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Summary

World Health Organization

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Abbreviations

ALRI	acute lower respiratory infection
CBA	cost–benefit analysis
BCR	benefit–cost ratio
CEA	cost–effectiveness analysis
CH_4	methane
CO	carbon monoxide
CO_2	carbon dioxide
COPD	chronic obstructive pulmonary disease
g/l	grams per litre
GHG	greenhouse gas
GNI	gross national income
HH	household
IAP	indoor air pollution
LPG	liquefied petroleum gas
MDG	Millennium Development Goal
MJ	megajoules
NPV	net present value (present value of economic benefits minus costs)
OECD	Organisation for Economic Co-operation and Development
PM	particulate matter
WHO	World Health Organization

Foreword

Worldwide, more than three billion people cook with wood, dung, coal and other solid fuels on open fires or traditional stoves. The resulting indoor air pollution is responsible for more than 1.5 million deaths annually due to respiratory diseases – mostly of young children and their mothers. Effective solutions to reduce levels of indoor air pollution and improve health do exist. They include cleaner and more efficient fuels, improved stoves that burn solid fuels more efficiently and completely, and better ventilation. To be effective and sustainable in the long term these solutions must be accompanied by behaviour change (Bruce et al., 2006).

In addition to improving health and reducing illness-related expenditures, household energy interventions have many impacts that, at the household level, improve family livelihoods and, at the population level, stimulate development and contribute to environmental sustainability. These benefits include time savings due to fewer days of illness and shorter time spent on fuel collection and cooking. Cost–benefit analysis is an analytical tool that takes into account all the costs and benefits of household energy interventions to reduce indoor air pollution, from a societal perspective. It can thus play an important role in guiding public policy-making and investments in household energy interventions.

The World Health Organization (WHO), in collaboration with the Swiss Tropical Institute, has developed a publications package on cost–benefit analysis of household energy and health interventions, consisting of three publications: *Guidelines for conducting cost–benefit analysis of household energy and health interventions to improve health* are intended for economists and professionals interested in conducting such an analysis at the national and subnational levels. Based on these guidelines, WHO has conducted a global cost–benefit analysis and published the results in *Evaluation of the costs and benefits of household energy and health interventions at global and regional levels*. This technical publication is intended for professionals working on household energy, environment and health. This *Summary* provides a synopsis of the key findings for policy-makers in the energy, environment and health sectors at the subnational, national and international levels.

This *Summary* outlines the methods and data sources that form the basis for cost–benefit analysis of household energy and health interventions, and presents the results for three intervention scenarios of particular relevance to energy policy in the context of the Millennium Development Goals. It concludes that the gains in health and productivity far outweigh the overall cost of the interventions. Demonstrating the economic benefits of investments in improving access to cleaner and more efficient household energy practices should contribute to sound policy-making and to overcoming the constraints on implementing household energy interventions.

Introduction

The economic evaluation of interventions is becoming increasingly important in the health and development field. Where funding is limited, it represents a recognized analytical tool for comparing the costs and impacts of one intervention with those of another.

Cost–benefit analysis (CBA) offers a method of economic evaluation of all benefits against all costs from a societal perspective. It can inform public policymakers in making decisions on how best to allocate funds between competing projects or programmes. CBA measures the net welfare effect on society of a defined intervention or mix of interventions. Both costs and benefits are presented in monetary units. The results of such an analysis can be used to select the most efficient intervention to achieve a given aim in a specific sector, but it can also be used to assign resources between different sectors of the economy. In contrast, cost–effectiveness analysis (CEA) measures intervention impacts, in non-monetary units, of decision-making in a single sector, such as the health sector. Previously, WHO has presented CEA results for household energy and health interventions as cost per healthy life year gained (Mehta & Shahpar, 2004).

The aim of this summary report is to present selected results from a study measuring the costs and benefits of household energy and health interventions (Hutton et al., 2006). Results are presented separately for urban and rural populations at the global level and for 11 developing and middle-income WHO subregions.

Methods

Methods follow the World Health Organization guidelines on conducting cost–benefit analysis of household energy and health interventions (Hutton & Rehfuess, 2006), which draw on international economic evaluation guidelines (Gold et al., 1996; Drummond et al., 1997; Tan-Torres Edejer et al., 2003).

Interventions modelled

Interventions were chosen based on their relevance to the household energy target "to halve, by 2015, the number of people without effective access to modern cooking fuels, and to make improved cooking stoves widely available" proposed by the Millennium Project in the context of the Millennium Development Goals (MDGs) (WHO, 2006). Taking into account amenability to a global-level analysis, two main intervention approaches were selected:

- reducing exposure through changing from solid fuels to cleaner fuels; and
- reducing exposure through a cleaner burning and more efficient improved stove.

Due to data constraints and the complexities of attempting to reflect different stove options in different parts of the world, a single stove option was modelled in this global study.

Costs and benefits were modelled under eight different intervention scenarios, covering three specific interventions[1] (liquefied petroleum gas (LPG), biofuel (ethanol) and a chimneyless "rocket" stove) at two levels of population coverage (to reduce the population not served in 2005 by 50% or 100% by 2015). The 50% scenarios were further subdivided into a base-case analysis, where all users of traditional fuels are targeted equally, and a pro-poor analysis, which first targets those with the most polluting and least efficient solid fuels in the following order: dung and agricultural residues; firewood; coal; charcoal.

[1] This study chose specific interventions based on their ability to reduce indoor air pollution levels substantially and their amenability to being implemented globally. It did not model a switch to kerosene or paraffin, because of the difficulty in taking a clear health position on these alternative fuels. The advantage of promoting a switch to kerosene or paraffin is that they reduce levels of indoor air pollution and the associated risks of respiratory disease among children and women. Furthermore, these fuels have considerable potential for expansion, given their widespread use and availability and their relatively low cost. At the same time, however, there is mounting evidence on the health hazards related to the unsafe use of kerosene and paraffin, in particular burns, poisonings and other unintentional injuries among children. Therefore, the preference for achieving the 2015 target would be to increase coverage through use of cleaner and *safe* fuels. Consequently, this study treated kerosene and paraffin as "neutral" fuels: the population currently using these fuels was classified as having access to cleaner fuels, but the interventions modelled in this study did not actively promote an increase in the number of people using these fuels.

Costs and benefits of modelled interventions are presented on an annual basis in United States Dollars (US$) for the year 2005. The analysis assumes a first year of intervention in 2006 and an intervention period of 10 years until the end of 2015. All input data were adjusted to reflect these start and end dates, based on the latest data available and, where necessary, predictions for the next 10 years. All costs and benefits occurring after 2005 were discounted to 2005 values using a discount rate of 3%.

This summary report focuses on the 50% coverage scenarios for LPG and improved stoves. It describes the LPG base-case analysis (scenario I), the LPG pro-poor approach (scenario II), and the improved stoves base-case analysis (scenario III). These scenarios were chosen because reaching 50% of the population using solid fuels is more realistic than achieving universal coverage between 2006 and 2015. Moreover, given the current distribution and use of cleaner fuels, scaling up coverage of LPG is more feasible than scaling up that of biofuels. Detailed results for all eight scenarios are available in the published report (Hutton et al., 2006).

Population targeted

Population coverage targets are based on the world's population at the end of 2015, using UN Population Division data on expected population growth for each country. The fuel and stove coverage of additions to the population (population growth) are assumed to be equal to the starting coverage in 2005. Rural and urban households are modelled separately for each WHO subregion.[1] Population coverage of fuel use and improved stove use reflect 2003 coverage[2] (WHO, unpublished data, 2005; Rehfuess et al., 2006). Given that input data for some costs and benefits are estimated at the household level, population size was converted to number of households using an average household size for each WHO subregion. This average household size is based on weighted country-level estimates, and was calculated separately for rural and urban populations. Table 1 shows the percentage of households using different types of solid fuels and traditional stoves, by WHO subregion. As non-A subregions, classified by WHO according to their very low child and very low adult mortality, have already made a near-complete transition to cleaner fuels, these geographical areas are not further discussed in this analysis.

Costs and benefits included

The benefit–cost ratio is calculated as the annual average economic benefits of the intervention divided by the annual average economic net costs of the intervention. Cost–benefit analysis is traditionally undertaken from a societal perspective, and should therefore include all important economic costs and benefits arising from an intervention.

[1] WHO distinguishes between the following geographical regions: African Region (AFR); Region of the Americas (AMR); Eastern Mediterranean Region (EMR); European Region (EUR); South-East Asia Region (SEAR); Western Pacific Region (WPR). WHO also differentiates between the following mortality strata: very low child, very low adult (A); low child, low adult (B); low child, high adult (C); high child, high adult (D); high child, very high adult (E).

[2] These data were not adjusted to the year 2005 due to lack of reliable data on rates of change over the period 2003–2005.

Table 1. Percentage of households using solid fuels and traditional stoves (year 2003)

	Solid fuel use								Traditional stove	
	Coal		Charcoal		Wood		Dung and other[a]			
WHO subregion	**Urban (%)**	**Rural (%)**	**Urban (%)**	**Rural (%)**	**Urban (%)**	**Rural (%)**	**Urban (%)**	**Rural (%)**	**Urban (%)**	**Rural (%)**
AFR-D	2.8	0.6	16.2	4.0	28.1	41.0	31.5	49.5	92.0	98.6
AFR-E	8.8	1.6	15.1	15.0	24.6	57.9	4.4	12.1	86.6	94.3
AMR-B	0.7	3.2	0.5	2.1	3.0	46.5	0.6	0.8	91.6	75.4
AMR-D	9.6	0.1	11.7	2.2	0.7	66.8	2.8	6.2	99.8	98.0
EMR-B	0.7	0.7	0.0	0.0	0.1	0.1	18.6	51.1	89.2	89.2
EMR-D	0.4	0.5	0.5	1.1	20.8	47.8	1.2	8.8	95.3	97.5
EUR-B	0.4	0.4	0.1	0.1	4.6	31.7	0.7	1.7	36.5	13.7
EUR-C	0.9	1.1	0.2	0.4	4.9	6.0	0.2	0.0	12.4	0.9
SEAR-B	0.4	0.0	25.7	0.3	0.0	85.4	0.0	0.0	96.0	90.3
SEAR-D	3.5	1.2	7.2	1.3	16.2	71.1	1.4	16.1	95.0	93.8
WPR-B	7.1	3.3	12.4	14.3	14.6	44.5	1.2	4.6	97.8	97.6

[a] "Other" includes agricultural residues, crop waste, grass and shrubs.

AFR, WHO African Region; AMR, WHO Region of the Americas; EMR, WHO Eastern Mediterranean Region; EUR, WHO European Region; SEAR, WHO South-East Asia Region; WPR, Western Pacific Region. Mortality strata: A, very low child, very low adult; B, low child, low adult; C, low child, high adult; D, high child, high adult; E, high child, very high adult.

Source: Rehfuess et al. (2006) and WHO, unpublished data (2005). For 49 countries, from World Health Survey 2003; for 33 countries, from other available sources; for the remaining 36 developing and middle-income countries, estimates are based on modelled data.

Intervention costs include fuel costs, stove costs, and programme costs for the distribution of cleaner fuels or improved stoves, including related research and development investments and accompanying educational measures. Intervention costs are calculated as a net value, by subtracting from the actual costs of the intervention any cost savings that occur as a result of switching away from traditional fuels or using less fuel due to efficiency gains.

Economic benefits include reduced health-related expenditure as a result of less illness, the value of assumed productivity gains resulting from less illness and fewer deaths, time savings due to the shorter time spent on fuel collection and cooking, and environmental impacts at the local and global levels. The health improvements included are those estimated as part of WHO's comparative risk assessment (Smith et al., 2004): acute lower respiratory infections (ALRI) in children younger than 5 years, chronic obstructive pulmonary disease (COPD) in adults older than 30 years and lung cancer in adults older than 30 years. Local environmental effects are assessed as fewer trees cut down, whereas the global environmental effects considered are reduced emissions of carbon dioxide (CO_2) and methane (CH_4). Table 2 summarizes the economic benefits included in the analysis.

Some other potential benefits of intervention were not modelled due to lack of evidence for intervention impacts or lack of suitable data for inclusion in a global analysis. These were: health effects for which the current evidence for indoor air pollution as a cause is inconclusive (e.g. tuberculosis, asthma, cataract and burns); improved food safety and nutrition; better quality of the home environment; reduced child labour for collecting biomass; and additional environmental impacts such as improved soil fertility, reduced destruction of habitats and biodiversity, and reductions in greenhouse gases other than CO_2 and CH_4.

Table 2. Overview of costs and impacts, and time horizon of modelled impacts

Variable	Immediate cost or impact	Delayed cost or impact[a]
Intervention costs	Investment costs, such as stove purchase cost and cost of house alterations	NA
	Recurrent costs, such as fuel costs and programme costs	
Health benefits and savings on health-care costs	ALRI Lung cancer	COPD
Productivity gains due to reduced morbidity	Related to ALRI	Related to COPD and lung cancer
Productivity gains due to reduced mortality	NA	Related to ALRI for children, and to COPD and lung cancer for all age groups
Time savings	Fuel collection time and cooking time	NA
Environmental benefits	Local and global environmental benefits	NA

NA, not applicable; COPD, chronic obstructive pulmonary disease; ALRI, acute lower respiratory infections.

[a] Future costs and impacts are discounted at a 3% discount rate per year.

Cost data sources and inputs

Given the global and regional nature of the analysis, sources of appropriate cost and impact data were identified to apply to these levels. Different data sources available at the global, regional and country levels were compared for relevance. For price data on traded goods available at the international level, prices were adjusted for insurance and freight using an average price multiplier available for the 11 WHO subregions.

Stove prices. For the improved stove, a chimneyless "rocket" stove was chosen because it is used widely and prices are available for several countries. Its cost is US$ 6 (lower limit US$ 2) and it has an expected length of useful life of 3 years (range 1–4 years). Other types of improved stove, such as chimney stoves, can cost up to US$ 80 but often have additional functions and last longer. Based on laboratory data, improved stoves were assumed to lead to fuel savings of 34% due to greater heat transfer efficiency. Based on the findings of Mehta & Shahpar (2004), the cost of the LPG burner is US$ 60 and that of the LPG cylinder US$ 50, with an expected 10-year length of useful life. Programme unit costs per stove distributed are based on published WHO data (Mehta & Shahpar, 2004).

Fuel consumption. The average consumption of different solid fuels for household cooking purposes was obtained from the UN Statistics Division (Energy Section), which reports data on total household consumption for selected countries and commodities. Smith et al. (2005) presented total residential LPG consumption in the 10 largest developing countries, which were used to reflect the WHO subregions.

Fuel prices. Fuel prices also vary by country and region. For the purposes of estimating representative fuel prices for each WHO subregion, fuels were categorized into those that are principally traded on the international market and for which international prices are available (LPG, biofuels and coal) and those which are only traded domestically (charcoal and firewood). Agricultural waste products (crop residues and dung) are assumed to be collected or made by each household and thus incur no direct cost.

According to the World LP Gas Association (2006), the world price for butane (used to produce LPG) is US$ 0.26 per litre. For ethanol a near-term industry estimate of US$ 0.36 was used in the base case analysis. Unit prices in rural areas were adjusted upwards by 20% to reflect additional transport costs and potentially reduced competition among suppliers. For coal, the World Bank provides commodity prices for Australian export coal (a major world supplier) as US$ 0.51 per kilogram in the year 2005.

For biomass fuels not traded internationally – firewood and charcoal – local prices were collected both from the international literature and through contacts in selected countries. All households were assumed to purchase rather than produce their charcoal. On the other hand, the source of firewood was assumed to vary by location: 75% of urban dwellers and 25% of rural dwellers were assumed to purchase wood for fuel.

Benefit data sources and inputs

Health impacts. For the three diseases included in the study – ALRI, COPD and lung cancer – incidence and deaths attributable to indoor air pollution (IAP) were estimated for each WHO subregion for 2002. Figures for 2005 were derived by applying the disease rates per 100 000 population in 2002 to the 2005 population figures. The cleaner fuel interventions are assumed to reduce the risk of diseases attributable to IAP to the baseline risk in the population. The assumed health impacts of improved stoves are based on three studies that have compared personal exposure levels in homes where open fires are used with homes that use improved stoves, giving an average reduction in personal exposure of 35% (Naeher et al., 2000; Bruce et al., 2002; Bruce et al., 2004). In view of the limited number of studies and the uncertainty over treating reductions in personal exposure as a suitable proxy for reductions in adverse health outcomes, a range of 10% to 60% was tested in the sensitivity analysis.

Health care cost savings. A cost saving per case of disease averted is calculated based on data for each WHO subregion, disease and level of severity (e.g. treatment-seeking, unit costs of care). For an assumed proportion seeking modern health care, a cost for a typical case as an outpatient as well as the cost of hospitalization for a proportion of patients admitted to hospital were calculated. Both are estimated for primary facilities. Health system unit costs of outpatient and inpatient care were extracted from an international review of costs, available by WHO subregion (Mulligan et al., 2005). Costs of disease-specific treatments, such as medicines and procedures, were added to these unit costs. The prices of medicines are derived from the International Drug Price Indicator Guide 2005. The median international price was adjusted by the WHO subregional price multipliers to take into account the costs of insurance and freight. An average length of stay for hospital inpatients was assumed for each disease and level of severity.

Productivity gains due to improved health. The human capital approach, which uses market prices from the labour market to value changes in health status, is used to value illness-free days and deaths avoided. Despite the many limitations, this approach is the most applicable to a global study that relies on compilation of evidence from secondary sources. The number of days of illness varies according to the severity of the disease and to whether the individual sought and received treatment. For adults, the model values the economic benefits of reduced morbidity as the number of days of illness averted multiplied by the average daily gross national income (GNI) per capita for each WHO subregion. For children, the number of days of illness averted is multiplied by half the average daily GNI per capita. The economic benefits of averted deaths are calculated as the annual value of time (GNI per capita) multiplied by the number of years of income-earning life lost. The latter assumes an income-earning life from the age of 15 years to 65 years. Future years of income-earning time gained are discounted to the present time using an annual discount rate of 3%. In the sensitivity analysis, a value of 30% of GNI per capita was applied to adults only.

Time savings. Two types of time saving are included in the analysis: time saved in the collection or preparation of wood fuel, dung or other fuel sources, and time saved on cooking. Time savings are valued at the average GNI per capita for each WHO subregion, and at 30% of GNI in the sensitivity analysis. Estimates of time spent collecting wood for fuel are available in the literature and in surveys (Dutta et al., 2005). Subregional averages for time use were estimated by taking weighted averages of values available for selected countries. For dung and crop residues, almost no published information on collection or preparation time exists. The collection and preparation time for these fuels was assumed to be roughly half that required for collecting firewood. A stove comparison study conducted by the Aprovecho Research Center provides information on the time taken to boil a given quantity of water, and reports reductions in cooking time from using improved stoves rather than open fires of approximately 14% (Still et al., in press). Similar studies show time savings of approximately 12% from the use of non-solid fuels.

Environmental benefits. Environmental benefits are estimated at the local level and the global level. Local environmental benefits accrue as part of a switch away from biomass to cleaner fuels, or when improved and more fuel-efficient stoves lead to less consumption of biomass. This study includes the effect of fewer trees being cut down in an unsustainable fashion, as deforestation can lead to soil erosion, desertification, and, in hilly areas, to landslides. Rather than trying to place a value directly on these downstream effects, an alternative method values the cost of replacing trees, which would avert the possible adverse effects described above (called avertive expenditure). The replacement cost comprises the labour cost plus the cost of the tree sapling, adjusted by a wastage factor (percentage of saplings planted that do not mature). A Brazilian source estimated the average cost per tree replaced as US$ 0.60 (2005 prices).

Global environmental benefits occur when greenhouse gas (GHG) emissions are reduced. The burning of solid fuels in households leads to the emission of many different GHGs. This study focuses on CO_2 and CH_4. These are recognized under the Clean Development Mechanism (CDM) of the Kyoto Protocol, and values associated with reduced emissions of these gases are more readily available and more reliable. The exclusion of black carbon and other gases that are potentially linked to global warming gives a conservative estimate of the benefits. The global environmental value is calculated by estimating the total reduction in emissions achieved by each of the interventions modelled, based on:

- the amount of each fuel burnt per year, available from the study model;
- the CO_2 and CH_4 emissions for each kilogram of fuel burned, available from published studies (Smith et al., 2000; Thomas et al., 2000); and
- the economic value of averting emissions of GHGs, available from the carbon trading market.

A conservative trading price of US$ 4 per tonne of CO_2 emission reduced is used, ranging from US$ 1 to US$ 7 in the sensitivity analysis. A trading value for CH_4 was not found. However, based on the comparison of the instantaneous global warming potential between CH_4 and CO_2 (Smith et al., 2000), multiplying the CO_2 carbon trading value by the 7.6 times higher potency of CH_4 gives a value of US$ 30 per tonne of methane emissions reduced.

Sensitivity analysis. There is considerable uncertainty in the results due to the assumptions employed in the model as well as the lack of generalizable data for use at the subregional and global levels. The sensitivity analysis was performed to assess the impact on the benefit–cost ratio of high and low values of key parameters. Results are presented for changes in stove costs and efficiency; fuel prices; health impacts of improved stoves and the lag time for the health effect; the value of time; the treatment of children's time gains; savings in fuel collection and cooking times; costs of tree replacement; CO_2 and CH_4 emissions per kg of fuel burned; the economic value of emissions reductions per tonne; and the discount rate for future costs and benefits. High and low values were largely based on alternative values available in the literature or, where these were not available, assumptions about expected ranges.

Results

Base-case results

Costs. The annual net costs of intervention are presented in Table 3. They reflect the cost of intervention minus any cost savings from switching to cleaner fuels or from using less of the same fuel on an improved stove. Negative figures therefore indicate a net saving associated with the scenario. The global annual cost of scenario I is US$ 13 billion (total costs of US$ 24 billion minus savings of US$ 11 billion), compared with US$ 16 billion for scenario II (total costs of US$ 24 billion minus savings of US$ 8 billion), and a net saving of over US$ 34 billion for scenario III (total costs of just over US$ 2 billion minus savings of US$ 37 billion). The majority of the costs in scenarios I and II are household costs related to fuel and stove purchase, and, to a lesser extent, programme costs which

Table 3. Annual net intervention costs (million US$)

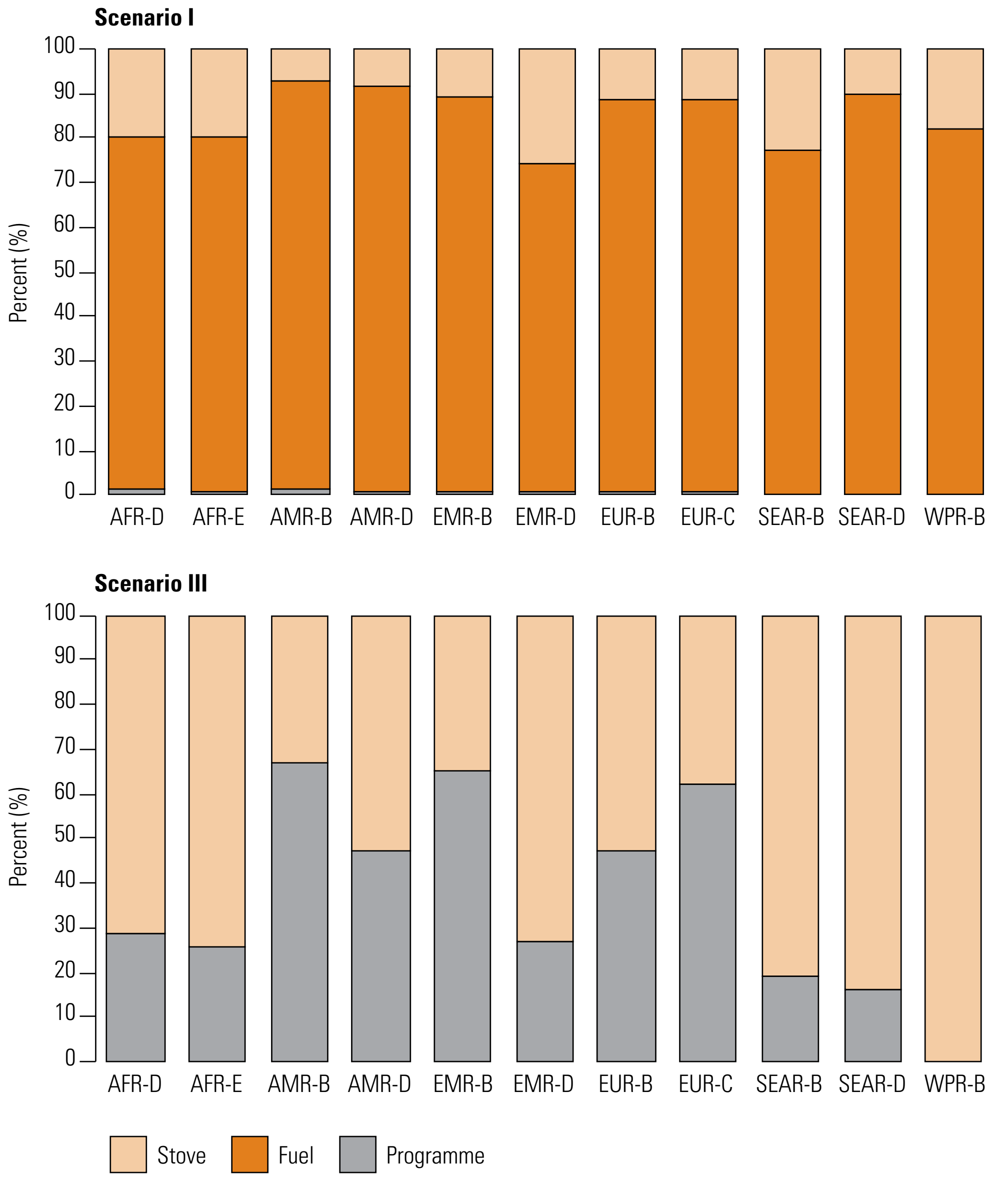
	By 2015, reduce by 50% population without access to a cleaner fuel or an improved stove					
	Scenario I (LPG)		Scenario II (LPG pro-poor)		Scenario III (improved stove)	
WHO subregion	**Urban**	**Rural**	**Urban**	**Rural**	**Urban**	**Rural**
AFR-D	100	840	760	950	-1 090	-100
AFR-E	-230	880	220	1 050	-2 100	-410
AMR-B	50	1 570	90	1 680	-3 430	-400
AMR-D	-60	260	130	240	-1 220	-50
EMR-B	270	500	270	500	40	30
EMR-D	-30	750	30	800	-1 810	-270
EUR-B	-60	340	-30	350	-1 830	-40
EUR-C	-90	120	-100	140	-790	-10
SEAR-B	-70	1 520	190	1 460	-1 220	-270
SEAR-D	1 000	3 610	1 790	3 640	-4 750	-80
WPR-B	1 670	200	730	490	-13 630	-940
World (non-A)	**2 550**	**10 590**	**4 080**	**11 300**	**-31 830**	**-2 540**
World (non-A)	**13 140**		**15 380**		**-34 370**	

AFR, WHO African Region; AMR, WHO Region of the Americas; EMR, WHO Eastern Mediterranean Region; EUR, WHO European Region; SEAR, WHO South-East Asia Region; WPR, Western Pacific Region. Mortality strata: A, very low child, very low adult; B, low child, low adult; C, low child, high adult; D, high child, high adult; E, high child, very high adult.

are traditionally paid by governments or donor agencies. In scenario III, the majority of the intervention costs relate to stove purchase, but this investment by the household is more than compensated by fuel savings.

In terms of the global distribution of costs, over half of the urban costs in scenario I are accounted for by WPR-B, while a significant proportion of rural costs are accounted for by SEAR-B. Scenario I results in cost savings in urban areas for AFR-E, AMR-D, EMR-D, EUR and SEAR-B. Scenario III leads to net savings in all regions except EMR-B.

***Figure 1. Contribution to gross intervention costs for scenario I** (liquefied petroleum gas; top) and scenario III (improved stoves; bottom)*



AFR, WHO African Region; AMR, WHO Region of the Americas; EMR, WHO Eastern Mediterranean Region; EUR, WHO European Region; SEAR, WHO South-East Asia Region; WPR, Western Pacific Region. Mortality strata: A, very low child, very low adult; B, low child, low adult; C, low child, high adult; D, high child, high adult; E, high child, very high adult.

Figure 1 shows the contribution of different intervention components to the total gross cost (i.e. before subtracting fuel savings), which has implications for financing. Stove and fuel costs are mostly borne at the household level whereas programme costs occur at the level of the implementing agency (e.g. governmental, nongovernmental or industry). For fuel change interventions such as in scenario I, fuel purchase accounts for a large proportion of the costs and stove purchase for a lower proportion. Programme costs make a small (< 2% of costs) contribution to gross intervention costs in all subregions. In contrast, the contribution of programme costs varies widely for scenario III, from a negligible contribution in WPR-B to over 60% in AMR-B and EMR-B.

Economic benefits. Total economic benefits are presented in Table 4. In halving the population without access to LPG, the total economic benefits amount to roughly US$ 91 billion per year compared to net intervention costs of only US$ 13 billion. A pro-poor approach to halving the population without access to LPG generates US$ 102 billion in economic benefits at a cost of US$ 15 billion. The improved stove scenario generates US$ 105 billion in economic benefits, and at the same time has a *negative* net intervention cost of US$ 34 billion.

Figure 2 shows the contribution of different types of intervention benefits to the total economic benefits. For both scenarios I and III, savings in time required for

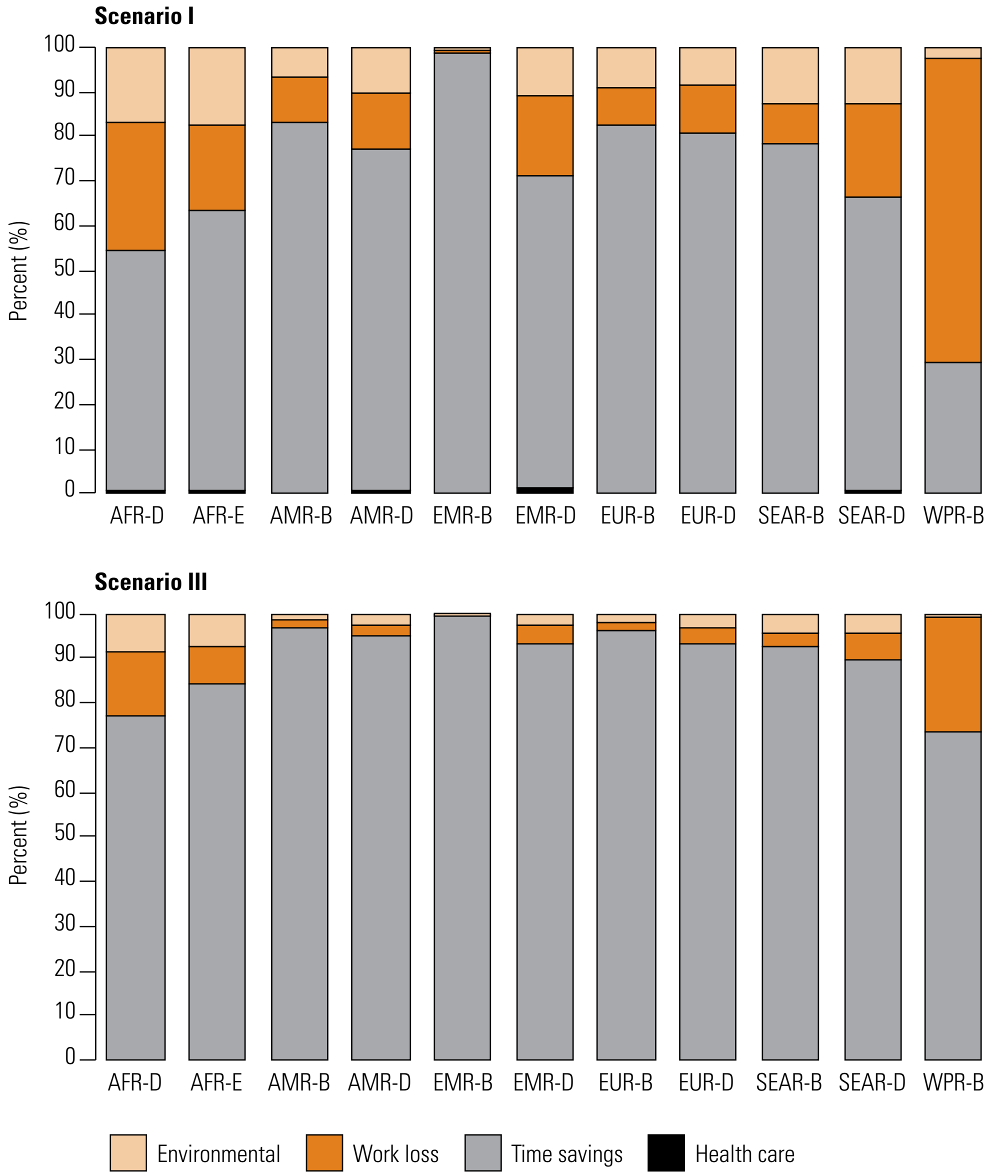
Table 4. Total annual economic benefits (million US$)

	By 2015, reduce by 50% population without access to a cleaner fuel or an improved stove					
	Scenario I (LPG)		Scenario II (LPG pro-poor)		Scenario III (improved stove)	
WHO subregion	**Urban**	**Rural**	**Urban**	**Rural**	**Urban**	**Rural**
AFR-D	2 540	3 080	2 500	3 080	1 910	2 070
AFR-E	2 420	5 450	2 690	7 210	2 480	3 850
AMR-B	610	5 980	620	6 250	9 600	7 510
AMR-D	220	440	120	830	790	480
EMR-B	1 330	2 080	1 350	2 130	4 980	2 910
EMR-D	470	1 620	460	1 670	1 300	1 890
EUR-B	410	1 030	420	1 030	2 130	410
EUR-C	500	410	530	430	910	70
SEAR-B	310	4 030	40	4 930	1 040	3 580
SEAR-D	2 610	5 440	2 440	6 690	5 600	4 130
WPR-B	45 180	4 240	50 200	7 010	42 970	3 910
World (non-A)	**56 600**	**33 800**	**61 370**	**41 260**	**73 710**	**30 810**
World (non-A)	**90 400**		**101 630**		**104 520**	

LPG, liquefied petroleum gas.

AFR, WHO African Region; AMR, WHO Region of the Americas; EMR, WHO Eastern Mediterranean Region; EUR, WHO European Region; SEAR, WHO South-East Asia Region; WPR, Western Pacific Region. Mortality strata: A, very low child, very low adult; B, low child, low adult; C, low child, high adult; D, high child, high adult; E, high child, very high adult.

***Figure 2. Contribution to economic benefits for scenario I** (liquefied petroleum gas; top) and scenario III (improved stoves; bottom)*



AFR, WHO African Region; AMR, WHO Region of the Americas; EMR, WHO Eastern Mediterranean Region; EUR, WHO European Region; SEAR, WHO South-East Asia Region; WPR, Western Pacific Region. Mortality strata: A, very low child, very low adult; B, low child, low adult; C, low child, high adult; D, high child, high adult; E, high child, very high adult.

fuel collection and cooking are the main benefits in most subregions. At the global level, for scenario I, savings in the cost of health care contribute US$ 0.2 billion (0.2%); savings in fuel collection time, US$ 21.1 billion (23.3%); savings on cooking time, US$ 22.9 billion (25.3%); illness avoided, US$ 1.5 billion (1.6%); deaths avoided, US$ 38.7 billion (42.9%); local environmental benefits, US$ 4.7 billion (4.8%); and global environmental benefits, US$ 1.3 billion (1.9%). For scenario III savings in time (85.0%) and health-related productivity (13.6%) represent the major economic benefits, followed by environmental benefits (1.3%) and health care savings (0.1%).

Table 5. Benefit–cost ratios for selected scenarios (US$ return per US$ 1 invested)

	By 2015, reduce by 50% population without access to a cleaner fuel or an improved stove					
	Scenario I (LPG)		Scenario II (LPG pro-poor)		Scenario III (improved stove)	
WHO subregion	**Urban**	**Rural**	**Urban**	**Rural**	**Urban**	**Rural**
AFR-D	26.5	3.7	3.3	3.2	Neg	Neg
AFR-E	Neg	6.2	12.7	6.9	Neg	Neg
AMR-B	14.3	3.8	6.9	3.7	Neg	Neg
AMR-D	Neg	1.8	0.9	3.6	Neg	Neg
EMR-B	4.9	4.2	4.9	4.3	136.1	89.9
EMR-D	Neg	2.2	16.1	2.1	Neg	Neg
EUR-B	Neg	3.0	Neg	2.9	Neg	Neg
EUR-C	Neg	3.4	Neg	3.1	Neg	Neg
SEAR-B	Neg	2.7	0.2	3.4	Neg	Neg
SEAR-D	2.6	1.5	1.4	1.8	Neg	Neg
WPR-B	27.0	21.2	68.5	14.6	Neg	Neg
World (non-A)	**22.3**	**3.2**	**15.1**	**3.7**	**Neg**	**Neg**
World (non-A)	**6.9**		**6.7**		**Neg**	

Neg: A negative benefit–cost ratio means that intervention cost savings exceed intervention costs.

AFR, WHO African Region; AMR, WHO Region of the Americas; EMR, WHO Eastern Mediterranean Region; EUR, WHO European Region; SEAR, WHO South-East Asia Region; WPR, Western Pacific Region. Mortality strata: A, very low child, very low adult; B, low child, low adult; C, low child, high adult; D, high child, high adult; E, high child, very high adult.

Benefit–cost ratios. In general, the results show favourable benefit–cost ratios. As shown in Table 5, ratios vary considerably according to WHO subregion and intervention type, and between rural and urban areas. For some scenarios and regions, negative net intervention costs resulted in a negative benefit–cost ratio. For LPG delivered to 50% of households, the benefit–cost ratio ranged from 1.5 in SEAR-D to 21.2 in WPR-B in rural areas, and from 2.6 to negative in urban areas. For improved stoves, the benefit–cost ratio is negative in all subregions, except EMR-B where the ratio is very high at over 100. Thus, overall, the base-case analysis of the three intervention scenarios shows very good value for money.

Net present value. The net present value, shown in Table 6, is the estimated annual economic surplus, and is calculated by subtracting net costs from economic benefits. The results show that the scenarios lead to net economic benefits of between US$ 77 billion and US$ 139 billion per year at global level. A significant proportion of these benefits is seen in WPR-B. Globally, the net present value tends to be higher in urban areas than in rural areas.

Understanding variations. As shown in Tables 3–6, intervention costs and benefits vary between rural and urban areas, and between subregions. The wide variation between WHO subregions is the result of differences in regional

Table 6. Net present value (average annual value; million US$)

	By 2015, reduce by 50% population without access to a cleaner fuel or an improved stove					
	Scenario I (LPG)		Scenario II (LPG pro-poor)		Scenario III (improved stove)	
WHO subregion	**Urban**	**Rural**	**Urban**	**Rural**	**Urban**	**Rural**
AFR-D	2 440	2 240	1 740	2 120	3 000	2 180
AFR-E	2 660	4 570	2 480	6 160	4 580	4 260
AMR-B	560	4 410	530	4 580	13 030	7 920
AMR-D	270	190	-10	600	2 010	520
EMR-B	1 060	1 590	1 070	1 630	4 940	2 880
EMR-D	500	870	430	870	3 110	2 150
EUR-B	470	690	450	680	3 960	450
EUR-C	580	290	630	290	1 690	80
SEAR-B	380	2 510	-140	3 460	2 260	3 850
SEAR-D	1 620	1 830	640	3 050	10 340	4 210
WPR-B	43 510	4 040	49 460	6 530	56 610	4 850
World (non-A)	**54 050**	**23 230**	**57 290**	**29 970**	**105 540**	**33 350**
World (non-A)	**77 490**		**97 430**		**138 920**	

AFR, WHO African Region; AMR, WHO Region of the Americas; EMR, WHO Eastern Mediterranean Region; EUR, WHO European Region; SEAR, WHO South-East Asia Region; WPR, Western Pacific Region. Mortality strata: A, very low child, very low adult; B, low child, low adult; C, low child, high adult; D, high child, high adult; E, high child, very high adult.

characteristics and the resulting data inputs and assumptions, such as type of solid fuel used, economic value of time and intervention costs.

For all scenarios modelled, the net intervention costs were found to be higher for rural populations, as the urban population purchases a larger proportion of its fuel, thus giving a higher cost saving following the switch to an alternative fuel. Similarly, savings in time spent on fuel collection were higher for rural areas because a larger proportion of this population collects rather than purchases fuel. In all three scenarios, the majority of the benefits in urban areas accrue to WPR-B, whereas benefits in rural areas are more evenly distributed among subregions (e.g. AMR-B and SEAR-D).

A higher benefit–cost ratio can be explained both by a smaller denominator (net cost) and a larger numerator (benefit), where the former has a relatively greater impact on the benefit–cost ratio than the latter. Consequently, the divergence in benefit–cost ratios between urban and rural areas can be largely attributed to the different way in which savings in fuel cost and time influence the calculations. Fuel savings are subtracted from the intervention cost in the denominator whereas time savings are added to the economic benefits in the numerator.

Sensitivity analysis

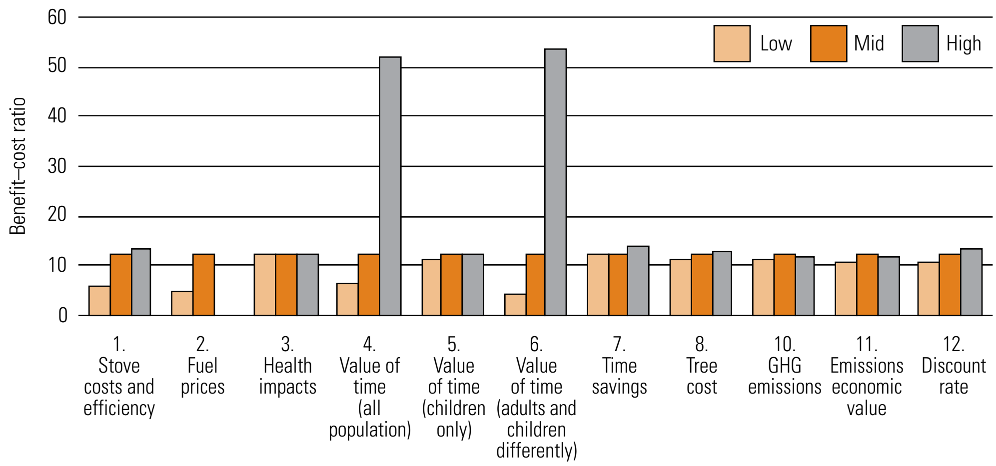
Twelve different sensitivity analyses were performed to evaluate the impact of changes in assumptions for selected variables on the results and conclusions.

For scenario I (LPG), benefit–cost ratios are affected considerably by changes in assumptions, especially in relation to stove costs and efficiency, fuel prices and the value of time assigned to time savings. Globally, an alternative time value of 30% of GNI per capita instead of the 100% GNI assumed in the base-case analysis reduces the benefit–cost ratio from 6.9 to 2.2. For the other variables tested in the one- and two-way sensitivity analyses, changes observed were not major, and even under pessimistic assumptions the benefit–cost ratio remained above 5.0. In fact, within the range of all optimistic and pessimistic alternatives tested in one- and two-way sensitivity analyses, the benefit–cost ratio always remained above 2.0. It should be noted, however, that simultaneously replacing all input variables with extreme values may lead to the benefit–cost ratio falling below 1.0. Figure 3 illustrates variations for AFR-E under low and high ranges for selected input variables compared with the base-case result (see Table 5).

For the LPG pro-poor option (Scenario II), the benefit–cost ratios were lower than for Scenario I for both the base-case analysis and under pessimistic assumptions in the sensitivity analysis. In some WHO subregions, the benefit–cost ratios for this scenario decrease to close to 1.0 for assumptions of high fuel prices and low time value. For improved stoves (Scenario III), the negative benefit–cost ratios remain negative for all 12 sensitivity analyses.

In conclusion, the findings of the sensitivity analysis highlight the potential impact of uncertain variables on the results of the cost–benefit analysis. They illustrate the need to improve data quality, based on further research and analysis.

Figure 3. Benefit–cost ratios for halving the population without access to liquefied petroleum gas (Scenario I) under different assumptions for WHO subregion AFR-E



AFR, WHO African Region; E (mortality stratum), high child, very high adult; GHG, greenhouse gas.

Conclusions

This cost–benefit analysis, conducted at the global and regional levels, shows that investments in household energy and health interventions are potentially cost-beneficial and in some cases cost-saving. Under the assumptions of the model, improved stoves led to the greatest overall benefit to society as reflected in the net present value (Table 6). This holds particularly true in urban settings where the majority of the population already pays for fuel. Making improved stoves available, by 2015, to half of those still burning biomass fuels and coal on traditional stoves in 2005 would result in a negative intervention cost of US$ 34 billion a year and generate an economic return of US$ 105 billion per year. Interventions to provide LPG and biofuel also generate large economic benefits in relation to the net intervention costs. Investing US$ 13 billion per year to provide, by 2015, half of those using solid fuels in 2005 with access to LPG would lead to a payback of US$ 91 billion per year. Making this change by providing people with access to ethanol leads to the same overall economic benefit, but at the higher cost of US$ 43 billion per year. Based on current prices, ethanol emerges as the more costly solution as this biofuel is currently less widely produced and available. Further applications of the model, using more reliable and detailed data at the national or local level, could give a better indication of the cost–benefit implications of investing in modern fuels or improved stoves in a specific country or setting.

These results should help promote household energy and health interventions nationally and internationally. Demonstrating the economic benefits of investments in improving access to cleaner and more efficient household energy should contribute to sound decision-making for development and to overcoming the constraints in the implementation of household energy interventions. The interventions demonstrate financial feasibility, given that the principal costs – stoves and fuel – are traditionally paid for by households, which will also benefit from cost savings related to less eventual fuel use and economic benefits related to improved health. Only a small proportion of the costs would need to be borne by "external" agencies such as the government, nongovernmental organizations or other implementers. These costs essentially consist of programme costs for distribution of the interventions, funds to stimulate research and development of interventions and measures to generate demand among users and to ensure the correct use of new technologies.

Using the programme costs per household produced in a WHO study on cost–effectiveness analysis (Mehta & Shahpar, 2004), halving the population without access to cleaner fuels would have an annual cost of US$ 3 million globally. Providing improved stoves to half the population currently cooking with solid fuels would result in an annual programme cost of US$ 20 million globally. Depending on the setting, programme costs may include subsidising or providing loans for the purchase of stoves or fuels. To make the most effective and equitable use of such subsidies, they should be targeted to low-income groups especially in rural areas.

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