention to post-intervention exposure levels for intervention households that adopt LPG as primar cooking fuel are estimated by using the integrated exposure-response (IER) methodology from the GBD 2015 Project presented in annex 1.

Estimated percentage reduction in health effects among beneficiary households is 45% if the households consistently use LPG as primary fuel. This relatively low percentage reduction in health effects is due to the post-intervention PM2.5 exposure of 50 μg/m$^3$ among adult women and children and 35 μg/m$^3$ among adult men. These relatively high exposure levels are associated with air pollution from surrounding households that continue to use solid fuels for cooking, as well as from the use of solid fuels as secondary cooking fuels in the household that uses LPG as primary fuel.

The estimated reduction in health effects from the intervention amounts to 4,956 deaths averted and 9,112 YLDs per year (table 5.3).

**Table 5.3. Health benefits of intervention**

| | |
|---|---|
| Averted deaths per year | 4,956 |
| Averted YLDs per year | 9,112 |

Source: Estimates by author.

Switching to LPG also has non-health benefits. Main benefits are reduced biomass fuel consumption, whether self-collected or purchased, and reduced cooking time. The magnitude of these benefits will depend on current cooking arrangements, household cooking patterns, cost of fuels, and household member valuation of time savings.

### Fuel savings

Estimation of the value of solid fuel savings from switching to LPG as primary cooking fuel follows the method applied under the improved cookstove intervention.

Households in the state spend on average 23 hours per month on solid fuel collection and preparation (Nielsen India, 2016). The value of time savings associated with no longer having to undertake this activity can be estimated based female wages rate, and a value of time equal to 50% of the female wage rate. Thus the annualized value of time savings amount to Rs. 7,073 per household per year over the lifetime of the LPG stove (i.e., 10 years) at 5% discount rate. A female wage rate is applied as most fuel collection and preparation is carried out by women.

### Cooking time savings

PAC (2014) reports an average cooking time saving of nearly 30% from the use of an LPG stove in South Asia. Average cooking time in Rajasthan in a household using solid fuels and a traditional cookstove is 142 minutes per day (Nielsen India, 2016). Thus cooking time savings are estimated at 43 minutes per day. A value of time equal to 50% of female wage rates is applied to estimate the value of cooking time savings. Annualized value of time savings over the life of the improved cookstove (at 5% discount rate) is Rs. 6,551 per household per year.

### Total benefits

The total annualized value of benefits of the intervention is estimated at Rs. 42 – 70 billion, depending on method used for valuation of deaths averted, i.e., VSL or YLL at 3 times GDP per capita (YLDs are valued at 3 times GDP per capita). Annualized benefits per household that adopts LPG as primary cooking fuel are Rs. 26,937 when averted deaths are valued using YLLs valued at 3 times GDP per capita, and Rs. 39,180 when averted deaths are valued using VSL. This includes CO2 emisison benefits presented in section 3.3 (table 5.4).[16]

Table 5.4. Value of benefits of intervention, Rs per household per year

| | VSL+YLD | YLL+YLD |
|---|---|---|
| Health benefits | 25,408 | 13,165 |
| Fuel collection time savings | 7,073 | 7,073 |
| Cooking time savings | 6,551 | 6,551 |
| $CO_2$ emission benefits | 149 | 149 |
| **Total benefits** | **39,180** | **26,937** |

Note: Discount rate: 5%. Source: Estimates by author.

### 3.3.3 Benefit-cost ratios

A comparison of benefits and costs, and benefit-cost ratios (BCRs) are presented in table 5.5. BCRs are in the range of 4.5-4.9 when averted deaths are valued using VSL and in the range of 2.8-36 when averted deaths are valued using YLL at 3 times GDP per capita.

Table 5.5 Benefits and costs of intervention, Rs million per year and BCRs

| | 3% discount rate | | | 5% discount rate | | | 8% discount rate | | |
|---|---|---|---|---|---|---|---|---|---|
| Valuation method | Benefit | Cost | **BCR** | Benefit | Cost | **BCR** | Benefit | Cost | **BCR** |
| VSL+YLD | 70,231 | 14,347 | 4.9 | 68,566 | 14,499 | 4.7 | 66,748 | 14,733 | 4.5 |
| YLL+YLD | 52,278 | 14,347 | 3.6 | 47,140 | 14,499 | 3.3 | 41,778 | 14,733 | 2.8 |

Source: Estimates by author.

## 5.4 Assessment of Quality of Evidence

The dimensions that most importantly affect the estimated benefits and costs of the intervention are presented in table 5.6. Quantified health benefits of the intervention are proportional to the baseline health data. These data are most likely of medium-strong quality. The relative risks (RR) of disease and mortality reductions are based on a large body of global research, but not specifically in Rajasthan. The value of statistical life (VSL) used for valuation of mortality benefits is from a benefit-transfer function developed by the World Bank (World Bank, 2016). The function is based on meta-analysis of VSL studies from mostly high- and medium-income countries and other available evidence of VSL by country income level. The rate of sustained adoption of the intervention has limited-medium evidence but does not substantially affect the BCRs. The time savings are based on medium evidence as studies from Rajasthan are limited.

Cost of intervention has strong evidence.

Table 5.6. Quality of evidence

| | Quality of evidence |
|---|---|
| Baseline health data | Medium-Strong |
| Relative risks (RR) for health benefits | Medium-Strong |
| Valuation of mortality | Medium-Strong |
| Sustained adoption rate of intervention | Limited-Medium |
| Time savings | Medium |
| Cost of intervention | Strong |
| *Total evidence* | **Medium-Strong** |

Source: Author.

# 6. Reduction of subsidies to LPG fuel

## 6.1 Description of intervention

LPG fuel has long been subsidized or priced below market price in India. The government moved towards closing the gap by gradually increasing the subsidized price. As of August 1st 2017 the average subsidy in four major urban markets was reduced to less than 10% of non-subsidized market price. However, world prices of crude oil and LPG have since increased. As of April 1st 2018 the non-subsidized price of LPG had increased by 24% since August 1st 2017 while the subsidized price increased by 2%. Consequently the average subsidy in these four markets was 25% of non-subsidized market price. The subsidy rate peaked at about 33% during November 2017 to February 2018 when the non-subsidized price was highest.

Increasing the subsidized price of LPG to reduce or eliminate the LPG fuel subsidy is likely to make some households cut LPG consumption and increase the use of solid fuels for cooking. This entails negative health effects. On the other hand, subsidy reduction will reduce the resource allocation inefficiency that subsidies create, simplest measured by the so-called deadweight loss.

Subsidies also create budgetary burdens for the government and/or state enterprises. The government of India has implemented measures that seek to limit LPG fuel subsidies to richer households such as encouraging richer households to voluntarily give up the subsidies.

The intervention assessed in this paper is a 50% reduction of the LPG fuel subsidy.

## 6.2 Effects of subsidy reduction

A reduction in the LPG fuel subsidy raises the effective price of LPG paid by LPG consumers. Total LPG consumption is consequently expected to decline. The magnitude of decline in LPG consumption can be estimated by applying a household price elasticity of demand for LPG. A 50% reduction in LPG subsidies, with subsidies measured by the difference in non-subsidized and subsidized LPG price as of April 1st 2018,[17] is estimated to reduce total household demand for LPG by 15%. This is based on a constant price elasticity of demand of -1.0.[18]

For simplicity it is assumed here that the reduction in consumption of LPG reflects a 15% reduction in the number of households that use LPG as primary cooking fuel and that these households will switch to solid biomass fuels for cooking. This is equivalent to 15% of the approximately 32% of households in Rajasthan that used LPG as primary fuel for cooking in 2015-16, i.e., around 722 thousand households.

These households will experience a "large" increase in health effects due to switching back to biomass fuels. In reality, however, the reduction in LPG consumption from subsidy reduction is likely distributed across a much larger number of households that to a varying extent use LPG as primary cooking fuel and households that to a varying extent use LPG as secondary fuel. Most of these households will partially reduce their LPG consumption, rather than completely switch to solid fuels. Thus the total increase in health effects is associated with relatively "small" changes in risk and health effects among households that are distributed along the relative risk curve. If changes in PM2.5 exposure levels are proportional to changes in LPG and biomass fuels, then the simplistic assumption described above and used in this paper is likely to somewhat underestimate the increase in total health effects of LPG subsidy reduction. This is associated with the non-linearity of the relative risk functions in figure 2.2.

Households will also incur costs associated with the purchase of biomass fuel and/or self-collection and preparation of biomass fuel to substitute for the reduction in LPG consumption. Households will also experience an increase in cooking time from the increased use of biomass fuels. Some households will also incur the cost of purchasing a biomass stove to replace the LPG stove, although this is a minor cost.

In terms of benefits, households will save the cost of LPG fuel (valued at non-subsidized market price). There will also be a reduction in inefficiency of resource allocation that arises from subsidies. This is here approximated by linear estimation of deadweight loss (0.5 * change in quantity of LPG * change in price of LPG).

## 6.3 Calculation of Costs and Benefits

### 6.3.1 Costs

Annualized cost per household that switches from LPG back to biomass fuels associated with 50% reduction of subsidies to LPG fuel are presented in table 6.1, using two valuation methods for mortality.

The cost of increased health effects reflects an estimated increase in mortality of 1,589 deaths and 2,921 YLDs per year. This is based on an assumption that half of households switching from LPG to biomass fuels would purchase an improved biomass cookstove and half would purchase a traditional cookstove.

The costs associated with fuel collection and cookng time are identical to the benefits of the free LPG connection intervention, as the effects are the reverse of this intervention and the applied time horizon is 10 years.

Half of households that switch from LPG to fuelwood are assumed to buy a traditional stove with 3 years of useful life in years 1, 4, and 7 at a cost of Rs. 600 per stove, and half of households buy an improved cookstove with 4 years of useful life in years 1 and 5 at a cost of Rs. 2,600 per stove. Annualized cost of these purchases is included in table 6.1.

Cost of $CO_2$ emission increase is also included in table 6.1, as calculated in section 3.3.

The number of households switching back to biomass fuel is 722 thousand, as estimated in the previous section. Total annualized cost is therefore about Rs. 18-24 billion (table 6.2).

Table 6.1. Annualized cost of intervention (Rs per household)

| | VSL+YLD | YLL+YLD |
|---|---|---|
| Increased health effects | 19,749 | 10,233 |
| Biomass fuel collection time | 7,073 | 7,073 |
| Increased cooking time | 6,551 | 6,551 |
| Biomass stove | 389 | 389 |
| $CO_2$ emission increase | 75 | 75 |
| **Total annualized intervention cost** | **33,837** | **24,320** |

Note: Annualized cost is calculated using a discount rate of 5%.

Table 6.2. Total annualized cost of intervention, Rs million

| | VSL+YLD | YLL+YLD |
|---|---|---|
| Affected households (000) | 722 | 722 |
| **Total annualized cost, Rs million** | **24,422** | **17,554** |

Note: Discount rate: 5%. Source: Estimates by author.

### 6.3.2 Benefits

The benefits of LPG fuel subsidy reduction are LPG fuel savings and reduction in resource allocation inefficiency. The LPG fuel saving per affected household is the same as the LPG fuel cost in the previous intervention. The reduction in resource allocation inefficiency, or reduction in deadweight loss, amounts to Rs. 4.85 billion per year, or Rs. 6726 per affected household, and is estimated as discussed in the previous section. Total annual benefit of subsidy reduction is Rs. 9.96 billion (table 6.4).

Table 6.3. Annual benefit of intervention (Rs per household)

| | |
|---|---|
| LPG fuel savings | 7,077 |
| Reduction in deadweight loss (DWL) | 6,726 |
| **Total annual benefit** | **13,803** |

Source: Estimates by author.

Table 6.4. Total annualized cost of intervention, Rs million

| | |
|---|---|
| Affected households (000) | 722 |
| **Total annualized benefit, Rs million** | **9,963** |

Source: Estimates by author.

### 6.3.3 Benefit-cost ratios

A comparison of benefits and costs, and benefit-cost ratios (BCRs) are presented in table 6.5. BCRs are about 0.4 when averted deaths are valued using VSL and in the range of 0.5-0.6 when averted deaths are valued using YLL at 3 times GDP per capita. These estimates indicate that the benefits of 50% LPG fuel subsidy reduction are about half of the costs.

Table 6.5 Benefits and costs of intervention, Rs million per year and BCRs

| | 3% discount rate | | | 5% discount rate | | | 8% discount rate | | |
|---|---|---|---|---|---|---|---|---|---|
| Valuation method | Benefit | Cost | BCR | Benefit | Cost | BCR | Benefit | Cost | BCR |
| VSL+YLD | 9,963 | 24,900 | 0.40 | 9,963 | 24,422 | 0.41 | 9,963 | 23,852 | 0.42 |
| YLL+YLD | 9,963 | 19,144 | 0.52 | 9,963 | 17,554 | 0.57 | 9,963 | 15,848 | 0.63 |

Source: Estimates by author.

## 6.4 Assessment of Quality of Evidence

The dimensions that most importantly affect the estimated benefits and costs of the intervention are presented in table 6.6. Quantified health effects of the intervention are proportional to the baseline health data. These data are most likely of medium-strong quality. The relative risks (RR) of disease and mortality reductions are based on a large body of global research, but not specifically in Rajasthan. The value of statistical life (VSL) used for valuation of mortality benefits is from a benefit-transfer function developed by the World Bank (World Bank, 2016). The function is based on meta-analysis of VSL studies from mostly high- and medium-income countries and other available evidence of VSL by country income level. The price elasticity of demand for LPG has limited-medium evidence but does affect the BCRs (only total costs and total benefits). The time savings are based on medium evidence as studies from Rajasthan are limited.

Table 6.6. Quality of evidence

| | Quality of evidence |
|---|---|
| Baseline health data | Medium-Strong |
| Relative risks (RR) of health effects | Medium-Strong |
| Valuation of mortality | Medium-Strong |
| Price elasticity of demand for LPG | Limited-Medium |
| Cost of time use | Medium |
| *Total evidence* | **Medium-Strong** |

Source: Author.

# 7. Conclusion

This paper has evaluated the benefits and costs of three interventions that influence household air pollution from the use of solid fuels for cooking. The benefit-cost ratios (BCRs) are found to be the largest for promotion of improved biomass cookstoves, followed by free provison of LPG connection for poor households. A 50% reduction in subsidies to LPG fuel has a BCR of less than one. The quality of evidence associated with these interventions range from "medium" to "medium-strong" (table 7.1).

While the BCRs for promotion of improved biomass cookstoves are more than twice as large as for free provison of LPG connection for poor households, the health benefits of an improved cookstove is roughly half of the health benefits of using LPG as primary cooking fuel. Thus in order to make a substantial dent in the huge health effects of solid fuels used for cooking in Rajasthan, predominant and sustained use of LPG or other clean cooking solutions need to be achieved. However, improved biomass cookstoves can serve as an intermediate arrangement.

Table 7.1. Summary of the benefits and costs and interventions (Rs million annualized)

| | Interventions | Discount | Benefit | Cost | BCR | Quality of Evidence |
|---|---|---|---|---|---|---|
| 1 | Promotion of improved biomass cookstoves | 3% | 30,454 | 2,968 | 10.3 | Medium |
| | | 5% | 29,385 | 3,041 | 9.7 | |
| | | 8% | 28,527 | 3,149 | 9.1 | |
| 2 | Free provison of LPG connection to poor households | 3% | 70,231 | 14,347 | 4.9 | Medium-Strong |
| | | 5% | 68,566 | 14,499 | 4.7 | |
| | | 8% | 66,748 | 14,733 | 4.5 | |
| 3 | 50% reduction of subsidies to LPG fuel | 3% | 9,963 | 24,900 | 0.40 | Medium-Strong |
| | | 5% | 9,963 | 24,422 | 0.41 | |
| | | 8% | 9,963 | 23,852 | 0.42 | |

Notes: All figures use VSL for valuation of mortality benefits. BCRs using YLL at 3 times GDP per capita for valuation of mortality are +/- 1/3rd of the ones presented here. Source: Author.

An important dimension is also that the use of solid biomass cooking fuels by one household affects surrounding households. Smoke is vented out of one household for so to enter the dwellings of others and also pollute the ambient outdoor air. There are therefore benefits from stove promotion programs being community focused with the aim of achieving "unimproved stove free" and eventually "solid biomass free" communities along the lines of community lead sanitation programs and "open defecation free" communities.

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# Annex 1. Health effects of particulate matter pollution

Health effects of PM exposure include both morbidity and premature mortality. The methodologies to estimate these health effects have evolved as the body of research evidence has increased.

## 1.1 Outdoor particulate matter air pollution

Over a decade ago, Pope et al (2002) found elevated risk of cardiopulmonary (CP) and lung cancer (LC) mortality from long term exposure to outdoor ambient PM2.5 in a study of a large population of adults 30 or more years of age in the United States. CP mortality includes mortality from respiratory infections, cardiovascular disease, and chronic respiratory disease. The World Health Organization used the study by Pope et al when estimating global mortality from outdoor ambient air pollution (WHO 2004; 2009). Since then, recent research suggests that the *marginal increase* in relative risk of mortality from PM2.5 declines with increasing concentrations of PM2.5 (Pope et al 2009; 2011). Pope et al (2009; 2011) derive a shape of the PM2.5 exposure-response curve based on studies of mortality from active cigarette smoking, second-hand cigarette smoking (SHS), and outdoor ambient PM2.5 air pollution.

## 1.2 Household particulate matter air pollution

Combustion of solid fuels for cooking (and in some regions, heating) is a major source of household air pollution (HAP) in developing countries. Concentrations of PM2.5 often reach several hundred micrograms per cubic meter ($\mu g/m^3$) in the kitchen and living and sleeping environments. Combustion of these fuels is therefore associated with an increased risk of several health outcomes, such as acute lower respiratory infections (ALRI), chronic obstructive pulmonary disease (COPD) and chronic bronchitis (CB), and lung cancer (LC). The global evidence is summarized in meta-analyses by Desai et al (2004), Smith et al (2004), Dherani et al (2008), Po et al (2011), and Kurmi et al (2010). Risks of health outcomes reported in these meta-analyses are generally point estimates of relative risks of disease (with confidence intervals) from the use of fuel wood, coal and other biomass fuels[19] relative to the risks from use of liquid fuels (e.g., LPG).

A randomized intervention trial in Guatemala found that cooking with wood using an improved chimney stove, which greatly reduced PM2.5 exposure, was associated with lower systolic blood pressure (SBP) among adult women compared to SBP among women cooking with wood on open fire (McCracken et al, 2007). Baumgartner et al (2011) found that an increase in PM2.5 personal exposure was associated with an increase in SBP among a group of women in rural households using biomass fuels in China. These studies provide some evidence that PM air pollution in the household environment from combustion of solid fuels contributes to cardiovascular disease.

## 1.3 An integrated exposure-response function

The Global Burden of Disease (GBD) Project takes Pope et al (2009; 2011) some steps further by deriving an integrated exposure-response (IER) relative risk function (RR) for disease outcome, *k*, in age-group, *l,* associated with exposure to fine particulate matter pollution ($PM_{2.5}$) both in the outdoor and household environments:

$$RR(x)_{kl} = 1 \qquad \text{for } x < x_{cf} \qquad \text{(A1.1a)}$$

$$RR(x)_{kl} = 1 + \alpha_{kl}(1 - e^{-\beta_{kl}(x-x_{cf})^{\rho_{kl}}}) \qquad \text{for } x \geq x_{cf} \qquad \text{(A1.1b)}$$

where $x$ is the ambient concentration of $PM_{2.5}$ in $\mu g/m^3$ and $x_{cf}$ is a counterfactual concentration below which it is assumed that no association exists between $PM_{2.5}$ exposure and assessed health outcomes (theoretical minimum risk exposure level). The function allows prediction of RR over a very large range of $PM_{2.5}$ concentrations, with $RR(x_{cf}+1) \sim 1+\alpha\beta$ and $RR(\infty) = 1 + \alpha$ being the maximum risk (Shin et al, 2013; Burnett et al, 2014).

The parameter values of the risk function are derived based on studies of health outcomes associated with long term exposure to ambient particulate matter pollution, second hand tobacco smoking, household solid cooking fuels, and active tobacco smoking (Burnett et al, 2014). This provides a risk function that can be applied to a wide range of ambient $PM_{2.5}$ concentrations around the world as well as to high household air pollution levels of $PM_{2.5}$ from combustion of solid fuels.

The health outcomes assessed in the GBD Project are ischemic heart disease (IHD), cerebrovascular disease (stroke), lung cancer, chronic obstructive pulmonary disease (COPD), and acute lower respiratory infections (ALRI) (Lim et al, 2012; Mehta et al, 2013; Smith et al, 2014; Forouzanfar et al, 2015; Forouzanfar et al, 2016). The risk functions for IHD and cerebrovascular disease are age-specific with five-year age intervals from 25 years of age, while singular age-group risk functions are applied for lung cancer (≥ 25 years), COPD (≥ 25 years), and ALRI for children and adults in GBD 2013 and 2015. An $x_{cf}$ between 2.4 and 5.9 $\mu g/m^3$ is applied in the GBD 2015 Project (Forouzanfar et al, 2016).

The population attributable fraction of disease from PM2.5 exposure is then approximated by the following expression:

$$PAF = \sum_{i=1}^{n} P_i[RR\left(\frac{x_i+x_{i-1}}{2}\right) - 1]/(\sum_{i=1}^{n} P_i[RR(\frac{x_i+x_{i-1}}{2}) - 1] + 1) \qquad \text{(A1.2)}$$

where $P_i$ is the share of the population exposed to PM2.5 concentrations in the range $x_{i-1}$ to $x_i$.[20] This attributable fraction is calculated for each disease outcome, $k$, and age group, $l$. The disease burden (D) in terms of annual cases of disease outcomes due to PM2.5 exposure is then estimated by:

$$D = \sum_{k=1}^{t} \sum_{l=1}^{s} m_{kl} PAF_{kl} \qquad \text{(A1.3)}$$

where $m_{kl}$ is the total annual number of cases of disease (baseline cases), $k$, in age group, $l$, and $PAF_{kl}$ is the population attributable fraction of these cases of disease, $k$, in age group, $l$, due to PM2.5 exposure.

The potential impact fraction (PIF) is applied to estimate the change in disease burden from a change in the PM2.5 population exposure distribution that is expected to result from an intervention:

$$PIF = [\sum_{i=1}^{n} P_i RR\left(\frac{x_i+x_{i-1}}{2}\right) - \sum_{i=1}^{n} P_i' \, RR\left(\frac{x_i+x_{i-1}}{2}\right)]/(\sum_{i=1}^{n} P_i RR(\frac{x_i+x_{i-1}}{2}) \qquad \text{(A1.4)}$$

where $P'_i$ is the population exposure distribution after the intervention. The changes in annual cases of disease outcomes are then estimated by:

$$\Delta D = \sum_{k=1}^{t} \sum_{l=1}^{s} m_{kl} PIF_{kl} \qquad \text{(A1.5)}$$

[1] https://iocl.com/Products/Indanegas.aspx
[2] https://vizhub.healthdata.org/gbd-compare/india
[3] https://vizhub.healthdata.org/gbd-compare/india
[4] See annex 1 for methodological details.
[5] VSL is estimated by a "benefit transfer function" in World Bank (2016): $VSL_{c,n} = VSL_{OECD} * (\frac{Y_{c,n}}{Y_{OECD}})^{\epsilon}$ where $VSL_{c,n}$ is the estimated VSL for country *c* in year *n*, $VSL_{OECD}$ is the average base VSL in the sample of OECD countries with VSL studies (US$ 3.83 million), $Y_{c,n}$ is GDP per capita in country *c* in year *n*, and $Y_{OECD}$ is the average GDP per capita for the sample of OECD countries (US$ 37,000), and ε an income elasticity of 1.2 for low- and middle-income countries and 0.8 for high income countries. All values are in purchasing power parity (PPP) prices. Using a VSL of 72 times GDP per capita in Rajasthan in 2017 implies a VSL of Rs. 6.86 million. This value is multiplied by the number of deaths to estimate the welfare cost of premature mortality.
[6] A 40% reduction over the life of the ICS reflects a linear deterioration in exposure reduction from 55% in the first year to 25% in the fourth year, after which time the stove is either replaced or receives a major overhauled.
[7] These exposure reductions in relation to cooking location give in fact a very similar percentage reduction in exposure from own pollution across cooking locations, after subtracting exposure resulting from community pollution.
[8] http://www.downtoearth.org.in/coverage/india-steps-on-the-gas-58502
[9] https://thewire.in/energy/modi-lpg-scheme
[10] http://www.thehindubusinessline.com/economy/policy/modi-govts-ujjwala-scheme-leaves-women-healthier-happier/article9685035.ece
[11] http://www.livemint.com/Politics/oqLQDFKNuMdbmLEVL88krN/Indias-poor-are-not-using-LPG-cylinders-they-got-under-Ujjw.html
[12] http://www.downtoearth.org.in/coverage/india-steps-on-the-gas-58502
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[14] http://www.downtoearth.org.in/coverage/india-steps-on-the-gas-58502
[15] https://iocl.com/Products/Indanegas.aspx
[16] An omitted benefit is the cost of the traditional cookstove that households switching to LPG no longer need to purchase. These cookstoves are very inexpensive and therefore has negligible effect on total benefits.
[17] https://iocl.com/Products/Indanegas.aspx
[18] This is based on long-run price elasticities of demand for residential natural gas from international meta-analyses by Burke and Yang (2016) and Labandeira et al (2016). No substantial literature was idenfied that provides estimates of price elasticities of demand for LPG.
[19] Other biomass fuels used for cooking is mostly straw/shrubs/grass, agricultural crop residues and animal dung.
[20] With a non-linear RR function, the precision of the calculation of PAF increases as $x_i$-$x_{i-1}$ approaches zero, or "n" approaches infinity.

Rajasthan is the largest Indian state. It has a diversified economy, with mining, agriculture and tourism. Rajasthan has shown significant progress in improving governance and tackling corruption. However, it continues to face acute social and economic development challenges, and poverty remains widespread. What should local, state and national policymakers, donors, NGOs and businesses focus on first, to improve development and overcome the state's remaining issues? With limited resources and time, it is crucial that priorities are informed by what can be achieved by each rupee spent. To fulfil the state vision of "a healthy, educated, gender sensitive, prosperous and smiling Rajasthan with a well-developed economic infrastructure", Rajasthan needs to focus on the areas where the most can be achieved. It needs to leverage its core competencies to accelerate growth and ensure people achieve higher living standards. Rajasthan Priorities, as part of the larger India Consensus – a partnership between Tata Trusts and the Copenhagen Consensus Center, will work with stakeholders across the state to identify, analyze, and prioritize the best solutions to state challenges. It will commission some of the best economists in India, Rajasthan, and the world to calculate the social, environmental and economic costs and benefits of proposals.

RAJASTHAN PRIORITIES

AN INDIA CONSENSUS PRIORITIZATION PROJECT

**For more information visit www.rajasthanpriorities.com**

## COPENHAGEN CONSENSUS CENTER

Copenhagen Consensus Center is a think tank that investigates and publishes the best policies and investment opportunities based on social good (measured in dollars, but also incorporating e.g. welfare, health and environmental protection) for every dollar spent. The Copenhagen Consensus was conceived to address a fundamental, but overlooked topic in international development: In a world with limited budgets and attention spans, we need to find effective ways to do the most good for the most people. The Copenhagen Consensus works with 300+ of the world's top economists including 7 Nobel Laureates to prioritize solutions to the world's biggest problems, on the basis of data and cost-benefit analysis.