Lower household air pollution with improved cookstoves

Bjorn Larsen

Summary

The benefit-cost ratios (BCRs) of the assessed interventions are 11.7 for improved cookstoves for wood and 2.4-2.5 for cooking with Liquefied Petroleum Gas (LPG). The quantified benefits are health improvements, and cooking time and solid fuel savings. The quantified costs are cost of stove, stove maintenance, LPG fuel, and intervention promotion program. Benefits and costs are estimated per household that adopts the interventions. Total benefits and costs are not estimated because predicting intervention adoption rates is very difficult.

Improved cookstoves for wood is a short to medium term intervention because of its relatively moderate health benefits. LPG, or other clean options such as electricity, is as incomes grow the longer-term solution in order to achieve substantial health benefits.

The Problem

Cooking with solid fuels in inefficient traditional cookstoves is imposing an enormous burden on African households. Fine particulate (PM2.5) household air pollution from these fuels caused over 400 thousand deaths in Africa in 2017 according to the Global Burden of Disease 2017 (GBD 2017). As many as 60% of these deaths were from acute lower respiratory infections (ALRI), of which 60% were among children under the age of five years.[26] And a survey of 22 countries in Sub-Saharan Africa found that households spend on average 2 hours per day on fuelwood collection, ranging from 0.8-1.0 hours in Zimbabwe, Tanzania and Kenya to 4-5 hours in Niger and Sierra Leone (World Bank, 2014). This totals 100 billion hours, or 50 million man-years of work, for the 63% of the Sub-Saharan African population using wood as primary cooking fuel.

Clean fuels and technologies for cooking include electricity, gas, ethanol, solar and high-performance biomass gasifier stoves. Kerosene is not considered a clean fuel (WHO et al, 2018).[27] In the range of 93-99% of the population in North Africa[28] had access to clean fuels and technologies for cooking in 2016. However, only 14% of the population in Sub-Saharan Africa had such access (World Bank, 2019). In the low-income countries of Sub-Saharan Africa, only 5% had access to clean fuels and technologies for cooking.

Forty national household surveys in Sub-Saharan Africa from 2012-2017 provide an overview of the primary cooking fuel used by the populations in the region.[29] These surveys represent 93% of the population in Sub-Saharan Africa. The surveys find that 7% of the populations used LPG and equally many used electricity for cooking[30]; 4% used kerosene; 63% used wood; 15% used charcoal; and 4% used other solid fuels. In the low-income countries of Sub-Saharan Africa as many as 71% used wood for cooking.

Interventions

Two interventions are assessed in terms of benefits and costs:

- Improved cookstove using wood; and
- LPG stove.[31]

Benefits and costs are assessed for a period of 10 years from 2020 to 2030. The interventions are assessed for the low-income countries of

[26] See Stanaway et al (2018) and www.healthdata.org and http://ghdx.healthdata.org/gbd-results-tool

[27] Clean fuels and technologies are defined in relation to the immediate household environment.

[28] Algeria, Egypt, Libya, Morocco, Tunisia.

[29] Demographic and Health Surveys (DHS) and Multiple Indicator Cluster Surveys (MICS).

[30] And very minor amounts of other gaseous fuels.

[31] An alternative to LPG is electricity. An electric stove will have similar magnitudes of benefits as LPG. The main difference can be the cost, depending on marginal cost of electricity supply. Unreliable service of electricity can be a deterrent to switching to electricity for cooking in some countries.

Sub-Saharan Africa as 2/3rd of deaths from household air pollution on the continent resulting from the use of solid cooking fuels occur in this group of countries.

The motivation for the choice of interventions are:

- Over 70% of the population in the low-income countries of Sub-Saharan Africa use wood for cooking;
- As of recent assessments, only approximately 12% of the population in Sub-Saharan Africa use improved cookstoves of varying quality (World Bank, 2014); and
- Only 5% of the population in the low-income countries of Sub-Saharan Africa use clean fuels and technologies for cooking.

The first intervention is an improved cookstove for wood that provides more efficient and cleaner burning (e.g., Rocket stove), and thus lower PM2.5 emissions than a traditional cookstove or cooking over open fire.[32]

The second intervention conforms with "clean cooking fuel and technologies", and is far more effective in reducing household air pollution and health effects than improved cookstoves using wood, but is also much more expensive than improved cookstoves due to the cost of LPG fuel. This intervention is assessed under two scenarios: i) LPG being only partially adopted in a community and exposure levels therefore remains fairly high; and ii) LPG being fully adopted in a community and exposure levels are therefore substantially lower by avoiding the community pollution effect of solid fuel use.

Both interventions involve stoves with a minimum of two burners or plates so that households are less likely to continue using their old traditional solid fuel stove.

The pre-intervention scenario is a household that uses a traditional cookstove with wood. Post-intervention exposure levels are 35-50% lower (depending on household cooking location) with the use of improved cookstove and about 50-90% lower with the use of LPG (see Table A2 in annex). The exposure reduction from the use of LPG is influenced both by cooking location as well as by the degree of adoption of LPG in the community.

Intervention Costs

Four costs of the interventions are quantified in monetary terms: i) cost of stoves; ii) stove maintenance and repair; iii) fuel cost (LPG); and iv) stove promotion program.

Cost of stoves: The economic cost of an improved cookstove for wood (i.e., Rocket stove) as well as LPG stove, both with two burners, is expected to be around US$ 50. This is the price exclusive of any import duties and taxes.[33] The useful life of the improved cookstove and the LPG stove is 5 and 10 years respectively. The improved cookstove is therefore purchased twice during the 10-year assessment period while the LPG stove is purchased once. Additionally, US$ 25 is applied for the upfront cost of LPG cylinder and connection hose.

Maintenance and repair: Annual cost of maintenance and repair is assumed to be 5% of initial stove cost. Cost is assumed constant over the 10-year assessment period.

Fuel cost: The improved cookstove does not entail any additional fuel purchases (only fuel savings from improved stove efficiency). However, the LPG stove involves the purchase of LPG fuel, here assumed at 25 kg per person per year, or 125 kg per year for a 5-person household.[34] A survey of LPG retail prices in 21 Sub-Saharan African countries in 2011-12 found that prices ranged from US$ 0.4 to 3.1 per kg (World Bank, 2014). Retail prices were

[32] Benefits and costs of improved charcoal stoves are not assessed here although about 15% of the population in Sub-Saharan Africa uses charcoal as primary cooking fuel.

[33] Import duties and taxes are simply a transfer from consumers to government and are therefore not part of economic cost.

[34] This is the approximate energy requirement for cooking, based on an LPG stove efficiency of 55%.

on average US$ 2.0 in 11 low-income countries and US$ 1.5 in 7 middle-income countries. These prices include any import duties and taxes. The economic retail cost of LPG today is on the order of US$ 1.0-1.2 per kg depending on transport cost. A cost of US$ 1.1 is applied in the assessment here, and is assumed constant over the 10-year assessment period.

Stove promotion program: Stove promotion is needed to increase the demand for improved cookstoves and use of LPG for cooking. A cost of US$ 5 per household is applied here.[35] The program is repeated every 5 years to promote sustained use of improved cookstoves and LPG. Program cost is assumed to increase at the rate of GNI per capita growth to account for increase in real wages.

TABLE 3. PRESENT VALUE OF COSTS OF INTERVENTIONS, 2020-2030 (US$ PER HOUSEHOLD)

	ICS	LPG
Stove cost	85	71
Stove maintenance and repair	17	17
Fuel cost	-	1,142
Stove promotion program	10	10
Total costs	**111**	**1,240**

Source: The author.

Intervention Benefits

Three benefits of the interventions are quantified in monetary terms: i) health benefits in terms of averted mortality and morbidity; ii) cooking time savings; and iii) solid fuel savings.[36]

Health benefits: The health risk functions associated with PM2.5 exposure from the Global Burden of Disease 2017 (GBD 2017) are applied for assessing health benefits of the interventions (see Stanaway et al, 2018 Supplement). These health risk functions are also used by the WHO.

The improved cookstoves for wood are estimated to provide 23% reduction in health effects compared to the use of a traditional cookstove for wood. LPG is estimated to provide 40% reduction in health effects in the scenario with partial adoption of LPG in the community and 56% reduction in the scenario with full adoption of LPG.[37]

Health benefits are valued at 1.3 * GNI per capita per year of life saved and per year of disability from illness averted. GNI per capita growth of 4.9% per year is assumed for the low-income countries in Sub-Saharan Africa over the assessment period.

Cooking time savings: Households often spend multiple hours a day on cooking activities. The use of traditional stoves or open fire adds to the cooking time. A time saving of 20 minute per day is applied for the improved cookstove with wood and 40 minutes per day for LPG. These time savings are valued at 50% of average wages rates.[38] Wage rates are assumed to increase at the rate of GNI per capita growth.

Solid fuel savings: An improved cookstove for wood can save 40-50% of fuelwood used for cooking due to increased stove efficiency (IEA, 2017). A fuel saving of 40% is applied here for the improved cookstove. The exclusive use of LPG will save 100% of solid fuel use. Some fuelwood is purchased at various prices while

[35] The program cost may be higher depending on the stove intervention adoption rate aimed for. A tripling of the cost will reduce the benefit-cost ratio for the improved cookstove for wood by only about 15% and substantially less for the LPG stove.

[36] Greenhouse gas emissions reduction benefits of interventions are not quantified. Reductions depend on the unsustainable share of fuelwood harvesting. The unstainable share has been estimated at below 30% in most parts of Sub-Saharan Africa, with shares reaching over 50% in several East African countries (Bailis et al, 2015). At 30% unsustainability, an improved cookstove for wood and an LPG stove could save about 0.5 tons and 0.75 tons of CO2 per year per household, respectively. The global benefit of this reduction, at for instance a damage cost of US$ 25 per ton of CO2, is less than 10% of total quantified health and time benefits of the interventions.

[37] This is estimated using the PM2.5 exposure levels in Table A2 in the annex, the health risk functions from the GBD 2017, and the so-called "Potential Impact Fraction" equation. Reductions in non-acute health effects (IHD, stroke, COPD, and diabetes type II are assumed to be fully realized over a 10 year period, while the reductions in ALRI is realized within a year of the interventions.

[38] Average wage rates are estimated from GNI per capita, labor income share of GNI or GDP from PENN Tables 9.0, and labor force participation rates.

much of the fuelwood is self-collected by the households. The fuel savings are here valued in terms of collection time savings valued at 50% of average wage rates, with wage rates increasing at the rate of GNI per capita growth. A survey of 22 countries in Sub-Saharan Africa found that households spend on average 0.8 to 5 hours a day on fuelwood collection (World Bank, 2014). The average for the 22 countries is 2.1 hours per day, and 2.4 hours per day in the low-income countries of Sub-Sharan Africa.

TABLE 4. PRESENT VALUE OF BENEFITS OF INTERVENTIONS, 2020-2030 (US$ PER HOUSEHOLD)

	ICS	LPG Partial	LPG Full
Health benefits	200	336	481
Cooking time savings	286	573	573
Solid fuel savings	817	2042	2042
Total benefits	**1303**	**2951**	**3096**

Note: LPG Partial and LPG Full refers to the two adoption scenarios of the intervention. Source: The author.

Benefit-Cost Ratios

The benefit-cost ratios (BCR) range from 2.4-2.5 for LPG to 11.7 for improved cookstoves for wood. These BCRs are based on the cost and benefits presented above. While the health benefits of LPG with full community adoption is substantially higher than with partial adoption, the BCRs are very similar due to the main benefits being non-health.

A sensitivity analysis has also been undertaken with respect to the largest benefits and the largest costs, i.e., in relation to fuelwood collection time (sold fuel savings) and LPG fuel cost. Applying a fuelwood collection time of 1.5 hours instead of the average of 2.4 hours per day reduces the BCRs by about 25%, and so does an increase in the cost of LPG from US$ 1.1 to US$ 1.5 per kg. And an increase in the cost of LPG to US$ 2.0 per kg reduces the BCRs to 1.35-1.4, demonstrating the sensitivity to the LPG fuel cost.

TABLE 5. BENEFIT-COST RATIOS OF INTERVENTIONS

	ICS	LPG Partial	LPG Full
Base case	**11.7**	**2.4**	**2.5**
Case: Fuel collection time 1.5 hours	9.0	1.8	1.9
Case: LPG fuel cost US$ 1.5 per kg	11.7	1.8	1.9
Case: LPG fuel cost US$ 2.0 per kg		1.35	1.4

Note: LPG Partial and LPG Full refers to the two adoption scenarios of the intervention. Source: The author.

Discussion

The high prevalence of cooking with solid fuels in Sub-Saharan Africa has substantial health effects, and the use of clean cooking fuels and technologies in the low-income countries of Sub-Saharan Africa has only increased by 1 percentage point of the population from 2000 to 2016.

The BCR for improved cookstoves for wood is five times higher than the BCR for LPG. Improved cookstoves is therefore a reasonable intervention in the short to medium term, but not in the long term as the health benefits of improved cookstoves are only moderate. The longer-term solution is the use of LPG or other clean cooking energies such as electricity. And added health benefits will come from a community focus with the aim of achieving "solid fuel free" communities, along the lines of "open defecation free" communities.

For improved cookstoves, promotion programs must focus on dimensions and consumer preferences of stoves that enhance initial uptake as well as ensures high rates of continued use and proper maintenance of stoves.

To scale-up and speed-up implementation of interventions for cleaner cooking, it is important to eliminate price distortions that discourage uptake, such as import duties and taxes on stoves and LPG. It is also important to facilitate term financing for the purchase of improved cookstoves and LPG stoves and LPG connection equipment. Supplying smaller volume LPG cylinders has also been introduced in some countries to smooth the

cost of LPG fuel. Well targeted subsidies for LPG for poorer households may also need to be considered.

The use of electricity for cooking may be the preferred choice over LPG for many households in countries with increased access to electricity at affordable prices. The use of block tariff rates, with lower rates for small users (often poorer households), can be an added incentive for adoption of clean cooking with electricity.

References

Bailis, R., Drigo, R., Ghilardi, A., and Masera, O. 2015. The Global Footprint of Traditional Woodfuels. *Nature Climate Change*, 5: 266–272.

IEA. 2017. Energy Access Outlook 2017: From Poverty to Prosperity. World Energy Outlook Special Report. International Energy Agency.

NBS/UNICEF. 2018. Multiple Indicator Cluster Survey 2016-17, Survey Findings Report. Abuja, Nigeria: National Bureau of Statistics and United Nations Children's Fund.

Stanaway, J. and GBD 2017 Risk Factor Collaborators. 2018. Global, regional, and national comparative risk assessment of 84 behavioural, environmental and occupational, and metabolic risks or clusters of risks for 195 countries and territories, 1990–2017: a systematic analysis for the Global Burden of Disease Study 2017. *Lancet*, 392: 1923-94.

WHO, IEA, GACC, UNDP and World Bank. 2018. Achieving Universal Access to Clean and Modern Cooking Fuels and Technologies. Policy Brief # 2.

https://sustainabledevelopment.un.org/content/documents/17465PB_2_Draft.pdf

World Bank. 2019. World Development Indicators. Washington DC. USA.

World Bank. 2014. Clean and improved cooking in Sub-Saharan Africa. A landscape report. Washington DC. USA..

Annex

TABLE A1. HOUSEHOLD AIR POLLUTION (HAP) AND ACCESS TO CLEAN FUELS AND TECHNOLOGIES FOR COOKING IN AFRICA

Group	Countries	GDP per capita, US$, 2017	Population, Million, 2017	Deaths from HAP, 2017	Access to Clean fuels and technologies for cooking, % of population in 2016
SSA - LIC	27	639	576	265,250	5%
SSA - LMIC	14	1,899	390	125,184	15%
SSA - UMIC	7	5,681	96	12,802	71%
SSA - HIC	1	15,504	0.1	4	90%
N-Africa	5	3,148	193	1,150	97%
Africa total	55	1,807	1,255	404,388	26%

Source: World Bank (2019) and GBD 2017 (www.healthdata.org).

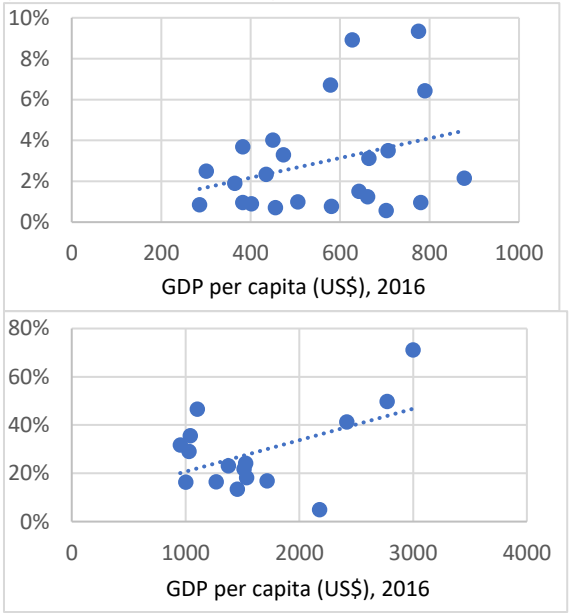
Household use of solid fuels for cooking and other purposes - such as wood, agricultural residues, dung, and charcoal/coal –causes elevated fine particulate air pollution (PM2.5), often with household member exposures of 100-200 µg/m^3 or 10-20 times the WHO annual guideline of 10 µg/m^3.

PM2.5 is the pollutant that globally is associated with the largest health effects of air pollution. Health effects include ischemic heart disease (IHD), stroke, chronic obstructive pulmonary disease (COPD), lung cancer, diabetes type 2, and acute lower respiratory infections (ALRI) (Stanaway et al, 2018).

An overview of income level, population, deaths from household air pollution (HAP), and access to clean fuels and technologies for cooking in Africa is provided in Table A1.

The use of clean fuels and technologies for cooking rises with higher GDP per capita as indicated by the upward sloping trend lines in Figure A1 for low-income (LI) and lower middle-income (LMI) countries in SSA. This relationship is also evident among the 8-upper middle-income (UMI) and high-income (HI) countries (not presented in Figure A1). But GDP per capita is not the only determinant of the use of clean fuels and technologies for cooking, as can be seen by the wide range of use at any given level of GDP per capita. For instance, at GDP per capita of a little less than US800, only 1% of the population in Mali is using clean fuels and technologies, while over 9% do so in Comoros. Similarly, at GDP per capita of US$ 1,000-1,100, 16% of the population in Eritrea uses clean fuels and technologies while 47% do so in Mauritania. As kerosene is not classified as a clean cooking fuel, only 5% of the population in Nigeria with a GDP per capita of US$ 2,176 in 2016 is using clean fuels and technologies. Nearly 13% of the population used kerosene as primary cooking fuel in 2016-17 according to NSB/UNICEF (2018).

FIGURE A1. USE OF CLEAN FUELS AND TECHNOLOGIES FOR COOKING IN SSA IN RELATION TO GDP PER CAPITA (% OF POPULATION, 2016)



Note: Includes low-income (LI) and lower-middle income (LMI) countries. Source: World Bank (2019).

National Demographic and Health Surveys (DHS) and Multiple Indicator Cluster Surveys (MICS) of households in 40 countries from 2012-2017 provide an overview of the primary cooking fuel used by the populations of SSA countries (Figure A2). The surveys find:

LPG and electricity: 7% of the population used LPG and equally many used electricity for cooking.[39] LPG is used by 25-79% in 7 countries (Cote D'Ivoire, Ghana, Lesotho, Senegal, Mauritania, Angola and Gabon). Electricity is used by 25-77% in 4 countries (Zimbabwe, Eswatini, Namibia and South Africa).

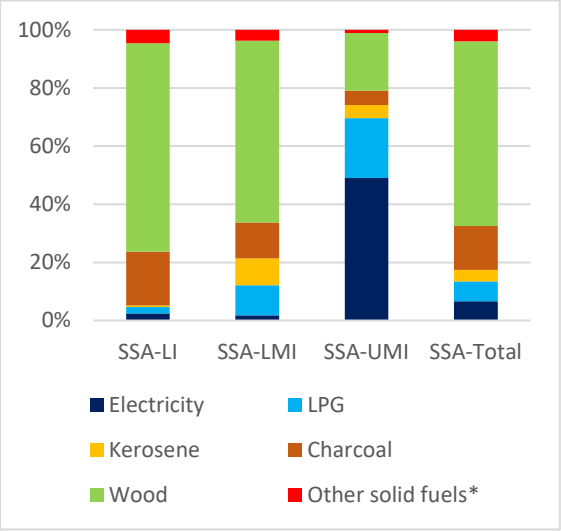
Kerosene: 4% of the population used kerosene. The fuel is used by 10-55% of the population in 6 countries (Congo Rep, Kenya, Nigeria, Comoros, Equatorial Guinea, and Sao Tome and Principe).

Charcoal: 15% of the population used charcoal. It is used by more than 20% of the population in 15 countries.

Wood: 63% of the population used wood. Wood is the predominant fuel is both LI and LMI countries. It is also used by 30-50% of the population in several UMI countries (Angola, Equatorial Guinea and Namibia).

Other solid fuels: 4% of the population used other solid fuels, such as coal, agricultural crop residues, animal dung and straw/grass/shrubs.

FIGURE A2. PRIMARY COOKING FUEL IN SSA, 2012-2017 (% OF POPULATION)



* Coal, agricultural residues, animal dung, straw/grass/shrubs. Source: DHS and MICS household surveys from 40 SSA countries, covering 93% of the SSA population.

The DHS and MICS surveys find that 72% of the population in SSA cook indoors (in the house or in a separate building) and that 26% cook outdoors. In the LI countries of SSA, 69% cook indoors and 29% outdoors.[40] While outdoor cooking reduces overall exposure to PM2.5, exposures are still many times the WHO guideline for the cook as well as for other household members as smoke from cooking enters the buildings in the community.

Personal exposures are highest for adult females who traditionally cook in the household, followed by young children who tend to spend much of their time in the household environment, and lowest for adult males who tend to spend a substantial part of their time further away from the household environment. The range in exposure within each group of household members reflects household cooking location, with highest exposures in households cooking indoors and lowest in households cooking outdoors.

TABLE A2. HOUSEHOLD MEMBER PM2.5 EXPOSURES (MG/M3)

	Pre-intervention TCS	Post-intervention ICS	Post-intervention LPG
Females (adults)	120-200	80-100	25-50
Males (adults)	70-120	45-60	25-35
Children (under 5 years)	100-170	65-85	25-50

Source: The author.

[39] And very minor amounts of other gaseous fuels.

[40] 2% cook elsewhere or do not cook in the household environment.