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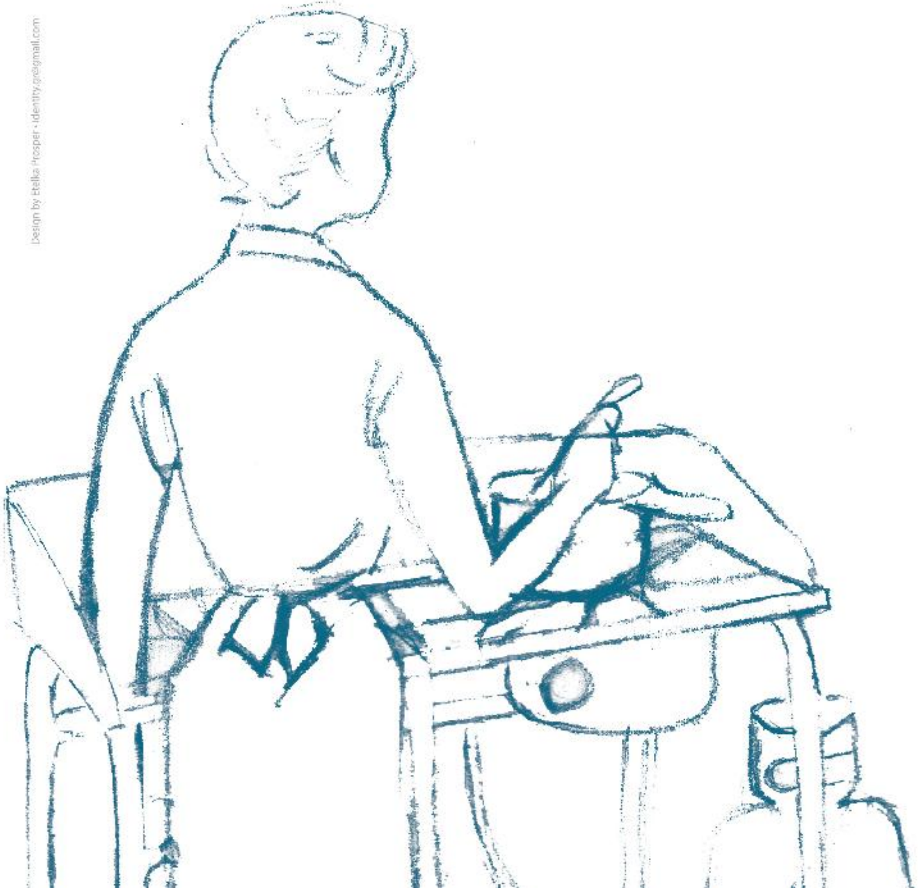
Benefit-Cost Analysis

Benefits and Costs of Cooking Options

for Household Air Pollution Control



COPENHAGEN CONSENSUS CENTER

Haïti Priorise
Un plan de **développement** alternatif

Benefits and Costs of Cooking Options for Household Air Pollution Control

Haïti Priorise

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This work has been produced as a part of the Haiti Priorise project.

This project is undertaken with the financial support of the Government of Canada. The opinions and interpretations in this publication are those of the author and do not necessarily reflect those of the Government of Canada.

Acronyms

AF	Attributable fraction
ALRI	Acute lower respiratory infection
CB	Chronic bronchitis
CBV	Cerebrovascular disease
CCC	Copenhagen Consensus Center
COPD	Chronic obstructive pulmonary disease
CP	Cardiopulmonary disease
DALY	Disability adjusted life year
GBD	Global burden of disease
GDP	Gross domestic product
HAP	Household air pollution
ICS	Improved cookstove
IHD	Ischemic heart disease
LC	Lung cancer
LPG	Liquefied petroleum gas
$\mu g/m^3$	microgram per cubic meter
PM	Particulate matter
PPP	Purchasing power parity
RR	Relative risk
VSL	Value of statistical life
YLD	Year lost to disease
YLL	Year of life lost to premature death
WHO	World Health Organization

Policy abstract

Context

Nearly 2.9 million people died globally in 2015 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 (GBD) Project. This makes household air pollution (HAP) one of the leading health risk factors in developing countries.

Over 8,200 people died from HAP in Haiti in 2016 according to the estimates in this paper. This makes HAP the fourth most serious health risk factor in Haiti in terms of death and disability after child and maternal malnutrition, unsafe sex, and high blood pressure according to the Global Burden of Disease Project 2015.[1]

About 95% of the population in Haiti relied on solid fuels for cooking in 2012 - evenly split between charcoal and wood – compared to about 40% globally. The rate of penetration of clean cooking fuels in Haiti, such as LPG, is the lowest in the Americas.

Very few households in Haiti have adopted improved wood and charcoal cookstoves with more efficient, cleaner burning and less pollution. Judging from exposure studies in the Americas and other regions, household members' average exposures to PM2.5 in Haiti may therefore be on the order of 100-200 $\mu g/m^3$ among households cooking with wood and on the order of 50-100 $\mu g/m^3$ among households cooking with charcoal, 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 $\mu g/m^3$, and cause serious health effects including heart disease, stroke, lung cancer and respiratory diseases.

Interventions

The objective of this paper is to assess benefits and costs of cook stove interventions that help reduce household PM2.5 air pollution from the use of solid fuels for cooking in Haiti. Beneficiaries are households that cook with solid fuels in unimproved, traditional stoves or over open fire, constituting over 90% of the population.

Specifically, the interventions are promotion programs for household adoption of:

i) Improved wood or charcoal stoves; and
ii) LPG or ethanol stoves.

The success of such stove promotion programs – i.e., high household adoption rates and sustained use and maintenance of the cook stove options - will depend on factors such as household acceptability of the characteristics of the stoves being promoted, stove financing arrangements,

[1] http://www.healthdata.org/haiti

household perceptions of benefits of the cook stoves, and program follow-up in terms of monitoring and promotion of sustained use of the stoves as well as proper stove maintenance and repair.

This paper focuses exclusively on benefits and costs of the cook stove options in order to elucidate if such promotion programs - if properly designed and implemented and households at least to some extent adopt and use the stoves being promoted - are likely to provide larger benefits than costs.

Benefits and costs

Benefits assessed are household health improvements from the stoves being promoted, biomass fuel savings, cooking time savings, and potential domestic production of ethanol fuel in Haiti. Benefits not assessed include: global climate benefits from reduced biomass consumption, ecological benefits of reduced biomass harvesting, and avoided environmental impacts of reduced charcoal production. The benefit-cost ratios (BCRs) presented in this paper are therefore conservative from this perspective.

Costs assessed are stove purchase, stove maintenance, LPG or ethanol fuel purchase, and costs of stove promotion programs. Benefits and costs are expressed as benefit-cost ratios (BCR), being the present value of total benefits divided by the present value of total costs.

Benefits of improved biomass stoves (ICS-W and ICS-C) are nearly four times larger than costs, while benefits of LPG and ethanol stoves are 1.2-2.2 times larger than costs.[2] However, health benefits of cooking with LPG or ethanol are nearly 2.5 times larger than cooking with an improved wood stove and 50% larger than cooking with an improved charcoal stove. Thus clean cooking options, such as LPG and ethanol, are the only longer term solutions to HAP.

TABLE 1. SUMMARY OF AVERAGE BCRS OF COOKSTOVE INTERVENTIONS, 2016*

Interventions	BCRs
Improved charcoal and wood stoves (ICS-C and ICS-W)	3.85
LPG and ethanol stoves for households currently cooking with wood (W)	1.25
LPG and ethanol stoves for households currently cooking with charcoal (C)	2.15

* Benefits and costs are annualized at a 5% discount rate. Source: Estimates by the author.

All BCRs are ranked “strong” in “quality of evidence” except for the improved charcoal stove (ICS-C) intervention due to the limited evidence of pre- and post-intervention PM2.5 exposure levels. However, the limited evidence does not have a major bearing on the BCR as health benefits only account for moderate share of total benefits. The “quality of evidence” of the BCR of the intervention is therefore ranked “medium to strong”.

[2] These BCRs are central estimates based on a discount rate of 5% and valuation of health benefits at 3 times GDP per capita per avoided year of life lost to disease (premature death or disability adjusted illness).

TABLE 2. AVERAGE BENEFITS AND COSTS OF COOKSTOVE INTERVENTIONS, 2016 (GOURDES/HOUSEHOLD/YEAR)*

	Benefits	Costs	**BCR**	**Quality of evidence**
ICS-W	3,529	910	3.9	Strong
ICS - C	6,312	1,643	3.8	Medium to Strong
LPG - W	8,462	6,916	1.2	Strong
Ethanol - W	9,056	6,864	1.3	Strong
LPG - C	14,441	6,916	2.1	Strong
Ethanol - C	15,035	6,864	2.2	Strong

* Benefits and costs are annualized at a 5% discount rate. Source: Estimates by the author.

Intervention programs

The BCRs estimated in this paper represent "potentials", and depend on the quality, intensity and duration of promotion programs. BCRs of interventions 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

The objective of this paper is to assess benefits and costs of cook stove interventions that help reduce household PM2.5 air pollution from the use of solid fuels for cooking in Haiti.

The use of solid fuels for cooking causes serious household air pollution (HAP) in the indoor and outdoor household environment. An estimated 2.9 million people died globally in 2015 from harmful exposure to PM2.5 emissions from household use of solid fuels according to the Global Burden of Disease (GBD) Project (Forouzanfar et al, 2016). This makes HAP one of the leading health risk factors in developing countries.

HAP is also a major public health issue in Haiti. Over 8,200 people died from HAP in Haiti in 2016 according to estimates in this paper. This makes HAP the fourth most serious risk factor in the country in terms of death and disability after child and maternal malnutrition, unsafe sex, and high blood pressure according to the Global Burden of Disease Project 2015.[1]

About 95% of the population relied on highly polluting solid fuels for cooking in 2012 according to the Haiti DHS 2012 survey, evenly split between charcoal and wood. Very few households have adopted improved cookstoves with more efficient, cleaner burning and less pollution and LPG has low penetration with the lowest rate in the Americas.

Haiti is severely deforested. Forest area is less than 4% of land area (World Bank, 2016a). Nearly 7 tons of wood is used to make 1 ton of charcoal (Ashden, 2013). A household cooking with charcoal uses about 0.5-0.8 tons of charcoal per year (Ashden, 2013; Bossuet and Serar, 2014). This is equivalent to 3.5-5.5 tons of wood. This is several times the approximately 1.4 tons of wood used by a household cooking with wood.

Biomass fuels are expensive, reflecting the scarcity of forested land. A kg of charcoal cost nearly US$ 0.5. Thus a household can spend US$ 0.75 – 1.0 on charcoal per day, this in light of the fact that 54% of the population lived on less than US$ 1 per person day as recently as in 2012 (World Bank, 2016a).

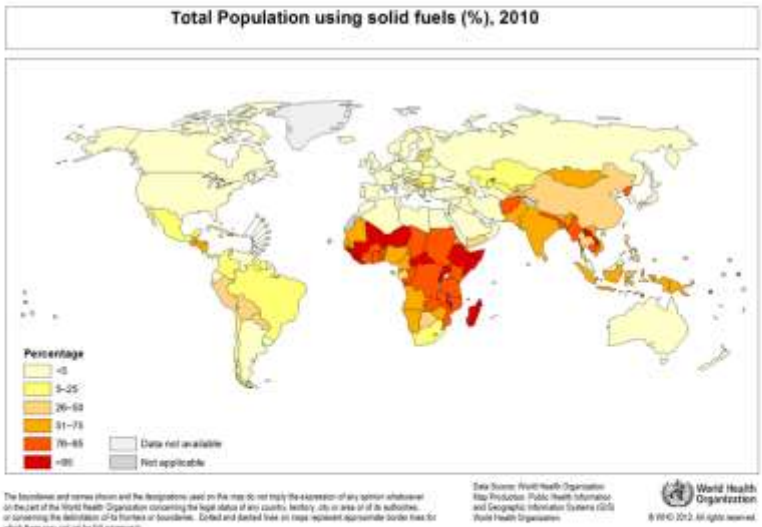
Projects, organizations and enterprises have in recent years started promoting improved cookstoves (ICS) and clean fuels. Several improved charcoal stoves are being promoted by various enterprises and with international donor support. A project is also promoting LPG stoves and cylinders to Haitian households (SWITCH Project). Ethanol stoves are also being promoted (Project Gaia), as in some African countries, eventually with local production of ethanol. Initial work indicates that ethanol is cost competitive with LPG.

[1] http://www.healthdata.org/haiti

2. Household use of solid biomass fuels

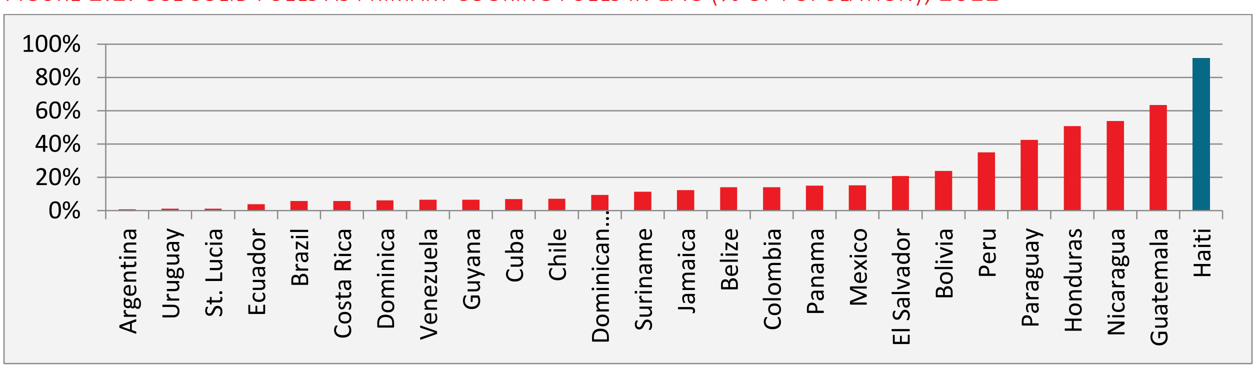
As many as 41% of households globally relied mainly on solid fuels for cooking in 2010 (Bonjour et al, 2013). Prevalence rates of solid fuel use are particularly high in Sub-Saharan Africa and several countries in Asia (figure 2.1). Prevalence is also still high in several countries in Latin America and the Caribbean (LAC), and reaches over 90% in Haiti (figure 2.2).

FIGURE 2.1 PREVALENCE OF SOLID FUEL USE, 2010



Source: Presented in Smith et al (2014).

FIGURE 2.2. USE SOLID FUELS AS PRIMARY COOKING FUELS IN LAC (% OF POPULATION), 2012



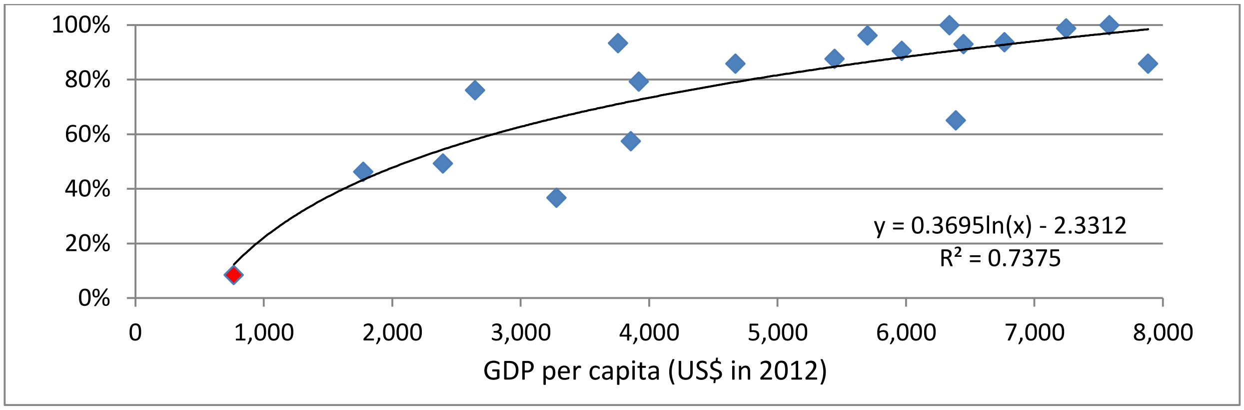
Note: Countries in LAC in 2012 with GDP per capita < US$ 16,000 or solid fuel use > 1%. Source: World Bank (2016a).

The use of modern fuels (e.g., LPG, natural gas, electricity) instead of solid fuels as primary cooking fuels generally increases with GDP per capita as evident in figure 2.3 for countries in the LAC region.[2] Countries above the solid line have a higher prevalence of modern fuel use than predicted by their GDP per capita, and countries below the line have a lower prevalence than predicted by

[22] The strongest relationship in LAC between prevalence rates of modern fuel use for cooking and GDP per capita is for countries with GDP per capita < US$ 8,000, with R^2=0.74 (19 countries). The relationship is also strong at higher levels of income, with R^2=0.68 for countries with GDP per capita < 16,000 (31 countries). The relationship between Purchasing Power Parity (PPP) adjusted GDP per capita and modern fuel use is similar to that of GDP per capita at market prices with R^2=0.70.

their GDP per capita. The prevalence of modern fuel use in Haiti is very close to the rate predicted by GDP per capita.

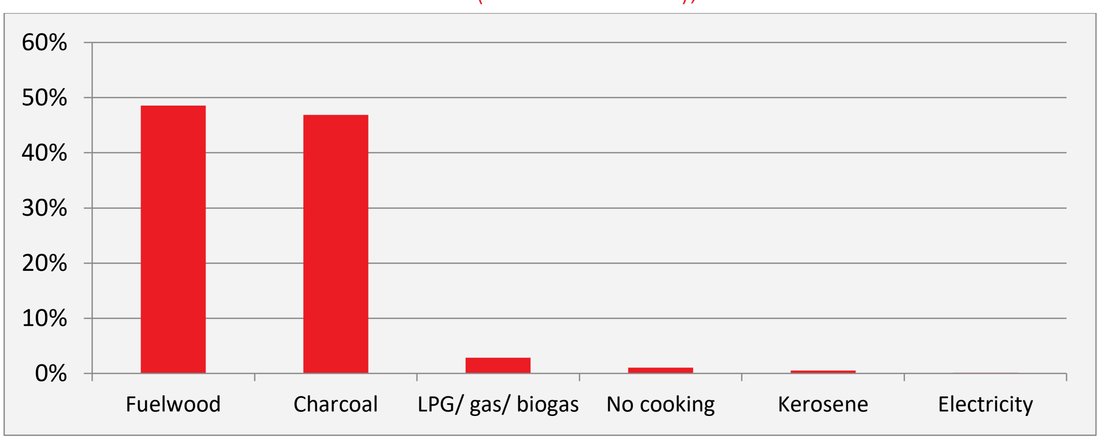
Figure 2.3. Use of modern fuels as primary cooking fuels in relation to income in LAC (% of population), 2012



Note: Haiti in red color. Source: Produced from data in World Bank (2016a).

About 95.5% of the population in Haiti lived in households cooking predominantly with solid fuels in 2012 according to the Haiti DHS 2012 (figure 2.4). Solid fuels were almost evenly split between fuelwood and charcoal, with charcoal as primary fuel mainly in urban areas and fuelwood as primary fuel mainly in rural areas.

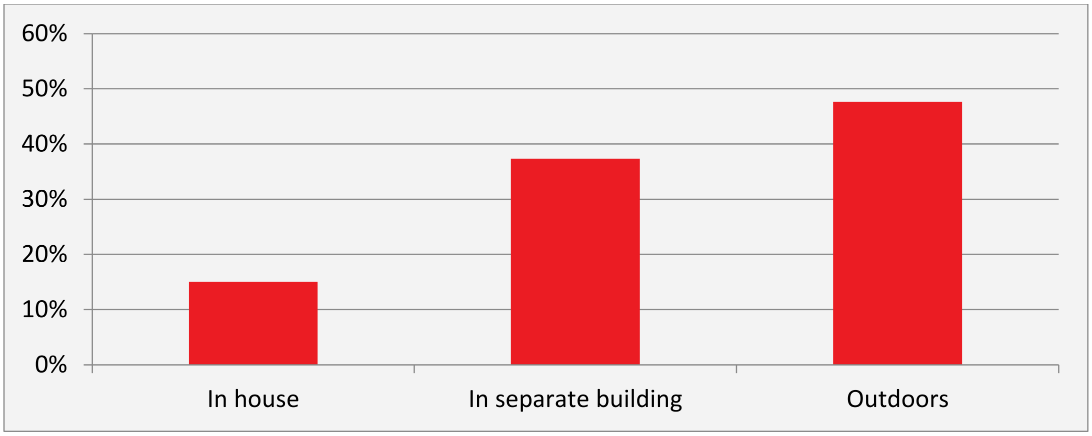
Figure 2.4 Predominant cooking fuel in Haiti (% of population), 2012



Source: Produced by the author from the Haiti DHS 2012 data.

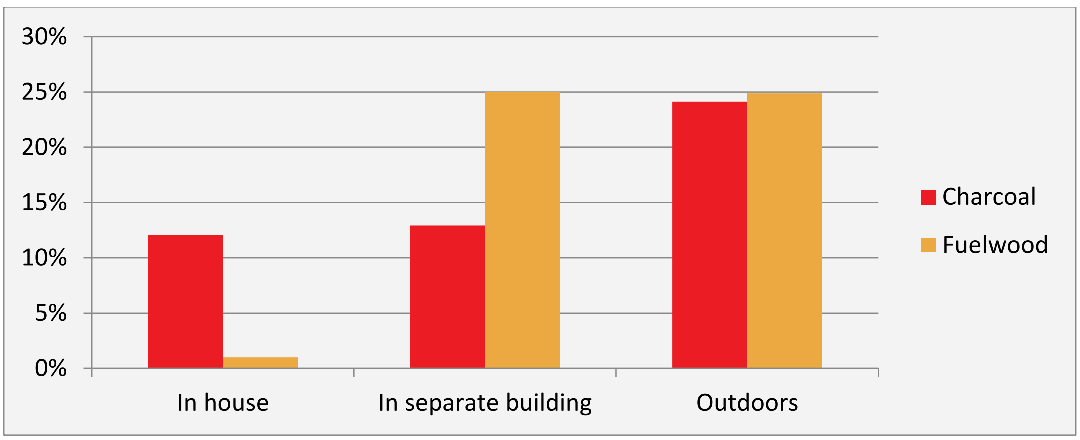
Nearly half of the population cooked outdoors, over 1/3rd cooked in a separate building, and 15% cooked in the house in 2012 (figure 2.5). Among households cooking with solid fuels, almost everyone cooking in the house used charcoal as primary fuel, while half of fuelwood users cooked in a separate building and half cooked outdoors (figure 2.6). Prevalence of solid fuel in 2016 is estimated at 94% based on historic projections (table 2.1).

Figure 2.5. Household cooking location in Haiti (% of population), 2012



Source: Produced by the author from the Haiti DHS 2012 data.

FIGURE 2.6. HOUSEHOLD COOKING LOCATION AMONG USERS OF SOLID FUELS IN HAITI (% OF SOLID FUEL USERS), 2012



Source: Produced by the author from the Haiti DHS 2012 data.

TABLE 2.1. ESTIMATED SOLID FUEL USE BY COOKING LOCATION IN HAITI, 2016 (% OF POPULATION)

	In house	In separate building	Outdoors	Total
Charcoal	11.3%	12.1%	22.8%	46.2%
Fuelwood	0.9%	23.5%	23.4%	47.8%
Total	12.2%	35.6%	46.2%	**94.0%**

Source: Estimates by the author.

3. 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 ($\mu g/m^3$) in the kitchen, and well over one hundred micrograms in the living and sleeping environments. These are findings from measurement studies around the world including in several countries of Latin American and the Caribbean (LAC) region (WHO, 2014). No comprehensive measurement studies of household PM2.5 are, however, available from Haiti. This section therefore presents studies from other LAC countries, as well as from other parts of the world.

Measurement studies in five LAC countries found 24-48 hours average PM2.5 kitchen concentrations of 130-1020 μg/m^3 among households that used wood for cooking over open fire or unimproved stoves. The same studies found that average concentrations declined to 50-340 μg/m^3 in the same kitchens after installation of improved cookstoves, often with an attached chimney (table 2.1).

Several studies also measured 24-48 hours personal PM2.5 exposure of the person cooking. Personal exposures averaged 116-260 μg/m^3 before and 58-100 μg/m^3 after the installation of improved cookstoves (table 2.2).

Some studies point to the community effects of cooking with solid fuels. A study in rural Mexico measured outdoor PM2.5 concentrations. Median 48-hours concentrations of about 80 μg/m^3 were found at the outdoor patio of the dwellings, and about 60 μg/m^3 at the community plaza with very little difference in concentration before and after installation of improved cookstoves with chimney (Zuk et al, 2007). A study in a semi-urban and a rural community in Honduras using solid fuels for cooking found 8-hour daytime average PM2.5 concentrations of 215 μg/m^3 outside dwellings using improved chimney stoves and 358 μg/m^3 outside dwellings cooking on open fire or traditional stoves (Clark et al, 2010).

Other studies point to the role of technologies and maintenance of the improved stoves and chimneys. Over 20% of the households in a study in Peru had a chimney above the fire. PM2.5 concentrations were, however, not statistically lower in these households than in households without chimney, suggesting that most of the smoke escaped into the kitchen from the open fire before reaching the chimney and/or that the chimneys were ineffective in venting the smoke (Pollard et al, 2014). Hartinger et al (2013), also in Peru, found that proper operation, maintenance and repair of stoves after installation was essential for reducing indoor PM2.5 concentrations, even in the first year. In Honduras, PM2.5 personal exposure levels and indoor concentrations decreased distinctly in relation to improvements in the quality of cookstoves (Clark et al, 2010).

Table 3.1. Average PM2.5 kitchen concentrations in households using solid fuels for cooking in Latin America (μg/m3)

Country	Unimproved stoves		Improved stoves		Source
Guatemala	Open fire	900	340	Improved chimney stove	Northcross et al (2010)
Honduras	Open fire/UCS	1002	266	Justa chimney stove	Clark et al (2009)*
Honduras	Open fire	310	60	ECO-Stove	Lam et al (2012)
Mexico	Open fire	257	101	Patsari chimney stove	Cynthia et al (2010)
Mexico	Open fire	1020	350	Patsari chimney stove	Cynthia et al (2008); Masera et al (2007)
Mexico	Open fire	658	255	Patsari chimney stove	Zuk et al (2007)
Nicaragua	Open fire	1801	416	Eco-Stove with chimney	Clark et al (2013)
Nicaragua	Open fire	514	53	Closed Eco-Stove	Terrado and Eitel (2005)
Nicaragua	Open fire	639	121	Semi-open Eco Stove	Terrado and Eitel (2005)
Peru	Open fire	130			Pollard et al (2014)
Peru	Various	173-207	50-84	Improved stove	Fitzgerald et al (2012)
Peru	Various	189	136	OPTIMA	Hartinger et al (2013)
Peru	Open fire	680	200	Inkawasina chimney stove	Winrock (2008)
Peru	Open fire	380	130	HNP 3-pot metal stove	Li et al (2011)
Peru	Open fire	320	110	BGC 3-pot metal stove	Li et al (2011)

Notes: Measurements are 24- to 48-hour averages. UCS=unimproved cookstove. * 8-hour daytime average.

Table 3.2. Average PM2.5 personal exposure in households using solid fuels for cooking in Latin America (μg/m3)

Country	Unimproved stoves		Improved stoves		Source
Guatemala	Open fire	264	102	Plancha chimney stove	McCracken et al (2007)*
Guatemala	Open fire	273	174	Plancha chimney stove	McCracken et al (2007)**
Guatemala	Open fire	200	70	Plancha chimney stove	McCracken et al (2013)*
Honduras	Open fire/UCS	198	74	Justa chimney stove	Clark et al (2009)
Mexico	Open fire	156	78	Patsari chimney stove	Cynthia et al (2010)
Mexico	Open fire	240	160	Patsari chimney stove	Cynthia et al (2008)
Nicaragua	Open fire	374	49	Closed Eco-Stove	Terrado and Eitel (2005)
Nicaragua	Open fire	355	96	Semi-open Eco Stove	Terrado and Eitel (2005)
Peru	Various	116-126	58-68	Improved stove	Fitzgerald et al (2012)
Peru	Open fire	190	80	HNP 3-pot metal stove	Li et al (2011)
Peru	Open fire	150	70	BGC 3-pot metal stove	Li et al (2011)

Notes: Measurements are 24- to 48-hour averages, except for in Honduras (8-hour daytime average). UCS=unimproved cookstove. * Control group (open fire) versus intervention group (chimney stove). ** Before (open fire) versus after (chimney stove) intervention. Also see McCracken et al (2011).

The studies of PM2.5 kitchen concentrations and personal exposure of the person cooking are summarized in table 3.3. Improved cookstoves reduced kitchen concentrations by over 65% and personal exposure by well over 55%.

Personal exposure is the indicator of importance in terms of health effects of household PM2.5. In household cooking over an open fire, the median[3] personal exposure of the person cooking was 200 μg/m³, or 20 times WHO's annual air quality guideline for outdoor PM2.5. The median personal exposure after installation of an improved cookstove was nearly 80 μg/m³ or still eight times WHO's annual guideline.

TABLE 3.3. PM2.5 KITCHEN CONCENTRATIONS AND PERSONAL EXPOSURE IN HOUSEHOLDS USING SOLID FUELS FOR COOKING IN LATIN AMERICA (μG/M³)

	Stat	No of studies	Open fire (μg/m³)	Improved stove (μg/m³)	Reductions from Improved stove
Kitchen concentrations	Mean	14	633	186	68%
	Median	14	577	133	66%
Personal exposure	Mean	11	229	92	57%
	Median	**11**	**200**	**78**	**58%**

Source: Calculated from studies presented above.

Exposure of adult women is used as a reference point for personal exposure in estimating the health effects of household air pollution, as well as the benefits and costs of cookstove options 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 discussed above are 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 3.4). 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, as the personal exposure studies presented above reflect this location. Personal exposures from cooking outdoors or in a separate building are set at 60-80% of exposure from cooking in the house (table 3.4). 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 3.4. 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/m³ is applied to adult women cooking in the house with *fuelwood* over open fire or traditional cookstove. This is the median exposure level of the cook in table 2.3. Average exposure levels of adult men and children under five years of age, and in various

[3] The median of the mean exposures in the studies referenced in this section.

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 3.4. So for instance, the exposure level of adult men in a household cooking outdoors with fuelwood is 200 μg/m^3 * H2 * L3 = 200 μg/m^3 * 60% * 60% = 72 μg/m^3 (table 3.5).

Very few measurements studies have been conducted of 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 PM2.5 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 3.5).

TABLE 3.5 LONG TERM PERSONAL PM2.5 EXPOSURE BY COOKING LOCATION IN HOUSEHOLDS USING TRADITIONAL COOKSTOVES WITH FUELWOOD OR CHARCOAL (μG/M3)

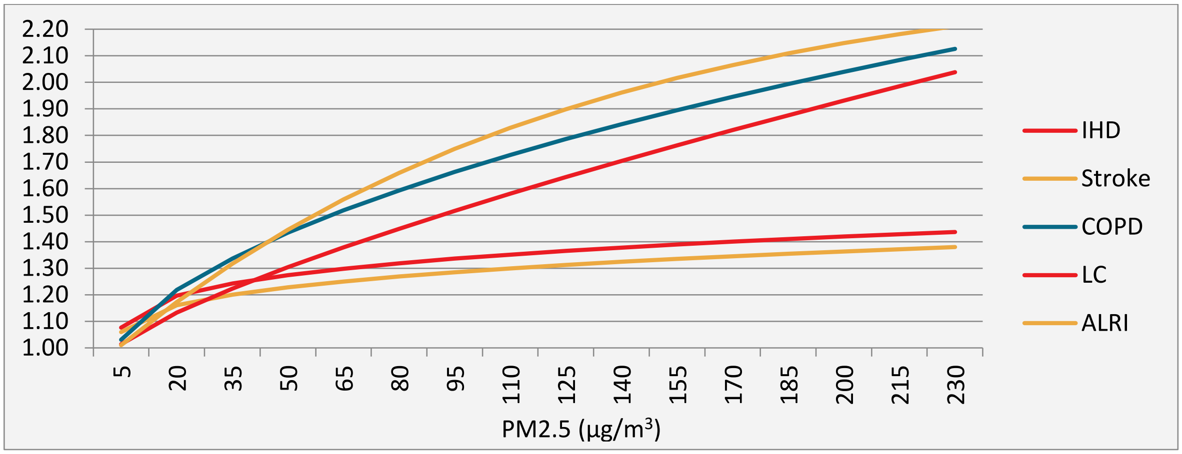
	Fuelwood - Traditional stove or open fire			**Charcoal** - Traditional stove		
	Adult women	Adult men	Children < 5 years	Adult women	Adult men	Children < 5 years
In house	200	120	170	120	72	102
Separate building	160	96	136	104	62	88
Outdoors	120	72	102	90	54	77

Source: Estimates by the author.

4. 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 under five years of age 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 4.1 shows how the risk of these five health effects in terms of mortality increases with increasing levels of PM2.5 exposure.

FIGURE 4.1 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 in table 2.1, PM2.5 exposure levels in table 3.5, and the relative risks of health effects in figure 4.1 are combined to estimate the health effects of household PM2.5 air pollution from the use of solid fuels. The results show that 22-24% of all IHD and stroke, and 32-42% of all COPD, lung cancer, and ALRI in the countries are from household PM2.5 air pollution.[4] The attributable percentages translate to annual deaths of 8,241 in 2016 (table 4.1). This is over 9% of all deaths from all causes in the country.

TABLE 4.1. ESTIMATED MORALITY ATTRIBUTABLE TO PM2.5 HOUSEHOLD AIR POLLUTION IN HAITI, 2016

	% of total cause-specific mortality	Annual cases of deaths
Ischemic heart disease (IHD)	24%	2,667
Cerebrovascular disease (stroke)	22%	2,125
COPD	39%	676
Lung cancer	32%	229
ALRI	42%	2,544
Total		**8,241**

Source: Estimates by the author.

The deaths and associated disease from HAP represents nearly 263 thousands disability adjusted life years (DALYs) lost among the population of Haiti in 2015 (table 4.2).

TABLE 4.2. ESTIMATED DALYS LOST ATTRIBUTABLE TO PM2.5 HOUSEHOLD AIR POLLUTION IN HAITI, 2016

	Per death	Total
Years of life lost to premature mortality (YLL)	31.33	258,187
Years lost to disease (YLD)	0.57	4,692
Disability adjusted life years (DALY)		**262,879**

[4] See annex 1 for methodological details.

Source: Estimates by the author.

The health effects from household air pollution can be monetized as a cost to society by using economic valuation methods. In the Haiti Priorities Project, the Copenhagen Consensus Center (CCC) applies a value per DALY of 1, 3, and 8 times GDP per capita, with DALYs discounted at an annual rate of 3, 5, and 12%. 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 Haiti is estimated at Gourdes 14.5 billion, equivalent to 3.6% of GDP.[5] The range of cost is Gourdes 2.6 – 49.2 billion, equivalent to 0.6 – 12.3% of GDP (table 4.3).[6]

For comparison, World Bank (2016b) proposes the use of "value of statistical life" or VSL for valuation of the welfare cost of premature mortality.[7] This implies an annual cost of Gourdes 16.7 billion, equivalent to 4.2% of GDP. This is almost identical to the cost when using a valuation of DALYs at 3 times GDP per capita and a discount rate of 4%.

TABLE 4.3. ANNUAL COST OF PM2.5 HOUSEHOLD AIR POLLUTION IN HAITI, 2016 (BILLION GOURDES, % OF GDP)

Discount rate/Value of DALYs	1*GDP/capita	3*GDP/capita	8*GDP/capita
3%	6.1	18.4	49.2
5%	4.8	14.5	38.6
12%	2.6	7.7	20.6
3%	1.5%	4.6%	12.3%
5%	1.2%	3.6%	9.7%
12%	0.6%	1.9%	5.2%

Note: Figures are for year 2016 in 2014 real prices. Source: Estimates by the author.

[5] DALY valued at 3 times GDP per capita, discounted at an annual rate of 5%.

[6] Cost of illness in terms of medical treatment and lost work days may be added to the estimated cost. This can be performed by first converting the YLDs to days of illness using disability weights. However, there is very limited information on how many of these days result in medical treatment and lost work days. If each day is valued at average wage rates, the total cost is about Gourdes 1.8 billion or a little over 10% of the central cost estimate of Gourdes 14.5 billion.

[7] By the methodology in World Bank (2016b), VSL is estimated by a "benefit transfer function" for countries in which no studies have estimated a VSL. Accordingly, VSL for Haiti is Gourdes 2,028,214 or 56 times GDP per capita, based on estimated GDP per capita in 2016 at 2014 prices. This value is multiplied by the number of deaths to estimate the welfare cost of premature mortality. The benefit transfer function is: $VSL_{c,n} = VSL_{OECD} * (\frac{Y_{c,n}}{Y_{OECD}})^{\epsilon}$ 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.

5. Pollution control interventions

The objective of this paper is to assess benefits and costs of cook stove interventions that help reduce household PM2.5 air pollution from the use of solid fuels for cooking in Haiti. Specifically, the interventions are promotion programs for household adoption of improved biomass cookstoves or clean fuel stoves (i.e., LPG and ethanol).

The success of such stove promotion programs – i.e., high household adoption rates and sustained use of the cook stove options - 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 cook stoves, 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).

Thus for large-scale adoption, sustained use, and realization of health benefits of cleaner cookstoves to occur in Haiti, several factors must be addressed, such as:

- i) Stoves with multiple burners to minimize continued use of old, traditional stoves;
- ii) High initial cost of improved charcoal, LPG and ethanol stoves;
- iii) High annual cost of LPG and ethanol fuel;
- iv) Tailoring of stoves to consumers' preferences for stove characteristics;
- v) Installment financing of stoves;
- vi) Public information (e.g health and non-health benefits);
- vii) Proper stove operation, maintenance and repair; and
- viii) Community focus similar to total sanitation and "open defecation free" community programs.

This paper, however, focuses exclusively on benefits and costs of the cook stove options in order to elucidate if such promotion programs - if properly designed and implemented and households at least to some extent adopt and use the stoves being promoted - are likely to provide larger benefits than costs.

The solid fuel use situation in Haiti is somewhat different than in the majority of developing countries in so far as charcoal is widely used as a cooking fuel. This warrants that both improved wood stoves and improved charcoal stoves are separately assessed in order to provide an adequate perspective on the economic and public health merits of household air pollution mitigation options. Moreover, as ethanol stoves are being promoted in Haiti (and may be a viable option to LPG) the ethanol option is also assessed and compared to LPG.

In total, benefits and costs of programs promoting four household cook stove interventions for household air pollution (HAP) control among households cooking with solid fuels over open fire or traditional, unimproved cookstove are assessed in this paper. The interventions and rationales for assessment are presented in table 5.1.

TABLE 5.1. COOKSTOVE INTERVENTIONS

	Interventions	Rationale for interventions
1	Improved wood stove (ICS-W)	48% of the population use fuelwood as primary fuel for cooking
2	Improved charcoal stove (ICS-C)	46% of households use charcoal as primary fuel for cooking
3	LPG stove	Haiti is severely deforested. Clean fuels such as LPG are by far most effective in protecting health.
4	Ethanol stove	Haiti is severely deforested. Clean fuels such as LPG are by far most effective in protecting health. Haiti needs local industry/agricultural development and employment generation (e.g., ethanol production).

Stoves that are assessed have a minimum of two burners so that households are less likely to continue using their traditional stoves for their cooking needs.

The cookstove 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 cookstove interventions are assessed in three cooking locations:

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

The interventions are assessed for two targeting scenarios in terms of community adoption rates of the cookstove interventions:

(1) *Partial adoption* with continued high community pollution from cooking; and
(2) *Full adoption* with substantially lower community pollution.

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.

6. Post-intervention PM2.5 exposures

The use of improved wood or charcoal cookstoves (ICS), LPG or ethanol for cooking is expected to substantially reduce household members' exposure to PM2.5. The review of the personal exposure studies in Latin America in section 3 before and after installation of an ICS for wood indicated a median reduction in exposure of over 55% from about 200 $\mu g/m^3$ to 80 $\mu g/m^3$.

The exposure reductions were 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 and is applied here to households cooking in the house.[8] 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.[9]

Table 6.1 summarizes the exposure reductions from ICS. The reductions are applied to both ICS for wood and charcoal. The reductions are relative to the exposure levels using traditional cookstoves (TCS) presented in table 3.5, and are applied to adult women, men and children.

TABLE 6.1. HOUSEHOLD MEMBER EXPOSURE REDUCTION FROM THE USE OF ICS FOR WOOD OR CHARCOAL

In house	40%
Separate building	35%
Outdoors	25%

Source: The author.

[8] A 40% reduction over the life of the ICS for wood 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.

[9] 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.

Combustion of LPG or ethanol 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 or ethanol 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.

In the case of full community adoption of LPG or ethanol, a personal exposure level of 25 μg/m^3 is applied to all household members. This exposure originates from other sources of PM2.5 in the household environment and non-solid fuel related outdoor ambient PM2.5.

Personal exposure levels in households using LPG or ethanol may decline to levels below 25 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 6.2 and reflect the exposure reductions from ICS and levels associated with LPG and ethanol discussed above. The exposure levels are broad averages and will vary substantially across individual households.

TABLE 6.2. HOUSEHOLD MEMBER AIR POLLUTION EXPOSURE BY INTERVENTION AND COOKING LOCATION (μG/M^3)

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

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

7. Health benefits of interventions

Health benefits of moving from pre-intervention to post-intervention exposure levels are estimated by using the integrated PM2.5 exposure-health response methodology from the GBD 2015 Project presented in annex 1 and health risks presented in figure 4.1.

Estimated percentage reductions in health effects of interventions are presented in table 6.1. The reductions – or health benefits - are larger among households cooking in the house than among households cooking in separate building or outdoors, due to larger exposure reductions in the former group of households.

It should also be noted that the percentage reduction in health effects from using an ICS is substantially smaller than the percentage reduction in PM2.5 exposure, as seen by comparing tables 6.1 and 7.1. This is because of the non-linear relationship between exposure level and health risks, as seen in figure 4.1.

Moreover, switching to LPG and ethanol will provide more than twice as high health benefits as switching to ICS among current fuelwood users, (column 3 vs. 1 in table 7.1), and about 50% higher health benefits among current charcoal users (column 4 vs. 2).

Table 7.1 Reduction in health effects from cookstove interventions

	1	2	3	4
	ICS -Wood	ICS -Charcoal	LPG or ethanol -From wood	LPG or ethanol -From charcoal
In house	26%	23%	60%	34%
In separate building	21%	19%	48%	27%
Outdoors	13%	12%	34%	20%

Source: Estimates by the author.

Percentage reductions in health effects in the case of full community adoption of LPG or ethanol are substantially larger than in the case of partial adoption (table 7.2). This is due to reduced community pollution from full adoption, and thus a reduction in personal PM2.5 exposure from 35-50 $\mu g/m^3$ to 25 $\mu g/m^3$ as seen in table 6.2. In total, over 4,150 deaths can be avoided annually by full community adoption of LPG or ethanol. If exposure after full adoption is 10 $\mu g/m^3$ instead of 25 $\mu g/m^3$, then 5,900 deaths are avoided annually.

TABLE 7.2 REDUCTION IN HEALTH EFFECTS FROM COOKSTOVE INTERVENTIONS – PARTIAL VERSUS FULL ADOPTION

	LPG or ethanol
Partial community adoption*	34%
Full community adoption*	52%
Annual deaths avoided (full community adoption of intervention)	**4,152**

* Weighted average by solid fuel and cooking location. Source: Estimates by the author.

8. Non-health benefits of interventions

Switching to an improved cookstove (ICS) or to LPG or ethanol also has non-health benefits. Main benefits are reduced fuelwood or charcoal 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. Use of ethanol also has economic benefits from local production of ethanol.

8.1 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.

As for charcoal, two improved charcoal cookstoves marketed in Haiti are reported to provide charcoal fuel savings of 43-55%. These are the D&E Eco Recho stove (Ashden, 2013) and the Prakti Wouj stove (Bossuet and Serrar, 2014).

It is here assumed that average fuel savings are 40% from the use of an improved cookstove for fuelwood and charcoal, instead of an unimproved stove or open fire. Use of LPG or ethanol results in 100% savings of biomass fuels.

Many urban households purchase some or all of the biomass fuels they use for cooking while the majority of rural households collects these fuels themselves. It is important to impute a value of these self-collected fuels. A common approach is to impute a value based on the amount of time households spend on biomass fuel collection.

For fuelwood, primarily used in rural areas, the value of fuel savings can be estimated based on a fuelwood collection time of 30 minutes per household per day among households using unimproved stoves or open fire, a female rural wages rate of Gourdes 10 per hour, and a value of time equal to 50% of the female wage rate. A female wage rate is applied as most fuel collection is carried out by women (or children).

Alternatively, the value of fuelwood savings may be estimated based on the rural market price of fuelwood, reported at about Gourdes 5 per kg in 2016 or Gourdes 4.3 per kg at 2014 real prices. Fuelwood consumption is estimated at 1,400 kg per household per year.[10]

The estimated value of fuelwood savings are presented in table 8.1. A mean of self-collection and purchase is applied as the value of fuelwood savings in the benefit-cost assessment in this paper, as some households purchase fuelwood or households in principle could sell the self-collected fuelwood.

TABLE 8.1 ESTIMATED VALUE OF FUELWOOD SAVINGS FROM AN IMPROVED COOKSTOVE, 2016

	Self-collection	Purchase
Fuelwood collection time (minutes/household/day)	30	
Female rural wage rate (Gourdes/hour)*	10	
Value of time (% of wage rate)	50%	
Rural market price of fuelwood (Gourdes/kg)*		4.25
Fuelwood consumption (kg/household/year)		1,400
Value of fuelwood (Gourdes/household/year)	900	6,000
Value of fuelwood savings (Gourdes/household/year)		
Improved cookstove (40% savings)	360	2,400
LPG and ethanol stove (100% savings)	900	6,000

* 2014 real prices. Source: Author's estimates.

For charcoal, primarily used in urban areas, the value of fuel savings are estimated based on a market price of charcoal of Gourdes 20.5 per kg and a conservative charcoal consumption of 1.5 kg per household per day among households using a traditional, unimproved charcoal stove.[11] Fuel savings are presented in table 8.2.

While the value or cost of annual charcoal consumption is very high, it is "only" 17% higher than the cost of using fuelwood in urban areas, at a fuelwood price of about Gourdes 8 per kg (Gourdes 6.8 in 2014 real prices) and estimated annual fuelwood consumption of 1,400 kg per household for cooking.

[10] Estimated based on LPG consumption of 30 kg per person per year, a fuelwood energy content of 15 MJ per kg and a 15% average energy efficiency of traditional woodstoves and open fire.
[11] Consumption is reported to be 1.3-2.3 kg per household per day for urban households in Haiti (Ashden, 2013; Bossuet and Serrar, 2014).

TABLE 8.2 ESTIMATED VALUE OF CHARCOAL SAVINGS FROM AN IMPROVED COOKSTOVE, 2016

Charcoal market price (Gourdes per kg)*	20.5
Charcoal consumption (kg/household/day)	1.5
Value of charcoal consumption (Gourdes/household/year)	11,200
Value of fuelwood savings (Gourdes/household/year)	
Improved cookstove (40% savings)	4,480
LPG and ethanol stove (100% savings)	11,200

* Real 2014 prices. Source: Author's estimates.

8.2 Cooking time savings

Households in developing countries typically spend 3-5 hours per day on cooking. 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. 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.

This paper applies a cooking time saving of 15 minutes per day from the use of an improved cookstove for fuelwood or charcoal and 30 minutes from the use of LPG or ethanol compared to an unimproved cookstove or open fire. As for fuelwood collection time savings, a value of time equal to 50% of female wage rates are applied to estimate the value of cooking time savings. Annual value of time savings per rural and urban household is presented in table 8.3.

TABLE 8.3. ESTIMATED VALUE OF COOKING TIME SAVINGS, 2016

	Gourdes/household/year	
	Rural	Urban
Female wage rate (Gourdes/hour)*	10	20
Improved cookstove	450	900
LPG and ethanol stove	900	1,800

* Real wages at 2014 prices. Source: Author's estimates.

8.3 Ethanol production

Ethanol for cooking can be produced locally in Haiti, in contrast to LPG. This has an added economic benefit. A household in Haiti may consume around 220 liters per year for cooking. This is estimated based on an LPG consumption of 30 kg per person per year, and relative energy contents and stove efficiencies of LPG and ethanol. Cost of ethanol is reported to be about US$ 0.6 per liter.[12] If economic benefits of local production are measured as a profit margin of 10%, then the benefit of local production is Gourdes 2.7 per liter or equivalent to Gourdes 594 per household per year (table 8.4).

1.4. ESTIMATE OF THE ECONOMIC BENEFIT OF ETHANOL PRODUCTION IN HAITI, 2016

Ethanol consumption (liters/household/year	220
Value of ethanol (Gourdes/liter)*	27
Value of annual ethanol consumption (Gourdes/household/year)	5,940
Economic benefit of production	10%
Economic benefit (Gourdes/household/year)	594

* Real 2014 prices. Source: Author's estimates.

Benefits not assessed in this paper include: global climate benefits from reduced biomass consumption, ecological benefits of reduced biomass harvesting, and avoided environmental impacts of reduced charcoal production. The benefit-cost ratios presented in this paper are therefore conservative from this perspective.

9. Costs of interventions

9.1 Cost of stoves

Cost of improved wood stoves varies tremendously depending on fuel and emission efficiency, durability, materials, and technology. Basic 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.

Several improved charcoal stoves are being promoted by various enterprises and international donor support. This includes the Prakti Wouj stove developed for the Haitian market and reported to cost US$ 50 and have a useful life of 5 years (Bossuet and Serrar, 2014), and the D&E Eco Recho stove reported to cost US$ 12-14 with a useful life of 2 years (Ashden, 2013).

The improved wood and charcoal stoves referenced above are single burner stoves. Households need at least two burners in order to discontinue cooking with the traditional stove or open fire. This effectively at least doubles the household cost of improved stoves.

An LPG kit with a 4-burner stove, 25 lbs tank, and a regulator hose is reported to cost US$ 125 in Haiti. The SWITCH Project promotes LPG stoves and cylinders to Haitian households. To overcome the high cost relative to income, the project turns to Haitians living abroad (3 million people) who

[12] http://cleancookstoves.org/about/news/01-29-2015-partner-spotlight-novogaz.html

can afford the initial stove and cylinder investment for their family in Haiti.

Ethanol stoves are also being promoted in Haiti (Project Gaia), as in some African countries, eventually with local production of ethanol. Initial work indicates that ethanol is cost competitive with LPG.[13]

Stove costs and useful life of the stoves applied in this paper are presented in table 9.1. The cost is for stoves that have at least two burners or, alternatively, for at least two single stoves so that cooking with the traditional, unimproved stove or open fire can be avoided.

TABLE 9.1. ESTIMATES OF COST OF STOVES, 2016

	Improved Cookstove -Wood	Improved Cookstove -Charcoal	LPG stove**	Ethanol stove
Cost of stove (Gourdes)*	2,200	4,500	5,600	4,500
Useful life of stove (years)	4	4	10	10
Annualized cost of stoves (3%, 5% and 12% discount rates)	575	1,175	637	512
	591	1,209	691	555
	647	1,323	885	711

* Real 2014 prices. ** Including 25 lbs tank and regulator hose. Source: The author.

9.2 Cost of LPG and ethanol fuel

It is here assumed that LPG consumption is 30 kg per person per year for households that exclusively use LPG for cooking. This is in line with estimates for several countries in Asia, Africa and South America (Kojima et al, 2011). Ethanol consumption is estimated based on its energy content and stove efficiency, assuming an equivalent consumption of effective energy as for LPG. Annual cost of LPG and ethanol per household is very similar based on the prices applied (table 9.2). The fuel cost is approximately 10 times the annualized cost of LPG and ethanol stoves.

TABLE 9.2. ESTIMATED COST OF FUELS, 2016

	LPG	Ethanol
Fuel consumption (person/year)	30 kg	50 liters
Fuel consumption (household/year)	130 kg	220 liters
Cost (Gourdes)*	45 per kg	27 per liter
Fuel cost (Gourdes/household/year)	5,800	5,940

* Real 2014 prices, based on US$ 1 per kg of LPG and US$ 0.6 per liter of ethanol. Source: The author.

9.3 Cost of stove maintenance and stove promotion programs

Cost of interventions also includes stove maintenance and repairs of improved cookstoves and LPG and ethanol stoves. Annual cost of maintenance and repair is assumed to be 5% of initial stove cost.

[13] http://cleancookstoves.org/about/news/01-29-2015-partner-spotlight-novogaz.html

Achieving adoption of modern energy and improved stoves for cooking requires promotion, community participation, and behavioral change programs. Such programs cost money and is part of the cost of achieving household adoption of cook stoves being promoted.

Program promotion cost will increase on the margin for programs with increased intensity and scale to achieve an increasing share of the population switching to modern energy or improved stoves. Thus it is very difficult to provide a single cost figure for program costs.

Programs are here assumed to cost US$ 10 per household in the first year (promotion and monitoring), and US$ 2 per household per year in subsequent years (monitoring).[14] These costs are costs per household that adopts the stoves being promoted.

10. Benefit-cost ratios

10.1 Valuation of health benefits

Household air pollution control 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) and lung cancer. It is therefore assumed that reduced incidence of and deaths from these diseases are gradually realized over ten years. For acute lower respiratory infections (ALRI) among young children, however, full health benefits are realized in the same year as PM2.5 exposure reduction. This means that over a time horizon of 20 years annualized health benefits are 77-85% of full benefits, i.e., of the estimated health benefits presented in section 7.[15]

Health benefits in terms of avoided deaths and associated illness from cleaner cookstoves can be monetized by using various benefit valuation measures. The Copenhagen Consensus Center (CCC) applies a value per avoided "disability adjusted life year" or DALY that is 1, 3 and 8 times GDP per capita in the Haiti Priorities Project as stated in section 4 . Thus health benefits are calculated by converting avoided deaths and disease from the cookstove interventions to DALYs (as in section 4), discounted at an annual rate of 3%, 5%, and 12%, and multiplied by a multiple of 1, 3 and 8 times GDP per capita.

10.2 Benefits and costs

Benefits and costs of interventions are compared by using their ratio. Benefit-cost ratio (BCR) greater than one indicates that benefits exceed costs of intervention. The ratio can be calculated as the present value of benefits over the present value of costs, or as annualized benefits over annualized costs. Discount rates of 3%, 5% and 12% are used in the calculations.

[14] Garcia-Frapolli et al (2010) apply a similar cost for maintenance and repair of a Patsari stove in the Purepecha region of Mexico, and a program cost of US$ 25 per stove.
[15] Discount rate is 3%, 5% and 12%.

BCRs of improved cookstoves (ICS) and LPG and ethanol stoves are presented in tables 10.1-2 for the case of health benefits expressed as DALYs valued at 3 times GDP per capita and discounted at 5%.[16] These BCRs are averages for the three cooking locations. BCRs for each cooking location are presented in tables 10.3a-c. BCRs using 1 and 8 times GDP per capita and discount rates of 3% and 12% are presented in annex 2. Benefits of cooking time and fuel savings are the same in each scenario.

Benefits of improved biomass stoves are on average nearly four times larger than costs (table 10.1). BCRs for improved wood stoves (ICS-W) are very similar to the BCRs for improved charcoal stoves (ICS-C). This is because the smaller health benefits of ICS-C are compensated for by the larger non-health benefits of fuel savings.

Benefits of LPG and ethanol stoves are on average 1.25-2.15 times larger than costs (table 10.1). BCRs of switching to LPG or ethanol from charcoal are larger than switching from fuelwood. This is because of the larger non-health benefits of charcoal fuel savings. BCRs of ethanol are slightly larger than for LPG, mainly due to the additional economic benefit of local ethanol production.

BCRs of cooking with LPG or ethanol are much lower than for ICS, reflecting the cost of LPG and ethanol fuel. But health benefits of cooking with LPG or ethanol are more than twice as large as cooking with an ICS using wood and about 50% larger than cooking with an ICS using charcoal. Clean energies, such as LPG or ethanol, are therefore the only option for effectively combatting health effects of solid fuels. In other words, ICS may be the most efficient solution as reflected by the high benefit-cost ratios, but not the most effective solution.

Table 10.1. Summary of average BCRs of cookstove interventions, 2016*

Interventions	BCRs
Improved charcoal and wood stoves (ICS-C and ICS-W)	3.85
LPG and ethanol stoves for households currently cooking with wood (W)	1.25
LPG and ethanol stoves for households currently cooking with charcoal (C)	2.15

* Benefits and costs are annualized at a 5% discount rate. Source: Estimates by the author.

Average annual benefits and costs per household and BCRs are presented in more detail in table 10.2. These BCRs are also averages for the three cooking locations.

In relation to cooking location, BCRs for households cooking outdoors are only 10-20% lower than for households cooking in the house because of substantial non-health benefits (tables 10.3a-c).

[16] Monetized health benefits in this case are only slightly lower than using VSL for deaths averted with the methodology proposed in World Bank (2016b) (see section 4).

TABLE 10.2 AVERAGE BENEFITS AND COSTS OF COOKSTOVE INTERVENTIONS, 2016 (GOURDES/HOUSEHOLD/YEAR)*

	Benefits	Costs	BCR
ICS-W	3,529	910	3.9
ICS - C	6,312	1,643	3.8
LPG - W	8,462	6,916	1.2
Ethanol - W	9,056	6,864	1.3
LPG - C	14,441	6,916	2.1
Ethanol - C	15,035	6,864	2.2

* Benefits and costs are annualized at a 5% discount rate. Source: Estimates by the author.

TABLE 10.3A. BENEFITS AND COSTS OF INTERVENTIONS FOR COOKING IN THE HOUSE, 2016 (GOURDES/HOUSEHOLD/YEAR)*

	Benefits	Costs	BCR
ICS-W	4,017	910	**4.4**
ICS - C	6,674	1,643	**4.1**
LPG - W	9,508	6,916	**1.4**
Ethanol - W	10,102	6,864	**1.5**
LPG - C	14,912	6,916	**2.2**
Ethanol - C	15,506	6,864	**2.3**

* Benefits and costs are annualized at a 5% discount rate. Source: Estimates by the author.

TABLE 10.3B. BENEFITS AND COSTS OF INTERVENTIONS FOR COOKING IN SEPARATE BUILDING, 2016 (GOURDES/ HOUSEHOLD/ YEAR)*

	Benefits	Costs	BCR
ICS-W	3,741	910	**4.1**
ICS - C	6,433	1,643	**3.9**
LPG - W	8,848	6,916	**1.3**
Ethanol - W	9,442	6,864	**1.4**
LPG - C	14,529	6,916	**2.1**
Ethanol - C	15,123	6,864	**2.2**

* Benefits and costs are annualized at a 5% discount rate. Source: Estimates by the author.

TABLE 10.3C. BENEFITS AND COSTS OF INTERVENTIONS FOR COOKING OUTDOORS, 2016 (GOURDES/HOUSEHOLD/YEAR)*

	Benefit	Cost	BCR
ICS-W	3,296	910	**3.6**
ICS - C	6,066	1,643	**3.7**
LPG - W	8,032	6,916	**1.2**
Ethanol - W	8,626	6,864	**1.3**
LPG - C	14,158	6,916	**2.0**
Ethanol - C	14,752	6,864	**2.1**

* Benefits and costs are annualized at a 5% discount rate. Source: Estimates by the author.

The use of solid 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 pollutes 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 fuel free" communities along the lines of community lead sanitation programs and open defecation free communities. BCRs estimated in this paper with full community adoption of LPG or ethanol are about 10% higher than partial adoption of interventions, reflecting reduced community pollution and about 50% larger health benefits of full adoption.

10.3 Quality of evidence

The robustness of the benefit-cost analysis and the confidence in the BCRs of the interventions depend critically on each of the benefit and cost components.

The largest share of benefits is biomass fuel savings, followed by health benefits and time savings (table 10.4). The biomass fuel savings are particularly large for users of charcoal adopting an improved charcoal stove (ICS-C) or LPG or ethanol stove.

The largest share of costs is stove purchase for the improved wood or charcoal stoves (ICS-W and ICS-C) interventions and fuel purchase for the LPG and ethanol stove interventions (table 10.5). Promotion program cost is moderate for the improved stove interventions, but negligible for the clean fuel interventions.

Table 10.4. Estimated shares of total benefits of interventions

	Improved wood stove (ICS-W)	Improved charcoal stove (ICS-C)	LPG and Ethanol Stove (from wood)	LPG and Ethanol Stove (from charcoal)
Health benefits	23-37%	11-19%	22-36%	8-13%
Fuel savings	52-63%	67-74%	52-65%	72-79%
Time savings	11-14%	14-15%	9-11%	12-13%

Note: Benefit shares are for the scenario with 5% discount rate and health benefits valued at 3 times GDP per capita per DALY. Source: Estimates by the author.

Table 10.5. Estimated shares of total costs of interventions

	Improved wood stove (ICS-W)	Improved charcoal stove (ICS-C)	LPG and Ethanol Stove (from wood)	LPG and Ethanol Stove (from charcoal)
Stove purchase	65%	74%	8-10%	8-10%
Fuel purchase	-		84-87%	84-87%
Stove maintenance	12%	14%	3-4%	3-4%
Promotion program	23%	13%	2%	2%

Note: Cost shares are for the scenario with 5% discount rate. Source: Estimates by the author.

The benefit and cost shares can be used to assess their relative importance in the benefit-cost analysis, ranging from "Low" importance for low shares to "High" importance for large shares (table 10.5). This can then be combined with the "quality of evidence" of the estimation of the shares to rate the BCRs of the interventions in terms of the "quality of evidence" (table 10.6).

The main issue relates to the improved charcoal stove (ICS-C) intervention in terms of health benefits due to limited evidence of exposure pre- and post-intervention. However, as the health benefit share is only of "medium" size or importance, the overall "quality of evidence" of the ICS-C intervention remains "medium-strong", while the "quality of evidence" is "strong" for the improved wood stove (ICS-W) and LPG and ethanol interventions.

TABLE 10.6. IMPORTANCE AND QUALITY OF EVIDENCE OF BENEFIT AND COST SHARES OF INTERVENTIONS

	Importance			**Quality of evidence**		
	Improved wood stove (ICS-W)	Improved charcoal stove (ICS-C)	LPG and Ethanol stove	Improved wood stove (ICS-W)	Improved charcoal stove (ICS-C)	LPG and Ethanol stove
Health benefits	Medium-High	Medium	Medium-High	Strong	Limited-Medium	Strong
Fuel savings	High	High	High	Strong	Strong	Strong
Time savings	Low	Low	Low	Medium	Medium	Medium
Stove, fuel purchase	High	High	Very High	Strong	Strong	Strong
Stove maintenance	Low	Very Low	Very low	Limited	Limited	Limited
Promotion program	Medium	Low	Very Low	Medium-Limited	Medium-Limited	Medium-Limited
Benefit-cost ratio				**Strong**	**Medium-Strong**	**Strong**

Source: Estimates by the author.

The success of stove promotion programs is measured by the rate of household adoption, sustained use, and proper maintenance of the cook stoves. This is influenced by the effectiveness of promotion programs as discussed in section 5.

The cost effectiveness – i.e., program promotion cost per household that actually adopts one of the cookstove options in a sustained manner - can therefore vary substantially. Effective programs can not only provide larger total net benefits through higher adoption rates, but can also result in larger BCRs, while the opposite is the case for ineffective programs. The potentially large effect on BCRs is particularly the case for improved wood and charcoal stoves because promotion cost as a share of total cost is highest for these two interventions as reported in table 10.5.

To illustrate this effect: The BCR of the improved wood and charcoal stoves (ICS-W; ICS-C) in table 10.2 increases from 3-8-3.9 to 4.3-4.7 (by 10-20%) if the promotion program is 4 times more cost effective than applied in this paper. On the other hand, the BCRs decline to 2.3-2.8 (by 30-40%) if the promotion program is 4 times less cost effective, and BCRs decline to < 1 if the program is more than 15 times less cost effective. In the latter case, the promotion cost is 2-4 times higher than stove and maintenance cost combined.

11. Conclusions

As many as 94% of the population in Haiti cooks with solid fuels - evenly split between fuelwood and charcoal. Nearly half of the population cooks outdoors, over 1/3rd cooks in a separate building, and 15% cooks in the house. Almost all households using solid fuels cook over open fire or an open stove. This makes household air pollution from solid fuels a major public health issue in Haiti, with over 8,200 people deaths in 2016.

Improved cookstoves (ICS) for wood or charcoal provide benefits that are 3.7-4.1 times their cost when DALYs are valued at 3 times GDP per capita and discounted at an annual rate of 5%. Cooking with LPG or ethanol is much more expensive due to the fuel cost, but nevertheless has benefit-cost ratios of 1.2-2.3. The health benefits of LPG or ethanol are 1.5-2.5 times larger than cooking with ICS, and thus the only longer term solution to combatting the health effects of solid fuels.

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 premature mortality and morbidity. 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[17] 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.

[17] Other biomass fuels used for cooking is mostly straw/shrubs/grass, agricultural crop residues and animal dung.

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 *µg/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 *µg/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.[18] 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, *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 is applied to estimate the reduction in disease burden from a change in the population exposure distribution that can result from an intervention to control PM2.5 exposure levels among a sub-set of the population:

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

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

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

This approach is applied in this paper to estimate the reduction in the disease burden from improved household cooking options.

[18] 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.

Annex 2. Benefit-cost ratios

TABLE A2.1 BENEFITS AND COSTS OF INTERVENTIONS, 2016 (GOURDES/HOUSEHOLD/YEAR) – HEALTH BENEFITS VALUED AT DALY=3*GDP PER CAPITA

Cooking in house	3% discount rate			5% discount rate			12% discount rate		
	Benefit	Cost	BCR	Benefit	Cost	BCR	Benefit	Cost	BCR
ICS-W	4,461	890	**5.0**	4,017	910	**4.4**	3,275	977	**3.4**
LPG - W	10,525	6,858	**1.5**	9,508	6,916	**1.4**	7,809	7,125	**1.1**
Ethanol - W	11,119	6,817	**1.6**	10,102	6,864	**1.5**	8,403	7,036	**1.2**
ICS - C	7,062	1,606	**4.4**	6,674	1,643	**4.1**	6,025	1,768	**3.4**
LPG - C	15,485	6,858	**2.3**	14,912	6,916	**2.2**	13,955	7,125	**2.0**
Ethanol - C	16,079	6,817	**2.4**	15,506	6,864	**2.3**	14,549	7,036	**2.1**

Cooking in separate building	3% discount rate			5% discount rate			12% discount rate		
	Benefit	Cost	BCR	Benefit	Cost	BCR	Benefit	Cost	BCR
ICS-W	4,101	890	**4.6**	3,741	910	**4.1**	3,138	977	**3.2**
LPG - W	9,666	6,858	**1.4**	8,848	6,916	**1.3**	7,480	7,125	**1.0**
Ethanol - W	10,260	6,817	**1.5**	9,442	6,864	**1.4**	8,074	7,036	**1.1**
ICS - C	6,748	1,606	**4.2**	6,433	1,643	**3.9**	5,905	1,768	**3.3**
LPG - C	14,986	6,858	**2.2**	14,529	6,916	**2.1**	13,764	7,125	**1.9**
Ethanol - C	15,580	6,817	**2.3**	15,123	6,864	**2.2**	14,358	7,036	**2.0**

Cooking outdoors	3% discount rate			5% discount rate			12% discount rate		
	Benefit	Cost	BCR	Benefit	Cost	BCR	Benefit	Cost	BCR
ICS-W	3,523	890	**4.0**	3,296	910	**3.6**	2,917	977	**3.0**
LPG - W	8,605	6,858	**1.3**	8,032	6,916	**1.2**	7,075	7,125	**1.0**
Ethanol - W	9,199	6,817	**1.3**	8,626	6,864	**1.3**	7,669	7,036	**1.1**
ICS - C	6,271	1,606	**3.9**	6,066	1,643	**3.7**	5,723	1,768	**3.2**
LPG - C	14,504	6,858	**2.1**	14,158	6,916	**2.0**	13,580	7,125	**1.9**
Ethanol - C	15,098	6,817	**2.2**	14,752	6,864	**2.1**	14,174	7,036	**2.0**

TABLE A2.2 BENEFITS AND COSTS OF INTERVENTIONS, 2016 (GOURDES/HOUSEHOLD/YEAR) – HEALTH BENEFITS VALUED AT DALY=1*GDP PER CAPITA

Cooking in house	3% discount rate			5% discount rate			12% discount rate		
	Benefit	Cost	**BCR**	Benefit	Cost	**BCR**	Benefit	Cost	**BCR**
ICS-W	3,181	890	**3.6**	3,033	910	**3.3**	2,786	977	**2.9**
LPG - W	7,594	6,858	**1.1**	7,255	6,916	**1.0**	6,689	7,125	**0.9**
Ethanol - W	8,188	6,817	**1.2**	7,849	6,864	**1.1**	7,283	7,036	**1.0**
ICS - C	5,943	1,606	**3.7**	5,814	1,643	**3.5**	5,598	1,768	**3.2**
LPG - C	13,834	6,858	**2.0**	13,643	6,916	**2.0**	13,324	7,125	**1.9**
Ethanol - C	14,428	6,817	**2.1**	14,237	6,864	**2.1**	13,918	7,036	**2.0**

Cooking in separate building	3% discount rate			5% discount rate			12% discount rate		
	Benefit	Cost	**BCR**	Benefit	Cost	**BCR**	Benefit	Cost	**BCR**
ICS-W	3,062	890	**3.4**	2,941	910	**3.2**	2,740	977	**2.8**
LPG - W	7,308	6,858	**1.1**	7,035	6,916	**1.0**	6,579	7,125	**0.9**
Ethanol - W	7,902	6,817	**1.2**	7,629	6,864	**1.1**	7,173	7,036	**1.0**
ICS - C	5,839	1,606	**3.6**	5,734	1,643	**3.5**	5,558	1,768	**3.1**
LPG - C	13,668	6,858	**2.0**	13,515	6,916	**2.0**	13,260	7,125	**1.9**
Ethanol - C	14,262	6,817	**2.1**	14,109	6,864	**2.1**	13,854	7,036	**2.0**

Cooking outdoors	3% discount rate			5% discount rate			12% discount rate		
	Benefit	Cost	**BCR**	Benefit	Cost	**BCR**	Benefit	Cost	**BCR**
ICS-W	2,869	890	**3.2**	2,793	910	**3.1**	2,667	977	**2.7**
LPG - W	6,954	6,858	**1.0**	6,763	6,916	**1.0**	6,444	7,125	**0.9**
Ethanol - W	7,548	6,817	**1.1**	7,357	6,864	**1.1**	7,038	7,036	**1.0**
ICS - C	5,679	1,606	**3.5**	5,611	1,643	**3.4**	5,497	1,768	**3.1**
LPG - C	13,507	6,858	**2.0**	13,392	6,916	**1.9**	13,199	7,125	**1.9**
Ethanol - C	14,101	6,817	**2.1**	13,986	6,864	**2.0**	13,793	7,036	**2.0**

TABLE A2.3 BENEFITS AND COSTS OF INTERVENTIONS, 2016 (GOURDES/HOUSEHOLD/YEAR) – HEALTH BENEFITS VALUED AT DALY=8*GDP PER CAPITA

Cooking in house	3% discount rate			5% discount rate			12% discount rate		
	Benefit	Cost	BCR	Benefit	Cost	BCR	Benefit	Cost	BCR
ICS-W	7,660	890	8.6	6,476	910	7.1	4,498	977	4.6
LPG - W	17,851	6,858	2.6	15,140	6,916	2.2	10,609	7,125	1.5
Ethanol - W	18,445	6,817	2.7	15,734	6,864	2.3	11,203	7,036	1.6
ICS - C	9,858	1,606	6.1	8,823	1,643	5.4	7,094	1,768	4.0
LPG - C	19,613	6,858	2.9	18,086	6,916	2.6	15,533	7,125	2.2
Ethanol - C	20,207	6,817	3.0	18,680	6,864	2.7	16,127	7,036	2.3
Cooking in separate building	3% discount rate			5% discount rate			12% discount rate		
	Benefit	Cost	BCR	Benefit	Cost	BCR	Benefit	Cost	BCR
ICS-W	6,701	890	7.5	5,739	910	6.3	4,131	977	4.2
LPG - W	15,560	6,858	2.3	13,379	6,916	1.9	9,733	7,125	1.4
Ethanol - W	16,154	6,817	2.4	13,973	6,864	2.0	10,327	7,036	1.5
ICS - C	9,022	1,606	5.6	8,181	1,643	5.0	6,775	1,768	3.8
LPG - C	18,281	6,858	2.7	17,062	6,916	2.5	15,024	7,125	2.1
Ethanol - C	18,875	6,817	2.8	17,656	6,864	2.6	15,618	7,036	2.2
Cooking outdoors	3% discount rate			5% discount rate			12% discount rate		
	Benefit	Cost	BCR	Benefit	Cost	BCR	Benefit	Cost	BCR
ICS-W	5,159	890	5.8	4,554	910	5.0	3,542	977	3.6
LPG - W	12,733	6,858	1.9	11,206	6,916	1.6	8,653	7,125	1.2
Ethanol - W	13,327	6,817	2.0	11,800	6,864	1.7	9,247	7,036	1.3
ICS - C	7,748	1,606	4.8	7,202	1,643	4.4	6,288	1,768	3.6
LPG - C	16,996	6,858	2.5	16,074	6,916	2.3	14,532	7,125	2.0
Ethanol - C	17,590	6,817	2.6	16,668	6,864	2.4	15,126	7,036	2.1

How food is cooked, a health risk factor in Haiti

Haiti Priorise

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How food is cooked, a health risk factor in Haiti

The most commonly used cooking fuels for households in Haiti are wood energy and petroleum products. Wood energy represents 71% to 80% of the national energy demand covered by local resources (Jean René Marcoux, 2014), or 9% of the country's gross domestic product in 2003 (Jean-Pierre Angelier, 2005) and more than 4 times the amount of oil consumed. Indeed, firewood is consumed annually at rate of 3.4 to 3.7 million metric tons, or an equivalent of 1.6 to 1.7 million tons of oil. Of this total, up to 37% is converted into charcoal for 18% by weight of charcoal (Jean-Pierre Angelier, 2010) and for an annual consumption of 250 to 280 thousand tons (Peter Young, 1997). As a result, 95.5% of households in Haiti use wood for cooking their food (Bjorn Larsen, 2012).

Petroleum products, meanwhile, respond to a 24% national demand for fossil fuel per year (Jean René Marcoux, 2014). They benefit from an annual import growth rate of 7.3% for Liquefied Petroleum Gas (LPG) and 9.3% for kerosene since 1999 (Jean-Pierre Angelier, 2005). LPG, a blend of propane and butane, comes mainly from the Dominican Republic in tanker trucks and from Trinidad in small tanker ships. Kerosene is also imported by tanker ships especially from Venezuela (Alexandre Racicot, 2011). Together, they are distributed throughout the national territory via operators such as Total, Nationale, Texaco, Esso and in general businesses. Even if Haiti devotes up to 50% of its export currencies to imports (Alexandre Racicot, 2011), petroleum products only contribute 8% to domestic activities. In addition, the consumption of kerosene is twice as high as that of LPG, more popular for lighting due to inadequate access to electricity.

This high rate of wood energy use, particularly in cooking food, has resulted in a Haitian government currency savings estimated at US $ 88 million (Jean-Pierre Angelier, 2005). Because this solid fuel obviously supports a local response to petroleum products in relation to a growing national energy demand. It generates a subsistence income for 150 thousand people: rural workers, distributors, urban resellers involved in the commercial energy sector. And despite being 80% more expensive in the pot than per bag, it maintains a retail marketing that retains the accessibility also to its derivatives. However, this hoarding comes up against an economic cost estimated at 1.6 billion US dollars (Alexandre Racicot, 2011), due to significant social and environmental repercussions in Haiti.

Wood energy undoubtedly requires a wood raw material whose pace of collection is now superior to the rhythm of forest regeneration of the country. This greatly reduces the potential of arable land and greatly weakens all of Haiti's ecosystems to 1.2% of forest cover (Ministry of the Environment, 2013). It shows an 80% loss of energy at the time of its production (Mildred D. Régis and Wilfrid St-Jean, 2001), aggravated by fuel use practices and low-efficiency cooking appliances. In addition, its incomplete combustion releases harmful air pollutants, to which women and children are particularly vulnerable. While the perpetual use of wood energy by households in the Americas' only developing country appears to support better nutrition, it nevertheless affects a fundamental human right: the right to health. Given that 58.5 per cent of Haitians living in poverty are unable to meet their basic needs and that 23.8 per cent of them in extreme poverty cannot meet their food needs (Haitian Institute for Statistics and Informatics, 2014), the impact of cooking on the health of households should therefore be elucidated.

According to the World Bank, air pollution, together with agriculture, water and ecological disasters, is one of the most serious environmental problems facing developing countries. On the basis of this observation, it is clear throughout the world that "more than 4 million people die prematurely from diseases caused by domestic air pollution due to solid fuels" (World Health Organization, 2016). Knowing that more than 90% of wood energy is consumed in the economic South, households experiencing poverty or extreme poverty in low- and middle-income countries such as Haiti are more likely to be affected. Subsequently, they use rudimentary cooking equipment which, poorly burning wood energy, produces very toxic fumes. These fumes contain air pollutants whose prolonged exposure is detrimental to the respiratory system, the eyes, the immune system (Dr. Vinod Mishra, gathered in the issue: Health, Poverty, Environment from the Digital Magazine: Our Planet in a UN environment). These pollutants are also the basis for premature deaths of stroke, ischemic heart disease, Chronic Obstructive Pulmonary Disease (COPD) pneumonia and lung cancer, (World Health Organization, 2016), and is more or less accentuated by individuals' predisposition to these illnesses (Public Health Department of Montréal-Center, 2017).

Those are namely:

- Carbon monoxide (CO), which can cause headaches, nausea, dizziness, and aggravation of angina in people with heart problems;
- volatile Organic Compounds (VOCs) that can cause respiratory irritation, respiratory ailments, cancer (eg benzene) and contribute to smog;
- acrolein and formaldehyde which may cause irritation to the eyes and respiratory tract;
- fine particles (PM2.5) that can cause irritation of the lungs, worsening cardiorespiratory diseases and early mortality;
- nitrogen oxides (NOx) which can cause irritation of the respiratory system, pain during breathing, coughing, pulmonary edema and also acid rain;
- Polycyclic Aromatic Hydrocarbons (PAH), some of which are suspected or considered to be mutagenic or carcinogenic;

- dioxins and furans, possibly carcinogenic (Public Health Department of Montreal-Center, 2017).

From this list, fine particles with aerodynamic diameter less than or equal to 2.5 micrometers (PM2.5) are the most worrying. They are so small that they are deposited directly on the surface of the pulmonary alveoli when inhaled. They affect the respiratory and cardiovascular system by causing bronchial irritation and inflammation (Public Health Directorate of Montréal-Center, 2017). Also, when the cooking pieces are insufficiently ventilated, the resulting domestic fumes can reach a concentration 100 times higher than the acceptable levels (World Health Organization, 2016). As a result, 12.2% of the 95.5% of Haitian households using wood energy become particularly vulnerable to PM2.5 when cooking in a principle residence, 100% exposed, compared with 46.2% who are still cook outside are exposed at 60%, and 35.6% in a separate room in the principle residence, exposed at 80% (Bjorn Larsen, 2016). On the other hand, cooking with firewood, the foremost fuel of households, is generally associated with a greater degree of exposure than that of charcoal. Exposure to charcoal fire is known to release 60%, 65% and 75% of the wood fire in PM2.5 depending on whether the fire has actually been lit outside in a separate cooking room from the principle residence or in the residence. These results confirm that even if the PM2.5 content decreases as the cooking space is ventilated, they are nevertheless present in the immediate environment of any cooking space, incriminating the type of fuel adopted.

In addition, Haitian women experience 100% exposure to PM2.5 during cooking, whereas men are subject to 60% and children over 5 years 85% of that of women (Bjorn Larsen, 2016). But, children under 5 will tend to experience the same level of exposure as their mothers, being more dependent on it. In fact, more than half of all deaths from pneumonia are caused by inhalation of particulate matter from indoor air pollution (World Health Organization, 2016). Second, since women generally prepare meals in Haiti, they are the first designated victims of PM2.5-related illnesses. Likewise, they are the first victims to suffer from an extremely high social cost, because they spend a lot of time picking up and transporting wood energy, often away from their dwelling. They spend a lot of time cooking food because of low-efficiency cooking appliances and low-efficiency fuels. They spend a large part of household income on the purchase of solid fuels. They often suffer from chronic respiratory problems due to air pollution in the cooking space. They are more prone to attacks because of the distance to be traveled with wood energy and trauma such as burning, pain, red eyes, since they regularly light the cooking fire. In turn, their fetus' or their children under and over 5 years are rendered more vulnerable because of their notable exposure.

On the whole, if 22% of the 95.5% of households using wood energy in cooking died of a stroke, 24% had ischemic heart disease, 39% had COPD, 42% had pneumonia and 32% had Lung cancer, in 2016, Haiti had 8,241 premature deaths from PM2.5-related diseases (Bjorn Larsen, 2016). Referring to local estimates of Disability Adjusted Life Years (DALYs), these 8,241 deaths each lost 31.9 years of good health. This is related to an average economic cost of 14.5 billion gourdes, equivalent to 3.6% of Haiti's Gross Domestic Product (GDP) per capita (Bjorn Larsen, 2016). This estimate was obtained by combining discount rates of 3%, 5% and 12% with arbitrary values of 1, 3, and 8 times the per capita GDP applicable to the DALY methodology. However, by using full-scale petroleum cooking appliances, at least 4,151 Haitians out of 8,241 could be saved, or 51% fewer deaths per year (Bjorn Larsen, 2016). Exposure to PM2.5 would therefore be reduced by 52% by full adoption and 34% by partial adoption. This implies that over 20 years there would be a health gain of 77% to 85% (Bjorn Larsen, 2016), which would greatly benefit women and children. Improved fuel wood burning appliances were not considered in this assessment as they only recommend reduction results of 12% and 26%.

The full and partial adoption of petroleum product cooking appliances also promotes equal opportunities and promotes women's empowerment in Haiti. They save up to one hour a day on cooking time (Jeuland and Pattanayak, quoted by Bjorn Larsen, 2016) thanks to more efficient appliances and fuels, utensils without soot particles. This time saved is equivalent to a rate of pay of 10 gourdes per hour per rural household and 20 gourdes per hour per household in urban areas. With more time to devote to their personal development, they can therefore engage in other income-generating activities. As a bonus, in the long term, they save up to 900 gourdes per household per year in rural areas and up to 1,800 gourdes per household per year in urban areas, which can now be allocated to other household expenses. Secondly, with the added value of health, they spent more quality time with other members of the household, not to mention how their more robust children, weaned from the domestic task of collecting and purchasing of fuels, will be able to better focus on their education.

While the use of petroleum appliances seems to be beneficial in reducing household vulnerability and improving the health of users by reducing PM2.5 exposure, it nevertheless faces a significant challenge which hampers their popularization: their cost. In Haiti, buying appliances and LPG tanks requires a large start-up investment for urban households using 23 times more charcoal (Jean-Pierre Angelier, 2005). Their transport and replenishment are not convenient, especially for street vendors, since they are more cumbersome, the purchase of fuels is too sparse and suppliers are subject to fixed operating times. But despite these disadvantages, LPG is considered to be socially beneficial in cooking for urban households, while for rural households, kerosene is poorly accepted (Jean-Pierre Angelier, 2005). This explains why it is consumed at just 1% in this environment despite the availability, purchase, transport, storage very favorable to households usually in a situation of poverty. It should be noted that the purchase of a kerosene cooker is 10 times less than that of LPG (Jean-Pierre Angelier, 2005) and that the fuel is easily accessible from retailers. However, wood harvesting allows energy supply even when rural households do not have monetary income, confirmed by a 44 times greater use than kerosene (Jean-Pierre Angelier, 2005). On the other hand, for all LPG cooking appliances that are prioritized in urban areas and those for kerosene that are prioritized in rural areas, all of these petroleum products remain subject to an upward price fluctuation that is severely penalizing for final consumers.

Haiti, having adopted the objectives of sustainable development, fighting poverty, hunger, illiteracy, environmental degradation and discrimination against women would imply ensuring access to clean and efficient cooking energy. The method of cooking food as a health risk factor for PM2.5 exposure for households typically experiencing poverty or extreme poverty would require vigorous action in the short, medium and long term:

1. implementation of a public awareness campaign

The main objective is to facilitate the transition of households to using clean energy through an awareness-raising campaign that focuses on deforestation caused by the non-rational use of wood energy, on the evidence of standard target households that have actually saved time and money by switching to more efficient cooking appliances, on the impact of continuous exposure to PM2.5 with a neighborhood-like effect on the air quality in living spaces. Since Haitian society is culturally very family-oriented, it would be safer to reach out to the public opinion by presenting the impact of traditional cooking on women and children. Broadcasting positive messages, even denouncing distressing realities is an appropriate strategy for raising awareness without making people feel guilty.

2. production of improved traditional cooking appliances

Energy poverty is one of the major causes for the combined exposure of 82.3% of Haitians to PM2.5 in precarious situations. This atmospheric pollutant has a negative impact on local life expectancy in good health and positively on climate change. Even if the improvement of traditional cooking appliances does not provide a significant reduction in exposure, this is already a first step towards reducing the use of fuels. However, it is not only a matter of promoting massive private sector financial investments, non-profit institutions, and contextual technical investments by local research centers. The goal is to train tinsmiths in the production of improved appliances and to provide them with incentives to purchase raw materials for their manufacture. These craftsmen have developed such close proximity to the local population that, thanks to a production that is less energy intensive and easily accessible in the informal trade, the pressure on the wood resource would be greatly reduced. Competitively priced substitute fuels such as briquettes, mineral coal can also be introduced. Then, at the same time, some of the supporters of the commercial energy sector can be employed to protect and/or revive wooded areas in Haiti. They would have a knowledge of the wood resource that would certainly be valued.

3. diffusion of clean energy cooking appliances

Energy poverty in the context of a developing country such as Haiti can be controlled, among other things, by the implementation of a strategic policy focusing on access to clean energy cooking appliances. Domestic energy sources such as petroleum products will be prioritized because PM2.5 exposure is significantly reduced. This involves the dissemination of appliances that can be adapted for any type of cooking activity, such as heaters, ovens, stoves and to provide petroleum cylinders with a storage capacity lower than 25 pounds. Adaptable appliances support cooking food in homes, in the streets and in shops. Lower-capacity petroleum gas cylinders promote cheaper and even more frequent supplies. Knowing that the price of clean energy cooking appliances represents a significant portion of the household budget, a microcredit system with proposals depending on the financial profile of the applicants could concede to their acquisition. The possibility of a free distribution of cooking appliances by petrol station companies is not to be ruled out. They hold their return on investment during the year of continuous purchase of petroleum fuels. In order to prevent the country from being faced with an excessive import demand for petroleum products, it would be desirable to have creative collaborative strategies for less costly acquisition. The diversification of domestic energy is to be explored while substantially maintaining the same efficiency of other cooking appliances such as electricity, wind, solar, methanisation. Similarly, economic sale or resale agents previously involved in the wood energy market can become clean energy cooking appliance providers.

In conclusion, whatever efforts can be made to halt the impact of food preparation methods on health, they cannot be effective without an enhanced leading institution responsible for the rational governance of the energy sector. Moreover, the durability of the efforts cannot be guaranteed, even if they would have established, without a certification process for the production of cooking appliances. This certification will help maintain the quality and efficiency standards of the appliances in a concern for the preservation of the health and environment in Haiti.

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Haiti faces some of the most acute social and economic development challenges in the world. Despite an influx of aid in the aftermath of the 2010 earthquake, growth and progress continue to be minimal, at best. With so many actors and the wide breadth of challenges from food security and clean water access to health, education, environmental degradation, and infrastructure, what should the top priorities be for policy makers, international donors, NGOs and businesses? With limited resources and time, it is crucial that focus is informed by what will do the most good for each gourde spent. The Haïti Priorise project will work with stakeholders across the country to find, analyze, rank and disseminate the best solutions for the country. We engage Haitans from all parts of society, through readers of newspapers, along with NGOs, decision makers, sector experts and businesses to propose the best solutions. We have commissioned some of the best economists from Haiti and the world to calculate the social, environmental and economic costs and benefits of these proposals. This research will help set priorities for the country through a nationwide conversation about what the smart - and not-so-smart - solutions are for Haiti's future.

Haïti Priorise

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