



COST-BENEFIT ANALYSIS OF INTERVENTIONS

TO INCREASE THE USE OF CLEAN COOKING

FUELS IN GHANA

BJORN LARSEN

*Economist
Consultant*

MAXWELL DALABA

*Research FelloW
Navrongo Health Research Centre, Ghana
Institute of Health Research
University of Allied Sciences, Ho, Ghana*

NATIONAL DEVELOPMENT PLANNING COMMISSION

COPENHAGEN CONSENSUS CENTER



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info@copenhagenconsensus.com

www.copenhagenconsensus.com

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Cost-Benefit Analysis of Interventions to Increase the Use of Clean Cooking Fuels in Ghana

Ghana Priorities

Bjorn Larsen
Economist Consultant

Maxwell Dalaba
*Research Fellow, Navrongo Health Research Centre, Ghana; Institute of Health Research,
University of Allied Sciences, Ho, Ghana.*

Brad Wong
Chief Economist, Copenhagen Consensus Center

Academic Abstract

This paper evaluates the benefits and costs of interventions to control household air pollution caused by the use of solid fuels for cooking. Benefits and costs are presented as a ratio of the present value of benefits and the present value of costs (benefit-cost ratios) over the intervention time horizons.

Benefit-cost ratios (BCRs) are found to be the largest for promotion of improved fuelwood stoves (9-13) and improved charcoal stoves (6-8) followed by expanded distribution of Liquefied Petroleum Gas (LPG) in rural areas (2-6) and elimination of taxes on LPG fuel for cooking nationwide (1.9-2.6), applying a discount rate of 8% of future benefits and costs.

These BCRs reflect health benefits of the interventions valued at 1.3-1.6 times GDP per capita per “disability adjusted life year” (DALY) saved. Monetary values of time savings are estimated at 50% of wage rates. Fuel savings are valued at market prices when predominantly bought in the market and at fuel wood collection time savings in rural areas (using 50% of wage rates). 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 charcoal and fuelwood cookstoves are several times larger than for the intervention for expanded use of LPG and LPG tax removal, the health benefit of using LPG is roughly 50% larger than the health benefit of improved cookstoves. Thus, in order to make a substantial dent in the huge health effects of solid fuels used for cooking in Ghana, predominant and sustained use of LPG or other clean cooking solutions needs to be achieved. However, improved biomass cookstoves can serve as an intermediate solution for households that decide to use such stoves.

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 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 “improved stove” and “clean cooking fuel” communities along the lines of community-led sanitation programs and “open defecation free” communities.

Key Words: Improved biomass cookstoves, cylinder recycling, LPG, tax reduction

Policy Abstract

Key takeaways:

- Use of solid fuels for cooking is widespread across Ghana, with 78% of the population using wood, charcoal or other unclean fuels. This results in about 10,000 deaths per year.
- Promotion of improved charcoal and wood stoves has the highest BCR of all interventions studied. If 10% of all current users of charcoal and wood switch to improved stoves (565,000 households), 190 deaths would be avoided per year in the medium run, along with significant time and fuel savings. The estimated BCRs for improved cookstove promotion are between 6 and 13.
- Cost and lack of access to LPG is the main impediment to its use in rural Ghana. We estimate that the long distances to urban refilling stations increases the effective cost of LPG by about 50% for the rural households closest to cities, taking into account their travel costs. For households further out, the distance precludes the use of LPG entirely.
- Implementing a rural distribution model enabled by cylinder recirculation would give 3.5m rural households access to LPG within their communities, including the 350,000 who currently travel great distances to buy LPG. We estimate that this would lead to 448,000 new households actually adopting LPG in rural areas, increasing the percentage of the rural population using LPG from 6 to 17%. This would reduce deaths from household air pollution by 180 per year in the medium run, while also delivering significant time and fuel savings. The BCR of this intervention is 2.1.
- Eliminating the 23% VAT on LPG would lead to 391,000 urban households and 80,000 rural households switching to LPG due to the lower cost of fuel. This would reduce deaths by 193 per year in the medium run while delivering significant time and fuel savings. Households which currently use LPG, would also enjoy the benefit of reduced fuel costs. However, elimination of the tax would cost the government GHS 1.3bn in lost revenue per year. The BCR of this intervention is 1.9.

The Problem

Over 1.6 million people died globally in 2017 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 2017 (GBD 2017) Project. This makes household air pollution (HAP) one of the leading health risk factors in developing countries.

Nearly 10,000 people died from HAP in Ghana in 2017 according to GBD 2017. As many as 78% of the population in Ghana relied on solid fuels as primary cooking fuels in 2017, while 21% used LPG according to the Ghana Maternal Health Survey 2017. Charcoal is the predominant solid fuel used in urban areas and fuelwood is the predominant fuel in rural areas. While 35% of the urban population used LPG, only slightly over 6% used LPG in rural areas.

Adoption of improved cookstoves is low in Ghana with very few households using improved charcoal stoves. Currently the popular and most used improved cookstove is the Gyapa coal port stove while others are the Toyola stove, Kenya Jiko stove as well as improved wood stove such as Philips and environfit wood stoves.

Judging from exposure studies around the world, household members' average exposures to PM_{2.5} may be on the order of 100-200 $\mu\text{g}/\text{m}^3$ among households cooking with solid biomass fuels, depending on cooking location in the household environment (Larsen, 2017). These exposure levels are 10-20 times the WHO's outdoor annual air quality guideline (AQG) of 10 $\mu\text{g}/\text{m}^3$, and cause serious health effects including heart disease, stroke, lung cancer, respiratory diseases and diabetes.

In order to reduce the burden of the use of harmful cooking methods in Ghana, three interventions are evaluated in this paper in terms of their benefits and costs:

1. Promotion of improved fuelwood and charcoal cookstoves.
2. Expanded distribution of LPG in rural areas
3. Elimination of taxes on LPG fuel for cooking.

Benefits and costs are presented as a ratio of the present value of benefits and the present value of costs (benefit-cost ratios (BCRs) over a ten-year intervention horizon.

It should be noted that a comparison of benefits and costs of the 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 of 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 a sustained user rate of 65% of households that initially adopt the improved cookstoves, as some households invariably will discontinue the use of the improved stoves for various reasons.

No specific stove adoption rate has been assumed. Benefits and costs are rather estimated per household adopting the stoves.

Costs

The total costs of the intervention included initial cost of stove, cost of stove maintenance over its useful life, and stove promotion program cost. The present value of cost per household for the use of the intervention (Gyapa stoves) is estimated at GHS 459 (Table 1).

Benefits

The quantified benefits of the intervention are the value of health improvements (“disability adjusted life year” (DALY) valued at 1.3-1.6 times GDP per capita), biomass fuel savings resulting from the higher energy efficiency of the stoves (40% for improved fuelwood stoves and 30% for improved charcoal stoves), reduced cooking time resulting from the improved cookstove, and reduced CO₂ emissions. Value of fuel savings is time savings from reduced fuelwood collection in rural areas (with time valued at 50% of wage rate), and reduced purchase of fuelwood in urban areas and reduced purchase of charcoal in both rural and urban areas valued at market prices. The present value of total benefits per household that adopts the use

of improved cookstoves in rural and urban areas is estimated respectively at GHS 4,156 and GHS 6,125 for improved wood stoves and at GHS 2,665 and GHS 3,705 for improved charcoal stoves (Table 1).

Intervention 2: Expanded distribution of LPG in rural areas

Overview

An impediment to adoption of LPG for cooking in rural areas is household travel distance to LPG refilling stations for refilling of household LPG cylinder. A cylinder recycling program with Motorking (motorcycle with smaller trailer) distribution from refilling stations to local village retail outlets could improve this situation. This will reduce the cost of LPG (net of household travel time to refill stations) for rural households currently using LPG, increase the user rate of LPG among rural households currently within reach of a refill station, and more than double the number of rural households with access to LPG. Overall, we estimate the intervention will increase the number of households using LPG from about 350 thousand households to nearly 800 thousand households.

Implementation Considerations

Expanded distribution through a cylinder recycling program with village retail outlets can potentially be viewed with opposition by existing refilling stations. The expanded distribution proposed here therefore builds on existing stations rather than replacing them.

Costs and Benefits

Costs and benefits are estimated based on a sustained user rate of 65% of households that initially adopt LPG, as some households invariably will discontinue the use of LPG for various reasons.

Costs

For new rural users of LPG resulting from a new distribution system, the main household cost is the cost of LPG fuel representing 85-90% of total costs. Other costs are cost of LPG stove; cylinder and connection equipment; stove maintenance; and an LPG promotion program. The total present value of cost per household for expanded distribution of LPG in rural areas over a ten-year intervention horizon is estimated at GHS 3,869 for new users of LPG.

For current rural users of LPG, the present value of cost is simply new cost of distribution, or GHS 347 per household, while the benefit is the savings from no longer having to travel to a refill station (Table 1).

Benefits

The quantified benefits of the intervention are the value of health improvements, biomass fuel savings resulting from switching to LPG or increased use of LPG, reduced cooking time resulting from the LPG cookstove, travel cost savings for rural household currently refilling their LPG cylinder at a refill station (and not having to incur this travel with an expanded distribution to local retail outlets), and reduced CO₂ emissions relative to the use of fuelwood and charcoal of which a share of wood harvesting is considered unsustainable. Biomass fuel savings are valued by the same method as in the first intervention. The travel cost savings are about six times larger than the incremental cost of Motorking distribution to local village retail outlets. The total present value of benefits per household for expanded distribution of LPG in rural areas was estimated at GHS 7,064 for new users of LPG and as much as GHS 2,177 in travel cost savings for current rural users of LPG (Table 1).

Intervention 3: Elimination of taxes on LPG fuel for cooking

Overview

Recent implementation of 23% taxes on LPG fuel by the government of Ghana is seen as having a negative effect on LPG consumption for cooking, and thus a drawback on the government's LPG penetration objectives. Removing the taxes will lower end-user prices of LPG and this in turn increase the use of LPG for cooking in both urban and rural areas. It is here estimated that removing the 23% tax on LPG will increase the number of households using LPG by 23% if the price elasticity of demand for LPG is -1.0, thus from currently 2.05 million households to 2.5 million.

Implementation Considerations

Elimination of taxes on LPG fuel for cooking has implications on the finances of the government of Ghana. That notwithstanding, imposition of taxes on LPG has negative implications for households that are already using LPG as well as those intending to switch to LPG. An implementation consideration is therefore to identify designs that protect households from increased expenditure on LPG as well as improving health and the environment from the harmful effects of the use of biomass.

Costs and Benefits

Costs

The main household cost of switching to LPG as the price of LPG declines from the removal of LPG taxes is the cost of LPG fuel. This is followed by the cost LPG stove, cylinder and connection equipment for users who may not previously have used LPG; and stove maintenance cost. The present value of cost per household over the ten-year intervention horizon is estimated at GHS 3,744. If the government tax revenue loss is included as a cost, then the cost is GHS 6,445 per household (Table 1).

Benefits

The quantified benefit of eliminating taxes on LPG fuel for cooking, and resultant increased use of LPG instead of biomass fuels, is the value of health improvements, biomass fuel savings resulting from switching to LPG or increased use of LPG, reduced cooking time resulting from the LPG cookstove, and reduced CO₂ emissions, as in the case of expanding LPG distribution in rural areas. The present value of benefits per household with the intervention of eliminating taxes on LPG was estimated at GHS 9,770. If the tax removal is included as a benefit to households, then the total benefit is GHS 12,471 per household (Table 1).

BCR

Benefit-cost ratios (BCRs) are found to be the largest for promotion of improved fuelwood cookstoves among households that currently use traditional wood stoves or open fire (BCR=9-13) and for promotion of improved charcoal cookstoves among households that currently use traditional charcoal stoves (BCR=6-8). This is followed by expanded distribution of LPG in rural areas (BCR=2-6) and elimination of taxes on LPG fuel for cooking nationwide (BCR=1.9-2.6). The BCRs are larger in urban areas than in rural areas primarily because of the higher value of fuel savings and household valuation of time savings in urban areas. 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 charcoal and fuelwood cookstoves are several times larger than for the interventions for expanded use of LPG and LPG tax removal, the health benefits of using LPG is roughly 50% larger than the health benefits of improved cookstoves. Thus, in order to make a substantial dent in the huge health effects of solid fuels used for cooking in Ghana, predominant and sustained use of LPG or other clean cooking

solutions need to be achieved. However, improved biomass cookstoves can serve as an intermediate solution for households that elect to do so.

Table 1: Summary of the benefits and costs of interventions (GHS per household)

	Interventions		Benefit	Cost	BCR	Quality of evidence
1a	Promotion of improved wood stove	Rural	4,156	459	9.1	Medium
1b		Urban	6,125	459	13.3	
1c	Promotion of improved charcoal stove	Rural	2,665	459	5.8	Medium
1d		Urban	3,705	459	8.1	
	Expanded distribution of LPG in rural areas	Rural	4,926	2,328	2.1	Medium-Strong
2a	Current users of LPG	Rural	2,177	347	6.3	
2b	New users of LPG	Rural	7,064	3,869	1.8	
	Elimination on taxes on LPG for cooking					Medium-Strong
3a	Excluding tax transfer	National	9,770	3,744	2.6	
3b	Including tax transfer	National	12,471	6,445	1.9	

Notes: Benefit and cost are present values over the intervention period of ten years. All figures are discounted at 8% annual rate Source: Estimates by authors.

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 “improved stove” and “clean cooking fuel” communities along the lines of community-led sanitation programs and “open defecation free” communities.

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1. Introduction

The main objective of this paper is to assess benefits and costs of cook stove interventions that would help reduce household PM_{2.5} air pollution from the use of solid fuels for cooking in Ghana. The use of solid fuels for cooking causes serious household air pollution (HAP) in the indoor and outdoor household environment.

According to the Global burden of Disease (GBD), over 1.6 million people died globally in 2017 from harmful exposure to PM_{2.5} emissions from household use of solid fuels such as wood, coal, charcoal, and agricultural residues for cooking. HAP is one of the leading health risk factors in developing countries.

The use of solid fuel for household cooking leads to deforestation and also increases the time and energy spent in gathering fuel which poses a significant opportunity cost to educational, health and income-generating activities, particularly for women and children (Dickinson et al. 2015; Agbokey et al. 2019).

While cleaner-burning cookstoves have potential health, environmental, and social benefits, efforts to disseminate the use have fallen short and the practice of cooking with biomass over open fires remains dominant (Dickinson et al. 2018).

1.1 Cooking fuels in Ghana

In Ghana, HAP is a major public health problem and nearly 10,000 people died from HAP in 2017 according to GBD 2017. As many as 78% of Ghana's population relied on solid fuels (charcoal and wood) as primary cooking fuels in 2017, while 21% used LPG, according to the Ghana Maternal Health Survey (GMHS) report 2017 (GMHS 2017). Further, the GMHS revealed that charcoal is the predominant solid fuel used in urban areas and fuelwood is the predominant fuel in rural areas. While 35% of the urban population used LPG, only slightly over 6% used LPG rural areas (GMHS 2017). Rural Ghanaian households spend over 430 million hours or 217 thousand full time work-years on fuelwood collection per year, based on an average fuel collection time of 0.5 hours per household per day (Table 2).

Table 2: Primary fuels used for cooking in Ghana, 2020 estimate

Parameters	Rural	Urban	Total
Population using wood	11,332,091	2,329,032	13,661,123
HHs using wood	2,378,985	518,148	2,897,133
Population using charcoal	2,741,635	7,091,605	9,833,240
HHs using charcoal	801,457	1,949,643	2,751,099
Population using LPG	959,572	5,165,674	6,125,247
HHs using LPG	348,144	1,699,351	2,047,495

Note: Projection from the Ghana Maternal Health Survey 2017.

A review of exposure studies around the world revealed that, household members' average exposures to PM_{2.5} may be on the order of 100-200 µg/m³ among households cooking with solid biomass fuels, depending on cooking location in the household environment (Larsen, 2017). These exposure levels are 10-20 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, respiratory diseases and diabetes.

1.2 Interventions

Over the past decade, there have been several efforts by governments in development countries to promote the use of improved cooking methods in order to reduce the harmful effects of HAP.

In 2012, Ghana promulgated the Sustainable Energy for All Action Plan which is in line with the United Nation's Sustainable Energy for All (SE4A) program. This plan includes strategies to significantly increase the use of improved cooking methods such as the use of LPG for cooking in Ghana particularly in rural areas (Asante et al. 2018). The country targeted expansion of LPG access to 50% of the population by 2030. However, achieving this target is constrained by numerous challenges relating to household's adoption and usage of these improved cooking methods.

Studies of household adoption of improved cookstoves and clean fuels have identified some factors that hinder their use, with cost being the main obstacle (Dalaba et al. 2018; Asante et al. 2018).

In Ghana, to promote the use of improved cooking methods such as the use of LPG in rural areas, the LPG Promotion Project was piloted in 2014 with the aim of ensuring LPG use in rural areas where the majority of Ghanaians live and the use of biomass fuel is high (Asante et al. 2018). As part of the project, the Government of Ghana provided LPG cylinders, stoves and

other logistics free of charge to selected rural areas. Asante et al (2018) report the results of evaluation of Ghana's rural LPG in five rural communities in the Nkoranza North District of Ghana. The study found out that the use of LPG increased but transporting cylinders to the filling station was commonly reported as a main barrier to the use of LPG for cooking (Asante et al. 2018).

Dalaba et al (2018) reported the results LPG supply and demand in northern Ghana where household use of LPG is low in the country. The results showed large rural–urban differences in LPG uptake: less than 10% of rural households own LPG stoves compared with over half of urban households. Awareness of LPG was high across the region, but accessibility of fuel supply was highly limited, with just one refilling station located in the urban area. Affordability was reported as the main barrier to LPG adoption, and acceptability was also limited by widespread concerns about the safety of cooking with LPG. It was suggested that transitioning to a cylinder recirculation model, and providing more targeted subsidies and credit options, should be explored to expand access to improved cooking methods (Dalaba et al. 2018).

A study was conducted on experiences with the Mass Distribution of LPG Stoves in Rural Communities of Ghana by Abdulai et al 2018 (Abdulai et al. 2018). Some of the reasons ascribed to the low usage of the LPG cookstoves were financial constraints, distance to LPG filling point and fear of burns. Community members appreciate the convenience of using LPG. They emphasized the need for innovative accessibility interventions which included improving nearness to LPG filling stations to overcome the barriers to sustained LPG use (Abdulai et al. 2018).

In general, the predominant cook stoves being used in Ghana is the charcoal coal pot and the traditional three stone wood stove. In recent times, some types of improved cookstoves are being introduced and the popular one being the Gyapa coal and wood stoves. Other types of improved stoves being piloted and promoted are the Toyola charcoal stove, Kenya charcoal stove, Philips wood stove, Envirofit wood, African Clean Energy (ACE), Greenway Jumbo, Biolite, among others (Agyemang 2018; Coffey et al. 2017; Dickinson et al. 2018; 2015; Agbokey et al. 2019; Piedrahita et al. 2016). These improved cookstoves produces less smoke and are more efficient than the traditional stoves.

Therefore, in order to reduce the burden of the use of solid fuels, three interventions are evaluated in this paper in terms of their benefits and costs:

2. Promotion of improved fuelwood and charcoal cookstoves.
3. Expanded distribution of LPG in rural areas with the introduction of a cylinder recirculation model and retail outlets in rural areas
4. Elimination of taxes on LPG fuel for cooking.

1.3 Common Data

Many of the data utilized in this paper are common to the three interventions. Data on primary fuels used for cooking are from Ghana Maternal Health Survey 2017 (GMHS 2017), projected to 2020. The baseline health data used for the estimation of health benefits of the interventions are from the Global Burden of Diseases 2017 (GBD 2017) for Ghana.¹ Benefits and costs of all interventions are assessed for 10 years. Discount rates of future cost and benefits are 5, 8, and 14% for all interventions.

2. Household air pollution and health effects

2.1 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 ($\mu\text{g}/\text{m}^3$) 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).

However, personal exposure is the indicator of importance in terms of health effects of household PM2.5, and personal exposures are lower than kitchen concentrations. Balakrishnan et al (2012; 2013) estimate a nationwide long-term personal exposure in households using solid fuels in India of $338 \mu\text{g}/\text{m}^3$ among women, $285 \mu\text{g}/\text{m}^3$ among children, and $205 \mu\text{g}/\text{m}^3$ among men. A review of eleven exposure studies in Latin America finds a median personal exposure of $200 \mu\text{g}/\text{m}^3$ for the cook from cooking with wood over open fire. The median personal exposure after installation of an improved wood fuel cookstove was nearly $80 \mu\text{g}/\text{m}^3$ or still eight times WHO's annual guideline (Larsen, 2017).

¹ www.healthdata.org

Exposure of adult women is used as a reference point in this report for personal exposure in estimating the health effects of HAP and health benefits of interventions. 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, consistent with the estimates by Balakrishnan et al (2012; 2013) (Table 3). 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 3). 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 3: 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 authors.

An average exposure level of $200 \mu\text{g}/\text{m}^3$ is applied to adult women cooking in the house with biomass over open fire or traditional cookstove. This level is consistent with the findings from Latin America in Larsen (2017).

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. So, for instance, the exposure level of adult men in a household cooking outdoors with biomass fuels is $200 \mu\text{g}/\text{m}^3 * H_2 * L_3 = 200 \mu\text{g}/\text{m}^3 * 60\% * 60\% = 72 \mu\text{g}/\text{m}^3$ (Table 4).

Very few measurements studies have been conducted on personal exposure from cooking with charcoal. This is mainly because charcoal is a primary cooking fuel only in a small minority of countries. Cooking with charcoal is generally associated with lower personal exposure levels of PM_{2.5} than cooking with fuelwood. Personal exposures from cooking with *charcoal* are set at 60%, 65% and 75% of personal exposures from cooking with fuelwood in the house, in separate building and outdoors, respectively (Table 4).

Table 4: Long term personal PM2.5 exposure by cooking location ($\mu\text{g}/\text{m}^3$)

	Fuelwood - Traditional stove or open fire			Charcoal - Traditional stove		
	Adult women	Adult men	Children < 5 years	Adult women	Adult men	Children < 5 years
In house	200	120	170	120	72	102
Separate building	160	96	136	104	62	88
Outdoors	120	72	102	90	54	77

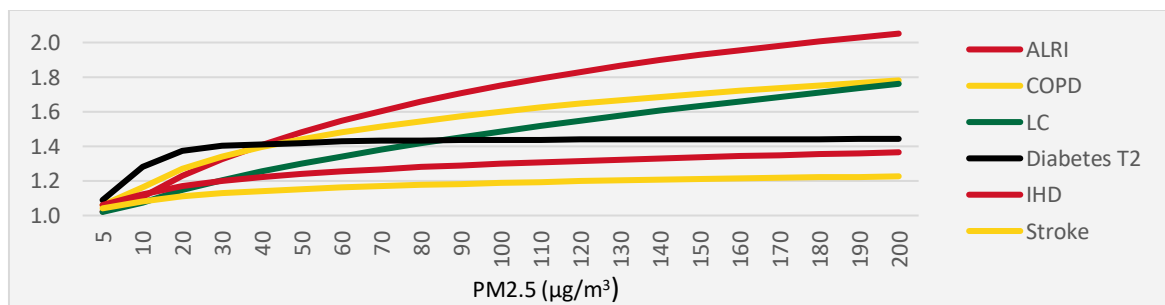
Source: Estimates by the authors.

2.2 Health effects 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), (iv) chronic obstructive pulmonary disease (COPD) and (v) diabetes type II among adult women and men, and (vi) 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 2017 (GBD 2017) (Stanaway et al, 2018).

Figure 1 shows how the risk of these six health effects in terms of mortality increases with increasing levels of PM2.5 exposure. At the average exposure level of adult women cooking with fuelwood in the house (i.e., $200 \mu\text{g}/\text{m}^3$ of PM2.5) the risk of these six health outcomes is 23-105% higher than if the exposure level were below a theoretical minimum risk exposure level of $2.4\text{-}5.9 \mu\text{g}/\text{m}^3$. Even at the average exposure level of adult men in households cooking with fuelwood outdoors (i.e., $72 \mu\text{g}/\text{m}^3$) the risk is 17-60% higher.

Figure 1: Relative risk of mortality from long term PM2.5 exposure, GBD 2017



Note: Age-weighted relative risks. Source: Produced from Stanaway et al (2018) Supplement Appendix 1.

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 GBD 2017 estimates that nearly 10,000 people died from household air

pollution in Ghana in 2017. Additionally, household air pollution caused nearly 40,000 years lived with disability (YLD) from the six health outcomes (Table 5).²

Table 5: Health effects of household air pollution from solid fuels cooking in Ghana, 2017

	Deaths	YLDs
Ischemic heart disease (IHD)	2151	317
Stroke	1489	1975
Chronic obstructive pulmonary disease (COPD)	604	16940
Lung cancer	192	45
Lower respiratory infections (LRI)	4627	113
Diabetes mellitus type 2	718	20300
Total	9781	39690

Source: Produced from GBD 2017 at www.healthdata.org

2.3 Post-intervention PM_{2.5} exposures

The use of improved wood or charcoal cookstoves (ICS) or LPG for cooking is expected to substantially reduce household members' exposure to PM_{2.5}.

Bensch and Peters (2015) evaluated the take-up and impacts of low-cost improved cookstoves through a randomized controlled trial in rural Senegal. The study found considerable effects on firewood consumption and on smoke exposure and, consequently, smoke-related disease symptoms. The reduced smoke exposure results from behavioral changes in terms of increased outside cooking and a reduction in cooking time (Bensch and Peters 2015).

A systematic review by Pope et al (2017) was carried out to synthesize evidence for changes in PM_{2.5} kitchen concentrations and personal exposure following introduction of 'improved' solid fuel stoves and cleaner fuels in low- and middle-income countries (LMIC).³ Most of the 42 included studies (112 estimates) addressed solid fuel stoves. There was an observed large reduction in pooled kitchen PM_{2.5} ranging from 41% (29–50%) for advanced combustion stoves to 83% (64–94%) for ethanol stoves. Reductions in personal exposure of 55% (19–87%) for PM_{2.5} were observed for solid fuel stoves with chimneys. For the majority of interventions,

²YLD=D*W/365 where D is duration of disease (days) and W is severity weight of disease (ranging from 0 to 1).

³ The review also included studies of CO kitchen concentrations and personal exposures. CO is, however, not considered in this paper as PM_{2.5} is the pollutant with health effects assessed in the Global Burden of Disease studies.

post-intervention kitchen PM_{2.5} levels remained well above WHO air quality guideline (AQG) limit values. Subgroup and sensitivity analyses did not substantially alter findings.

The review of personal exposure studies in Latin America before and after installation of an ICS for wood indicated a median reduction in PM_{2.5} personal exposure of over 55% from about 200 µg/m³ to 80 µg/m³ (Larsen, 2017). The exposure reductions were measured within relatively short times 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.

An exposure reduction over the three-year lifetime of the stoves ranging from 35% for outdoor cooking to 50% for cooking in the house by using an ICS for wood is applied here. A somewhat lower range of 25-40% exposure reduction is applied for ICS for charcoal (Table 6). The reductions are relative to the exposure levels using traditional cookstoves (TCS) and are applied to adult women, men and children.

Table 6: Household member exposure reduction from the use of ICS for wood or charcoal

	Wood	Charcoal
In house	50%	40%
Separate building	45%	35%
Outdoors	35%	25%

Source: The author.

Combustion of LPG results in very little PM emissions and is therefore considered a clean cooking fuel. Studies have however found that household PM_{2.5} concentrations among users of LPG often remain as high as 40-60 µg/m³, presumably mainly due to the community pollution from neighboring households using solid fuels and wider ambient air pollution. It is therefore stipulated here that exposure levels associated with cooking with LPG are on average 50 µg/m³. This exposure level is applied to adult women and children and is independent of cooking location. A somewhat lower exposure level of 35 µg/m³ 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.

In the case of full community adoption of LPG, a personal exposure level of 25 µg/m³ is applied to all household members. This exposure originates from other sources of PM_{2.5} in the household environment and non-solid fuel related outdoor ambient PM_{2.5}.

Personal exposure levels in households using LPG may decline to levels below 25 $\mu\text{g}/\text{m}^3$. Joon et al (2011) found a 24-hour average PM_{2.5} exposure for the cook of 25 $\mu\text{g}/\text{m}^3$ among rural households using LPG in Haryana, India. Titcombe and Simcik (2011) measured an average PM_{2.5} personal exposure of 14 $\mu\text{g}/\text{m}^3$ in households in the southern highlands of Tanzania cooking indoors with LPG.

Pre- and post-intervention levels of personal exposure to PM_{2.5} are presented in Table 7 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 7: Household member air pollution exposure by intervention and cooking location ($\mu\text{g}/\text{m}^3$)

	Pre-Intervention		Post-Intervention			
	TCS -Wood	TCS - Charcoal	ICS - Wood	ICS - Charcoal	LPG - Partial Adoption	LPG - Full Adoption
Adult female						
Outdoors	120	90	78	68	50	25
Separate building	160	104	88	68	50	25
In house	200	120	100	72	50	25
Adult male						
Outdoors	72	54	47	41	35	25
Separate building	96	62	53	41	35	25
In house	120	72	60	43	35	25
Children						
Outdoors	102	77	66	57	50	25
Separate building	136	88	75	57	50	25
In house	170	102	85	61	50	25

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

2.4 Health benefits of interventions

Health benefits of moving from pre-intervention to post-intervention exposure levels are estimated by using the integrated PM_{2.5} exposure-health response methodology from the GBD 2017, with relative risks for six health outcomes as previously discussed and the intervention exposure reductions in the table above.

Averted mortality is converted to averted years of life lost (YLLs) based on expected remaining years of life at average age of death from each of the six health outcomes using lifetables for

Ghana. Averted morbidity is averted years lived with disability (YLD). Averted YLLs and YLDs are summed to averted DALYs. Valuation of a DALY follows the methodology of the Copenhagen Consensus Center, with a value of 1.3 times GDP per capita in 2020 and 1.6 times GDP per capita at the end of the ten-year intervention period in 2030.

Reduced exposure to PM2.5 is unlikely to instantaneously provide full benefits for health outcomes that develop over long periods of PM2.5 exposure, i.e., for heart disease, stroke, chronic obstructive pulmonary disease (COPD), lung cancer, and diabetes. It is therefore assumed that reduced incidence of and deaths from these non-communicable diseases (NCDs) are gradually realized over ten years. For acute lower respiratory infections (ALRI), however, full health benefits are realized in the same year as PM2.5 exposure reduction.

Reduction in NCDs account for 30% of DALYs and reduction in ALRI for 70% of DALYs averted from the interventions. On average 15 years of expected remaining life are lost from a death due to the NCDs and 28 years from a death due to ALRI.⁴ Assuming there is no reduction in the NCD burden from reduced PM2.5 in the first year of the intervention, only 81% of the full health benefits are realized that year, gradually rising to 100% in year 10 (Table 8).

Table 8: Realized health benefits of interventions

Intervention horizon (Years)	1	2	3	4	5	6	7	8	9	10
	DALYS averted									
Non-communicable diseases (30% of DALYs)	0	2	4	6	8	10	12	13	14	15
ALRI (70% of DALYs)	28	28	28	28	28	28	28	28	28	28
Weighted average	19	20	21	21	22	23	23	23	24	24
Realized health benefits (% of full benefits)	81%	84%	86%	89%	91%	94%	96%	97%	99%	100%

Source: The authors.

3. Promotion of improved fuelwood and charcoal cookstoves

3.1 Description of intervention

In Ghana, the main cook stoves being used by households for domestic cooking is the charcoal coal pot and the traditional three-stone wood stove. These inefficient biomass stoves used for

⁴ Calculated from the Global Burden of Disease (www.healthdata.org) and Ghana life tables.

cooking leads to health consequences and excessive fuel use and cooking time. It is therefore important to promote improved, efficient biomass stoves in order to reduce the burden of HAP as well as reduce biomass consumption and cooking time.

As an intermediate solution to reduce the burden of HAP, some NGOs and the Ghana Energy commission is trying to promote the use of Gyapa coal and wood stoves. This type of stove can be produced locally and is more affordable compared to the other improved stoves. The Gyapa stoves cooks food quicker than traditional cookstoves, requires 50-60% less fuel and produces less smoky fumes (“Gyapa Cookstoves for More Efficient Cooking” n.d.).

Therefore, the proposed improved biomass cookstove for this study is the Gyapa wood and charcoal stoves. At least two Gyapa stove burners are needed for households to minimize the continued use of their traditional stoves. This adds to the initial cost but provides substantial increased health benefits, fuel savings, and cooking time savings benefits.

3.2 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).

A study was conducted in the middle belt of Ghana to explore and document the enablers and barriers for adoption of clean cookstoves. The findings showed convenience of clean cookstove use, reduced firewood usage, less smoke emissions and associated health problems, time spent on firewood collection and cooking, and good smell and taste of food as enabling factors for clean cookstove adoption. Factors such as safety, financial constraint (cost), non-availability

of spare parts on the open market to replace faulty stove accessories, stove size and household size were the potential barriers to clean cookstove adoption (Agbokey et al. 2019).

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 communication (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, a long-term user rate of 65% of the households that initially adopt the interventions is applied in the benefit-cost assessment in this paper, as some households invariably will discontinue using the interventions for various reasons. The rate is the mid-point of findings in Pillarisetti et al and Ruiz-Mercado et al.

3.3 Calculation of costs and benefits

3.3.1 Costs

Costs of improved cookstove promotion include initial cost of stove, stove maintenance (O&M) cost, and the cost of promotion program.

Cost of improved stoves usually depends on the fuel and emission efficiency, durability and materials used in the manufacturing. Simple improved stoves can cost less than US\$10 but these stoves often do not provide fuel savings beyond 25%, provide limited emission reduction benefits, and have poor durability. Intermediate improved stoves cost US\$25-35 and include Rocket stoves. These stoves can provide up to 50% fuel savings and substantial emission reduction benefits.

The intervention stove for this analysis is the Gyapa improved wood and charcoal stove developed by the Gyapa enterprise Ghana for the citizens. The cost is GHS 40-50 (US\$ 8-10) for a stove with one burner. For the improved wood and charcoal Gyapa stoves referenced for this intervention households need at least two burners in order to discontinue cooking with the

traditional stove or open fire. This brings the cost of stoves to GHS 80-100 (US\$ 16-20) per household. The intervention time horizon is 10 years. A useful life of the stoves of 3 years is applied in the analysis. The improved stoves are therefore replaced every three years. Annual O&M cost is assumed to be 5% of stove cost.

Promotion programs are needed for higher rates of household adoption of improved cookstoves. The cost of such programs per target household and per household actually adopting improved stoves can vary substantially depending on the intensity of the program and type of marketing. A recent program in India that targeted 1000 households in nearly 100 rural Himalayan communities involved a cost of US\$ 17 per target household and US\$ 34 per household adopting the stoves being promoted (Pattanayak et al, 2019). Other programs may cost less, but may achieve lower stove adoption rates. There may also be substantial economies of scale that drive down cost per household for larger national programs.

A promotion program cost of US\$34 per household is applied to Ghana. The promotion program is repeated after five years for follow up.

Not all households who initially adopt improved cookstoves are likely to sustain the use of the stoves over the 10-year period for one reason or the other. It is therefore assumed that 80% of households that initially adopt the improved stoves will continue using them after one year and 65% will continue using them from year two and onwards. Cost and benefits are calculated accordingly.

Total present value of cost per household over the ten-year intervention period is estimated at GHS 459 (Table 9).

Table 9: Present value of cost of Gyapa stove promotion (GHS per household)

	GHS
Cost of stove	178
Stove O&M	21
Promotion program	260
Total costs	459

Note: Present value (PV) of cost is calculated at discount rate of 8%. Source: Estimates by authors.

3.3.2 Benefits

The quantified benefits of the intervention are:

- i. The value of health improvements (“disability adjusted life year” (DALY));

- ii. Reduced cooking time resulting from the improved cookstove (20 minutes per day for improved woodstove and 15 minutes per day for improved charcoal stove);
- iii. Biomass fuel savings resulting from the higher energy efficiency of the stoves (40% for improved fuelwood stoves compared to traditional woodstoves, and 30% for improved charcoal stoves compared to traditional charcoal stoves); and
- iv. Reduced CO₂ emissions.

The health benefits of the improved wood stove are twice as large as for the improved charcoal stove. This is a result of the much larger absolute reduction in PM_{2.5} exposure from the improved woodstove. There is little difference in the value of health benefits between rural and urban households as the unit health benefits are valued at the same amount for both rural and urban households.

For cooking time savings, Hutton et al (2006) report that it takes 11-14% less time to boil water with a Rocket stove (improved cookstove) or LPG stove 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 in Uganda. 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. Siddiqui et al (2009) report that daily fuel burning time for cooking in a semi-rural community outside Karachi was 30 minutes less in households using natural gas than in households using wood, and that time spent in the kitchen was 40 minutes less. Jeuland and Pattanayak (2012) assumes that an improved wood stove saves around 10 minutes per day and that LPG saves one hour per day in cooking time. 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 as the person cooking often engages in multiple household activities simultaneously. Hafner et al (2018) find in a performance assessment of an improved cookstove in Tanzania, compared to cooking over three-stone fire, that cooking time savings are 30-50 minutes for cooking various meals by a medium-sized household.

Based on these reviews, a cooking time saving of 20 minutes per day from the use of an improved wood fuel cookstove and 15 minutes per day from the use of an improved charcoal cookstove is applied here compared to an unimproved cookstove or open fire. A value of time equal to 50% of rural and urban wage rates are applied to estimate the value of cooking time savings in rural and urban areas respectively.

Value of fuelwood savings in rural areas is time savings from reduced fuelwood collection, with time valued at 50% of wage rate. Fuelwood collection for rural households using traditional woodstoves is 0.5 hours per day.⁵ Value of fuelwood savings in urban areas is the market price of fuelwood. Price applied for fuelwood in urban area is GHS 0.5 per kg. Value of charcoal savings is the market price of charcoal, estimated at GHS 0.77 per kg in rural areas and GHS 1.07 in urban areas.⁶

The value of cooking time savings and fuel savings are substantially higher for urban than for rural households due to higher urban wage rates and higher cost of fuels in urban areas

CO₂ emissions reductions from reduced fuelwood and charcoal consumption is based the share of biomass consumption that is non-renewable, i.e., the share of biomass consumption that is unsustainable and leads to permanent destruction of biomass growth. A non-renewable share of 28% is applied here for Ghana (Bailis et al, 2015). And applying a social price per ton of CO₂ of US\$ 7.6 at 5% discount rate and US\$ 0 at 8% and 14% discount rates (ToI, 2011), the present value of carbon benefits of the improved cookstove intervention over a ten-year intervention period is GHS 85 per household with a 5% discount rate and GHS 0 for 8% and 14% discount rates.

For the Gyapa wood stove, the total benefits per household for rural and urban is estimated at GHS 4,156 and GHS 6,125 respectively. For the Gyapa charcoal stove, the total benefits per household for rural and urban is estimated at GHS 2,665 and GHS 3,705 respectively.

Table 10: Present value of benefits per household (GHS)

	Improved wood stove (Rural)	Improved wood stove (urban)	Improved charcoal stove (rural)	Improved charcoal stove (urban)
Health benefits	1,456	1,374	703	747
Cooking time savings	1,688	2,578	1,266	1,933
Fuel savings	1,013	2,173	696	1,024
CO ₂ reductions	0	0	0	0
Total benefits	4,156	6,125	2,665	3,705

Note: Discount rate is 8%. Source: Estimates by authors.

⁵ Ghana sector mapping by Accenture 2012 for Global Alliance for Clean Cookstoves has 0.5 hrs/hh/day.

⁶ The rural-urban price difference is estimated using regional rural population shares and regional charcoal price data from the Ghana National Energy Statistics 2008-2017 by the Energy Commission of Ghana, 2018.

3.3.3 Benefit-cost ratios

Benefit-cost ratios (BCRs) are calculated as present value of total benefits divided by present value of total costs per household. The BCR is 9.1 for the intervention on promotion of improved wood Gyapa stoves for rural households and as much as 13.3 for urban households, at a discount rate of 8%. BCRs for the promotion of improved charcoal Gyapa stoves are somewhat lower than for the wood stoves, but yet as high as 5.8 for rural and 8.1 for urban households, at a discount rate of 8% (Table 11). In other words, benefits are GHS 5.8-13.3 for every GHS 1 spent. The BCRs do not differ substantially for the lower and higher discount rates.

Table 11: Present value of benefits and costs of intervention, GHS per household and BCRs

	5% discount rate	8% discount rate	14% discount rate
Improved wood cookstove (rural)			
Total benefits	4,944	4,156	3,152
Total costs	501	459	394
BCR	9.9	9.1	8.0
Improved wood cookstove (urban)			
Total benefits	7,234	6,125	4,660
Total costs	501	459	394
BCR	14.4	13.3	11.8
Improved charcoal cookstove (rural)			
Total benefits	3,193	2,665	2,029
Total costs	501	459	394
BCR	6.4	5.8	5.2
Improved charcoal cookstove (urban)			
Total benefits	4,402	3,705	2,826
Total costs	501	459	394
BCR	8.8	8.1	7.2

Source: Estimates by authors.

3.3.4 Assessment of quality of evidence

The data used in the analysis are most likely to be of medium accuracy. The relative risks (RR) of disease and mortality reductions are based on a large body of global research, but not specifically in Ghana. The value of statistical life (VSL) used for valuation of mortality benefits 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 improved Gyapa stoves has limited-medium evidence but the rate does not have material impact on the BCRs. The time savings are based on medium evidence as studies from Ghana are limited. Cost of intervention has medium evidence (Table 12).

Table 12: Quality of evidence

	Interventions	Area	Quality of evidence
1	Promotion of improved Gyapa wood stove	Rural	Medium
		Urban	Medium
2	Promotion of improved Gyapa charcoal stove	Rural	Medium
		Urban	Medium

Source: Assessment by the authors.

4. Expanded distribution of LPG in rural areas

4.1 Description of intervention

Only 21% of Ghana’s population use LPG with only 15% of these LPG users residing in rural areas (6% of the rural population). Ghana has made scaled-up access to LPG for cooking a national priority, with a target of achieving access to LPG for 50% of the population by 2030.

Ghana is both a producer of LPG through the Ghana National Gas Company Limited (GNGC) and an importer of LPG. In 2017, about 36% of Ghana's total LPG supply was produced in Ghana and around 64% was imported (Asante et al. 2018). As at 2018, LPG was distributed by about 42 LPG marketing companies to about 641 gas refilling stations across the country. These scarce refilling stations are largely located in urban areas and inaccessible to a majority of rural households. Customers travel with their empty cylinders to the gas filling stations to get them filled (Asante et al. 2018).

In Ghana, cylinder sizes range from 3kg to 52kg and the popular cylinder size being used by households is the 14.5kg. The median price for an empty 3kg cylinder is about US\$21.59; 5-8kg about US\$25; and 12-15kg about US\$31.82. The price for filling LPG range from US\$0.47 to US\$0.49 per liter with a median of US\$0.48 (Dalaba et al. 2018).

Aside from the cost of LPG, a barrier to adoption of LPG for cooking in rural areas is household travel distance to LPG refilling stations for refilling of household LPG cylinder.

This analysis examines the costs and benefits of implementing a new LPG distribution model, where low-cost vehicles such as a Motorking (motorcycle with small trailer) bring full cylinders from urban refilling stations to be sold at local stores in rural communities. These same vehicles would collect empty cylinders from rural stores. This new model allows LPG users in rural areas to buy fuel within their local communities, alleviating the need to travel

great distances to urban refilling stations, driving down costs of LPG refilling and increasing access.

The primary enabler of this new distribution system is the implementation of a cylinder recirculation model, common across developed countries and many developing countries. In this model, users do not own a given cylinder but instead swap empty cylinders for full ones at retail outlets. This model allows some LPG stock to exist within local communities in appropriate quantities rather than being completely held in urban refilling stations. Currently, households in Ghana buy, own, refill and use the same LPG cylinder. The current mode of individual LPG cylinder ownership is an impediment to the proposed intervention since it does not allow for LPG stock to be held within rural communities. At the time of writing this paper, the cylinder recirculation model had been slated for implementation, with some pilot projects complete. However, full national level implementation had not yet occurred.

Due to the shift in ownership structure of cylinders, as well as the introduction of retail outlets, the intervention requires stakeholder engagement and communication within rural communities.

4.2 A cylinder recirculation rural distribution model

The vast majority of the LPG refilling stations is clustered in and near urban areas. We here assume that there are about 80 such clusters, corresponding to approximately the number of cities with more than 20 thousand inhabitants in Ghana.⁷ We further assume that rural households within 15 km of a refilling station can potentially reach the station for LPG refill, by for instance using their household scooter. Approximately 6.7 million rural people, or 45% of the rural population, live within this area, of which nearly 1 million people use LPG as primary cooking fuel, corresponding to about 6.5% of the total rural population.⁸

With a new cylinder recirculation program, Motorkings could distribute LPG in cylinders to local stores in rural communities. Assuming that a Motorking could serve an area up to 25 km from refill stations, an additional 7.6 million rural people would have access to LPG in their community. Moreover, current rural users of LPG would no longer need to travel to refill stations.

⁷ See www.citypopulation.de

⁸ Projected to year 2020 based on LPG user rate in the Ghana MHS 2017.

4.2.1 Cost to current rural users of LPG

The cost basis for LPG refill for rural households currently traveling to a refill station is presented in Table 13. Number of cylinder refills per year is calculated based on consumption of 30 kg of LPG per person per year, an average household size of 2.76 for households currently using LPG, and the use of 3 kg cylinders.⁹ Roundtrip travel distance is based on an average 15 km to nearest refill station. Time spent per refill is based on a travelling speed of 40 km per hour and 10 minutes waiting at refill station. Fuel cost per km is calculated based on a scooter fuel efficiency of 40 km per liter and an economic fuel cost of US\$ 0.60 per liter.

Table 13: Cost basis for LPG refill for rural households

Cylinder refills per year (3 kg cylinder)	27
Roundtrip travel distance per refill (km)	30
Time spent per refill (travel plus waiting) (minutes)	55
Fuel cost per km traveled (GHS)	0.08

Source: Authors' calculations

Cost per LPG cylinder refill and per kg of LPG for rural households is presented in Table 14. Scooter capital cost of LPG refilling is prorated based on an initial cost of scooter of GHS 5400, a useful life of 70,000 km over 10 years, or 7,000 km per year, and 810 km of travel for LPG refill per year. Time spent on refill is valued at 50% of average rural wage rate. Total cost amounts to over GHS 8 per refill and nearly GHS 2.7 per kg of LPG. This is an incremental cost of nearly 50% on top of the price of LPG, and therefore a significant deterrent for many households to start using LPG for cooking.

Table 14: Cost of LPG cylinder refill for rural households

	GHS per refill	GHS per kg LPG
Scooter capital cost (8% discount rate)	3.45	1.15
Cost of time spent on refill	2.18	0.73
Cost of fuel for scooter	2.43	0.81
Total cost	8.06	2.69

Source: Authors' calculations

4.2.2 Cost of rural cylinder recirculation distribution

A cluster of refilling stations in an urban area could on average serve an area with a radius of 25 km by using Motorkings. A cluster could therefore serve around 84,000 rural people living

⁹ The average household size of households using LPG in rural areas is substantially smaller than the average household size according to the Ghana MHS 2017.

within 15 km of the cluster of refill stations who currently need to travel themselves to the refill station, and an additional 95,000 rural people living within 15-25 km from the cluster of refill stations who currently are too far from a refill station.

Each cluster would require five Motorkings with a capacity to distribute 40 cylinders (3 kg) per trip, at a cost of GHS 7,500 per Motorking and with a five-year useful life. Nearly 3,200 new cylinders would be needed per cluster, assuming 3 days refilling supply, at a cost of about GHS 150 per cylinder. Other costs include refill station inspections (initial safety inspection and certification at GHS 5,000 per station and recurrent inspections at GHS 500 per station per year), sensitization of retailers in rural communities at GHS 150 per retail outlet, Motorking maintenance at 10% of capital cost per year, Motorking fuel cost assuming 20 km per liter fuel efficiency, and cost of Motorking drivers at GHS 1,000 per driver per month. Total cost per cluster of refill stations are presented in Table 15. Additionally, a retail margin of 5% of the LPG price is added.

In total, this translates to a distribution cost of GHS 0.42 and GHS 0.45 per kg of LPG for rural household within 15 km and within 15-25 km of the refill station cluster.¹⁰ This is only a fraction of the current cost of GHS 2.7 for rural households traveling themselves to the refill stations.

Table 15: Cost of cylinder recycling distribution to rural communities (GHS per cluster)

<i>Initial capital cost</i>	Within 15 km	Within 15-25 km
Additional cylinders	222,213	255,340
Sensitization of retailers	12,556	14,230
Motorkings	24,889	38,133
Station inspection	2,939	5,103
<i>Recurrent annual cost</i>		
Motorking maintenance	2,489	3,813
Motorking fuel cost	14,282	21,881
Station inspection	197	303
Motorking drivers	23,696	36,304

Source: Authors.

4.2.3 Cost savings of rural cylinder recirculation and distribution

The total cost of LPG for rural households is presented in Table 16. Under the current system of households traveling to a refill station, estimated total cost is GHS 8.2 per kg of LPG. With a Motorking cylinder recycling distribution system to rural retail outlets estimated total cost is

¹⁰ Based on 8% discount rate.

a bit over GHS 5.9 per kg. This is a cost reduction of 28%. If the constant price elasticity of LPG demand is -1.0, this cost reduction would result in a 37% increase in LPG consumption among rural households within 15 km of the current refill stations, equivalent to bringing the total number of households using LPG as primary cooking fuel from nearly 350 thousand to about 480 thousand.¹¹ Additionally, the Motorking distribution system about doubles the rural population with access to LPG by reaching 25 km from the refill stations. This may add another 400 thousand rural households using LPG.

Table 16: Cost of LPG for rural households (GHS per kg)

	Current system	Cylinder recirculation with rural distribution
Current price of LPG	5.52	5.52
Additional cost of rural access	2.69	0.42
Total cost of LPG for rural households	8.21	5.94

Source: Authors.

4.3 Calculation of costs and benefits

4.3.1 Costs

The analysis distinguishes between current rural users of LPG and new rural users of LPG resulting from the LPG distribution intervention.

The costs associated with the intervention for new users of LPG are the cost of LPG stove, cylinder and cylinder auxiliary equipment; cost of LPG fuel; cost of stove maintenance (O&M); and cost of LPG promotion program.

The intervention stove for this analysis is a two-burner LPG stove costing about US\$ 20. Additional costs of cylinder, pressure regulator and hose are US\$ 25. The intervention time horizon is 10 years. A useful life of the stoves of 10 years is applied in the analysis.

Cost of LPG fuel is GHS 5.94 per kg, which includes the rural distribution cost using Motorking. Consumption is 30 kg per person per year. The cost of LPG fuel is higher for

¹¹ An elasticity of -1.0 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 identified that provides estimates of price elasticities of demand for LPG.

households switching from wood than for households switching from charcoal because of larger average household size.

Annual O&M cost is assumed to be 5% of stove cost. The applied cost of promotion program is US\$ 34 per household adopting LPG, as for the improved biomass cookstove intervention. The promotion program is repeated after five years for follow up.

Not all households who initially switch to LPG are likely to sustain the use of LPG over the 10-year period for one reason or the other. It is therefore assumed that 80% of households that initially switch to LPG will continue using LPG after one year and 65% will continue using LPG from year two and onwards. Cost and benefits are calculated accordingly.

Total present value of cost per household over the ten-year period is estimated at GHS 4,848 for households switching from fuelwood and GHS 3,625 for households switching from charcoal (Table 17). The cost of LPG fuel represents 85-90% of total cost.

Table 17: Present value of cost of switching to LPG for new users (GHS per household)

	Switching from fuelwood	Switching from charcoal
Cost of stove	225	225
Cost of LPG fuel	4,341	3,117
Stove O&M	23	23
Promotion program	260	260
Total costs	4,848	3,625

Note: Present value (PV) of cost is calculated at discount rate of 8%. Source: Estimates by authors.

The cost of the intervention for current rural users of LPG is simply the cost of distribution using Motorking. This is GHS 0.42 per kg of LPG, or GHS 1.28 per cylinder of LPG (3 kg), which translates to a present value of cost of GHS 347 per household over the ten-year intervention period, at a discount rate of 8%. The benefit is the savings from the household not having to travel to a refill station (see below).

4.3.2 Benefits

The quantified benefits of the intervention are:

- i. The value of health improvements (“disability adjusted life year” (DALY));
- ii. Reduced cooking time resulting from the use of LPG (40 minutes per day);
- iii. Biomass fuel savings resulting from switching to LPG; and
- iv. Reduced CO₂ emissions.

The health benefits of LPG are estimated based on partial community adoption of LPG, and therefore PM2.5 personal exposures of 35-50 $\mu\text{g}/\text{m}^3$. The health benefits of switching from fuelwood to LPG are more than twice as large as for switching from charcoal. This is a result of the much larger absolute reduction in PM2.5 exposure for switching from fuelwood.

For cooking time savings, Siddiqui et al (2009) report that daily fuel burning time for cooking in a semi-rural community outside Karachi was 30 minutes less in households using natural gas than in households using wood, and that time spent in the kitchen was 40 minutes less. Jeuland and Pattanayak (2012) assumes that LPG saves one hour per day in cooking time. Based on this review, a cooking time saving of 40 minutes per day from switching to LPG from fuelwood or charcoal is applied here. A value of time equal to 50% of rural wage rates are applied to estimate the value of these time savings.

Value of fuelwood savings in rural areas is time savings from reduced fuelwood collection, with time valued at 50% of wage rate. Fuelwood collection for rural households using traditional woodstoves is 0.5 hours per day.¹² Value of charcoal savings is the market price of charcoal, estimated at GHS 0.77 per kg in rural areas.¹³

As for CO₂ emissions reductions, applying the results from Bailis et al (2015) and Tol (2011) as for the improved wood and charcoal cookstoves, the present value of carbon benefits of switching to LPG over a ten-year intervention period is GHS 134 per household with a 5% discount rate and GHS 0 for 8% and 14% discount rates.

Total benefits per household is estimated at GHS 8,383 and GHS 6,734 for switching from fuelwood and charcoal respectively (Table 18).

Table 18: PV of benefits of switching to LPG for new rural users (GHS per household)

	Switching from fuelwood	Switching from charcoal
Health benefits	2,476	1,040
Cooking time savings	3,375	3,375
Fuel savings	2,531	2,320
CO2 reductions	0	0
Total benefits	8,383	6,734

Note: Discount rate is 8%. Source: Estimates by authors.

¹² Ghana sector mapping by Accenture 2012 for Global Alliance for Clean Cookstoves has 0.5 hrs/hh/day.

¹³ The rural-urban price difference is estimated using regional rural population shares and regional charcoal price data from the Ghana National Energy Statistics 2008-2017 by the Energy Commission of Ghana, 2018.

The benefit of the intervention for current rural users of LPG is avoided cost of traveling to a refill station. This amounts to a present value of benefit of GHS 2,177 per household over the ten-year intervention period, at a discount rate of 8%, based on the previously calculated cost of GHS 2.69 per kg of LPG.

4.3.3 Benefit-cost ratios

Benefit-cost ratios (BCRs) are calculated as present value of total benefits divided by present value of total costs per household. The BCR is 1.7 for new rural users of LPG switching from fuelwood and 1.9 for new rural users switching from charcoal. The BCR for current users of LPG is as high as 6.3 due to the large avoided costs of traveling to a refill station. Overall, for both new and current users the BCR is 2.1 (Table 19). In other words, benefits are GHS 2.1 for every GHS 1 spent. The BCRs differ minimally for the lower and higher discount rates. Quality of evidence for the calculations of costs and benefits is rated as medium-strong.

Table 19: Present value of benefits and costs of intervention, GHS per household and BCRs

Interventions	Benefit	Cost	BCR	Quality of evidence
Expanded distribution of LPG in rural areas				Medium-Strong
New users of LPG (switching from wood)	8,383	4,848	1.7	
New users of LPG (switching from charcoal)	6,734	3,625	1.9	
Current users of LPG	2,177	347	6.3	
New and current users of LPG	4,926	2,328	2.1	

Note: Discount rate is 8%. BCR for new and current users is 2.2 at 5% discount rate and 2.3 at 14% discount rate. Source: Estimates by authors.

5. Elimination of taxes on LPG fuel for cooking

5.1 Description of intervention

In Ghana, LPG used to be subsidized by government, but in recent times, as at July 2019, there has been a 23% tax on LPG which the LPG marketing companies' association is calling on government to as a matter of urgency to remove all taxes on LPG in order to promote the use of LPG by households (Ghanaweb, 2019).

According to the association, in 2015 a typical 14.5kg LPG filled cylinder cost about GHS 48 and a bag of charcoal was GHS 40. The bag of charcoal is now GHS 45 while the 14.5 kg LPG filled cylinder costs as much as GHS 80 (Ghanaweb, 2019).

This increase in the price of LPG, in part caused by the tax, is making some households cut LPG consumption and increase the use of solid fuels for cooking.

The intervention assessed in this paper is elimination of LPG fuel tax. The removal of the tax on LPG fuel decreases the effective price of LPG paid by LPG consumers. Total LPG consumption is consequently expected to increase. If the constant price elasticity of LPG demand is -1.0, the tax removal would result in a 23% increase in LPG consumption.¹⁴

5.2 Calculation of Costs and benefits

5.2.1 Costs

Eliminating taxes on LPG will increase the use of LPG fuel for cooking among both rural and urban households. The cost of this increase in the use of LPG is the cost of LPG stove, cylinder and connection equipment for users who may not previously have used LPG; cost of LPG fuel; cost of LPG stove maintenance. These costs were calculated for rural households in section 4 and are similarly done for urban households.

5.2.2 Benefits

The quantified benefit of eliminating taxes on LPG fuel for cooking, and resultant increase use of LPG instead of biomass fuels, is the value of health improvements, biomass fuel savings resulting from switching to LPG or increased use of LPG, reduced cooking time resulting from the LPG cookstove, and reduced CO₂ emissions. These benefits were calculated for rural households in section 4 and are similarly done for urban households.

5.3.3 Benefit-cost ratios

BCRs are estimated for four groups of households and aggregated to provide a single overall BCR. The four groups are: households switching to LPG from fuelwood in rural (1) and in urban areas (2), and households switching to LPG from charcoal in rural (3) and in urban areas (4). BCRs are higher among urban households because of higher value of biomass fuel savings and higher valuation of time savings due to higher incomes.

¹⁴ An elasticity of -1.0 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 identified that provides estimates of price elasticities of demand for LPG.

An aggregate BCR is then calculated based on rural and urban prevalence rates of fuelwood and charcoal use, and an assumption that most of the households that will switch to LPG due to the price decline in LPG from the tax removal are charcoal users (80%). This is because users of charcoal tend to be financially better off than users of fuelwood, and therefore can better afford to switch to LPG.

The BCRs are presented in Table 20. The aggregate BCR of tax removal is 2.6, meaning that benefits are GHS 2.6 for every GHS 1 spent by the household. If the loss in government tax revenue is included as a cost of the intervention, and as a transfer benefit to households, then the BCR is 1.9.

Table 20: Present value of benefits and costs of intervention, GHS per household and BCRs

Response to tax removal		Benefit	Cost	BCR	Quality of evidence
LPG from fuelwood	Rural	8,383	4,848	1.7	Medium-Strong
	Urban	12,925	4,296	3.0	
	Total	12,153	4,390	2.8	
LPG from charcoal	Rural	6,734	3,635	1.9	
	Urban	9,673	3,574	2.7	
	Total	9,174	3,582	2.6	
LPG (from wood and charcoal)	Total	9,770	3,744	2.6	

Note: Discount rate is 8%. BCR for 5% and 14% discount rate is 2.7 and 2.5 respectively. Source: Estimates by authors.

6. Conclusion

Benefit-cost ratios (BCRs) are found to be the largest for promotion of improved fuelwood stoves (9-13) and improved charcoal stoves (6-8) followed by expanded distribution of Liquefied Petroleum Gas (LPG) in rural areas (2-6) and elimination of taxes on LPG fuel for cooking nationwide (1.9-2.6), applying a discount rate of 8% of future benefits and costs.

These BCRs reflect health benefits of the interventions valued at 1.3-1.6 times GDP per capita per “disability adjusted life year” (DALY) saved. Monetary values of time savings are estimated at 50% of wage rates. Fuel savings are valued at market prices when predominantly bought in the market and at fuel wood collection time savings in rural areas (using 50% of wage rates). 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 charcoal and fuelwood cookstoves are several times larger than for the interventions for expanded use of LPG and LPG tax removal, the

health impact of using LPG is roughly 50% larger than the health impact of improved cookstoves. Thus, in order to make a substantial dent in the huge health effects of solid fuels used for cooking in Ghana, predominant and sustained use of LPG or other clean cooking solutions needs to be achieved. However, improved biomass cookstoves can serve as an intermediate solution for households that elect to do so.

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 “improved stove” and “clean cooking fuel” communities along the lines of community-led sanitation programs and “open defecation free” communities.

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