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Environment & Water Resources

OCCASIONAL PAPER SERIES

76894

Environmental Health in Nicaragua

Addressing Key Environmental Challenges

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The Environment and Water Resources Occasional Paper Series was developed under the direction of Karin Kemper, Sector Manager for Environment and Water Resources in the Latin America and Caribbean Region (LCSEN) of the World Bank. The publications in this Series were designed and produced by GRC Direct under the supervision of Emilia Battaglini and Rachel Pasternack (LCSEN).

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Environment and Water Resources
LCSEN Occasional Paper Series

Foreword

The Latin America and Caribbean (LAC) region has a unique mix of qualities and challenges when it comes to the environment. It is exceptionally endowed with natural assets, with globally significant biodiversity and valuable crops, and also harbors the world's greatest carbon sink in the Amazon. At the same time, however, the region registers the highest rates of urbanization in the developing world with pollution, overuse of its water and natural resources and detrimental impacts on the health of people, especially the poor, and the environment.

Over the past twenty years, the LAC region has made impressive gains in tackling these issues. It leads the developing world in biodiversity conservation and natural resource management and is at the forefront in reducing urban pollution. The World Bank has often been the partner of choice for those countries in the region that have had the initiative to pioneer innovative policies for environmental protection and natural resource management, strengthen institutions responsible for environmental management, enhance environmental sustainability, and introduce new approaches to water resources management. Such initiatives include fuel and air quality standards in Peru, carbon emission reduction in Mexico, payment for ecosystem services in Costa Rica, participatory and integrated water resources management in Brazil, and new approaches to irrigation management in Mexico.

In this context, it is our pleasure to introduce the Environment & Water Resources Occasional Paper Series, a publication of the Environment and Water Resources Unit (LCSEN) of the Sustainable Development Department in the World Bank's Latin America and the Caribbean Region. The purpose of the series is to contribute to the global knowledge exchange on innovation in environmental and water resources management and the pursuit of greener and more inclusive growth. The papers seek to bring to a broader public – decision makers, development practitioners, academics and other partners - lessons learned from World Bank-financed projects, technical assistance and other knowledge activities jointly undertaken with our partners. The series addresses issues relevant to the region's environmental sustainability agenda from water resources management to environmental health, natural resource management, biodiversity conservation, environmental policy, pollution management, environmental institutions and governance, ecosystem services, environmental financing, irrigation and climate change and their linkages to development and growth.

In this particular paper, we present you the findings of a study looking at three fundamental environmental health risks in Nicaragua, notably inadequate water and sanitation, indoor and outdoor air pollution. The results are striking in that these three risks alone amount to an estimated 2.4 percent of the country's GDP, affecting primarily the poorer segments of the population. The study proceeds to look at priority investments and solutions, including by ranking potential interventions in terms of their costs and the expected benefits they will generate. It is clear that solutions exist and that the returns to environmental improvements can be very high in terms of health improvements and better quality of life, particularly for children.

We hope that this paper, just as the entire series, will make a contribution to knowledge sharing within the LAC Region and globally.

Karin Kemper
Sector Manager, Environment & Water Resources
Sustainable Development Department
Latin America and the Caribbean Region

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Acronyms and Abbreviations

ARI: Acute respiratory infections

CEA: Country Environmental Analysis

COI: Cost of Illness

COPD: Chronic obstructive pulmonary disease

DALYs: Disability adjusted life years

EHS: Environmental Health Safeguards

ENACAL: Empresa Nicaragüense de Acueductos y Alcantarillados Sanitarios (Nicaraguan National Water Utility Company)

ENDESA: Encuesta Nacional de Demografía y Salud (National Survey on Demographics and Health)

GDP: Gross domestic product

GoN: Government of Nicaragua

HCA: Human Capital Approach

IAP: Indoor air pollution

LPG: Liquefied petroleum gas

MARENA: Ministerio de Ambiente y Recursos Naturales (Ministry of Environment and Natural Resources)

MINSA: Ministerio de Salud (Ministry of Health)

MDGs: Millennium Development Goals

NGO: Non-governmental organization

NIO: Nicaraguan Córdoba

NO2: Nitrogen dioxide

PM10: Particulate matter less than 10 microns in size

PM2.5: Particulate matter less than 2.5 microns in size

TSP: Total suspended particles

UNDP: United Nations Development Programme

VSL: Value of Statistical Life

WHO: World Health Organization

WSH: Water Sanitation and Hygiene

WSSH: Water Supply Sanitation and Hygiene

WSP: Water Sanitation

Environmental Health in Nicaragua

Addressing Key Environmental Challenges

Irina Klytchnikova, Senior Economist, World Bank
Juan Carlos Belausteguigoitia, Lead Environmental Economist, World Bank
Elena Strukova, Consultant, World Bank
Anjali Acharya, Senior Environmental Specialist, World Bank
Francisco Carranza, Water Sanitation Specialist, World Bank
Nelson Antonio Medina Rocha, Coordinator for Nicaragua, Water Sanitation Specialist, World Bank
Gerardo Sánchez, Environmental Specialist, World Bank

Acknowledgements

The authors would like to thank Yewande Awe (Sr. Environmental Engineer, ENV) and Ernesto Sánchez-Triana (Lead Environmental Specialist, SASDI) for their comments on this study. Assistance by Santiago Sandoval, Linda Castillo and editing by Janice Molina are gratefully acknowledged. The study was carried out under the overall guidance of Laura Frigenti (Country Director), Karin Kemper (Sector Manager since December 2009), Laura Tlaiye (Sector Manager until November 2009), Gregor Wolf (Sector Leader), Joseph Owen (Country Manager), and the guidance of the Steering Committee for the study, composed of high-level decision makers in Nicaragua. Financial support by the Government of the Netherlands through the Bank Netherlands Partnership Program (BNPP) is gratefully acknowledged.

In order to provide country-specific estimates, workshops were held with the Technical Working Group which was set up to provide inputs to, and comment on, this environmental health analysis. In addition, workshops and other meetings were held with key officials from MARENA and MINSA, as well as other key stakeholders; their assistance with data and information has been critical for this report. The authors would like to thank MARENA Vice Minister Roberto Araquistain, MINSA Vice Minister Nora Orozco, Messrs. Jesús Marín Ruíz and Boanerges Castro (MINSA), members of the Steering Committee for the Study, composed of high-level decision makers, and the inter-institutional Technical Working Group, composed of technical experts, for their overall support for, and guidance of, this analysis.

The study was completed and disseminated in Nicaragua in June 2010, and published in electronic form. The report was welcomed by MARENA, which also provided additional comments that future studies would need to address. This is the paper version of the electronic publication dated June 2010.

Abstract

In Nicaragua, poor access to water and sanitation, high use of fuelwood for cooking in rural areas, and growing vehicular use in urban areas are resulting in environmental health risks, especially in children under five years of age. The Government of Nicaragua requested the World Bank to undertake this study to answer two fundamental sets of questions on environment-related health problems in Nicaragua. The first set helps to demonstrate the significance of environment-related health problems: (a) How much disease and how many deaths are attributable to environmental risks? (b) Which subgroups bear the highest burden of disease? (c) What are the economic costs of the health impact of these environmental risks? The second set refers to the appropriate choice of interventions that the GoN can undertake to reduce these environmental risks to human health: (a) Which interventions are the most cost-effective?

This study estimates that environmental health costs represent a significant burden on Nicaragua's economy. While progress is being made on interventions to address environmental risks, much more attention and resources need to be invested in water supply coverage, improved sanitation coverage, and proper waste disposal. Indoor air quality, especially in rural areas where biomass is used for cooking, and outdoor air quality, especially in urban areas such as Managua, are growing and important concerns. These environmental health risks are especially important for the most vulnerable subgroups of Nicaragua's population, including children under age five, women, the elderly and the poor.

Several key messages have emerged from the process of putting together this study: (i) environmental health risks impose a significant burden on Nicaragua's economy, amounting to 2.6 billion NIO or 2.4 percent of the country's GDP, and result in premature deaths and infections, especially in children under five; (ii) cost-effective interventions to address these environmental health risks exist and should be prioritized in Nicaragua; (iii) country-specific health and environmental data are somewhat limited, especially in the case of air quality, and data collection and monitoring need to be further strengthened; and (iii) the capacity of MARENA and MINSA staff to conduct environmental health costing analysis needs to be strengthened through training.

Executive Summary

Globally, an estimated 24 percent of the disease burden (healthy life years lost) and an estimated 23 percent of all deaths (premature mortality) are attributable to environmental risks (WHO 2006). The burden of disease is unequally shared, with the children and the poor being particularly affected. Among children between the ages 0 and 14, the proportion of deaths attributable to environmental risks—such as poor water and sanitation, indoor air pollution and vector-borne diseases—is estimated to be as high as 36 percent (WHO 2006).

In its 2009–2011 Updated National Human Development Plan (NHDP), the Government of Nicaragua (GoN) has placed strong emphasis on preventive health measures and on addressing the root causes of ill health. The Plan has identified a series of measures to help Nicaragua achieve the MDG targets on child mortality and the environment. Recognizing the crucial role of improving the urban and rural populations' access to improved water and sanitation services, the GoN has also set ambitious targets to expand the provision of those services. This strategy has been reflected in the investment plans for the water supply and sanitation sector. The NHDP states the targets to expand access to public water supply in rural areas from 56 percent in 2007 to 64 percent by 2011, and to expand rural sanitation from 73 percent to 81 percent (including all types of sanitation and including unimproved latrines). In urban areas, the targets are to increase access to public water supply from 72 to 86 percent, and to sanitation from 36 to 48 percent over the same period. In the area of air quality management, the GoN is preparing guidelines for an air quality policy, to be adopted in the future. The findings and recommendations of this study are directly relevant to the GoN's efforts to address the environmental causes of diseases.

In Nicaragua, poor access to water and sanitation, high use of fuelwood for cooking in rural areas, and growing vehicular use in urban areas are resulting in environmental health risks, especially in children under five years of age. The Government of Nicaragua requested the World Bank to undertake a study to answer two fundamental sets of questions on environment-related health problems in Nicaragua. The *first set* helps to demonstrate the significance of environment-related health problems: (a) How much disease and how many deaths are attributable to environmental risks? (b) Which subgroups bear the highest burden of disease? (c) What are the economic costs of the health impact of these environmental risks? The *second set* refers to the appropriate choice of interventions that the GoN can undertake to reduce these environmental risks to human health: (a) Which interventions are the most cost-effective?

Using established methodology recommended by the World Health Organization and others, this study attempts to provide information and raise awareness about the importance of environmental health interventions in addressing health, specifically child health, issues in developing countries such as Nicaragua. This study concentrates on three main environmental health risk factors: inadequate water supply and sanitation, indoor air pollution and urban air pollution. Recognizing the importance of using country-specific data, this analysis has explicitly included data and figures provided by the Ministry of Environment and Natural Resources (MARENA) and by the Ministry of Health (MINSA).

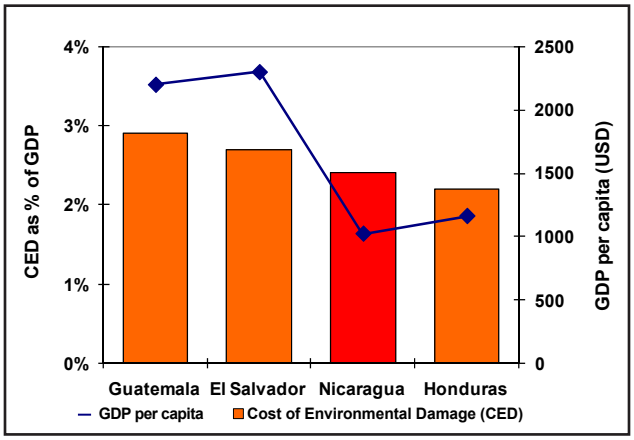
The preparation of this analysis was launched by a consultation workshop, which was attended by representatives of MARENA, MINSA, academia, nongovernmental organizations and donor agencies. Drafts of the analysis were shared with the Technical Working Group that was created to review the findings, and comments were elicited. In June 2009, the Bank team organized a targeted one-day training course for selected staff in the Ministry of Health, aimed at building local capacity to carry out this analysis. The draft report with results of the study were shared with MINSA, MARENA and high-level decision makers from other agencies in March 2010, and the feedback received during these consultations has been incorporated in this version.

Several key messages have emerged from the process of putting together this study: (i) environmental health risks impose a significant burden on Nicaragua's economy, amounting to 2.6 billion NIO or 2.4 percent of the country's GDP, and result in premature deaths and infections, especially in children under five; (ii) cost-effective interventions to address these environmental health risks exist and should be prioritized in Nicaragua; (iii) country-specific health and environmental data are somewhat limited, especially in the case of air quality, and data collection and monitoring need to be further strengthened; and (iii) the capacity of MARENA and MINSA staff to conduct environmental health costing analysis needs to be strengthened through proper training.

Assessing the Economic Burden of Environmental Health Risks

Environmental health costs represent a significant burden on Nicaragua's economy. While progress is being made on interventions to address environmental risks, much more attention and resources need to be invested in water supply coverage, improved sanitation coverage, and proper waste disposal. Indoor air quality, especially in rural areas where biomass is used for cooking, and outdoor air quality, especially in urban areas such as Managua, are growing and important concerns. These environmental health risks are especially important for the most vulnerable subgroups of Nicaragua's population, including children under age five, women, the elderly and the poor. This study follows a methodology validated around the world for conducting analyses of the health burden of environmental degradation (Box ES 1).

Figure ES 1: Costs of Environmental Degradation



Source: CEA studies, World Bank 2005–2009.

Box ES 1. Estimation of Environmental Health Costs

The analyses to assess the health impacts and subsequent costs attributed to risks from urban air pollution, poor water and sanitation, and indoor air pollution are based on World Health Organization (WHO) standard methodologies and on international research.

Water, sanitation and hygiene: Data on Nicaragua's population and on diarrheal mortality and prevalence in children under five are used to estimate the mortality and illness attributed to poor water and sanitation (WHO estimates that about 90 percent of diarrheal illness is attributable to inadequate water sanitation and hygiene). Estimates are made also for adult morbidity. Costs associated with this risk factor include expenses to treat diarrheal illness, such as doctor fees, laboratory tests, drugs and bed charges when hospitalization is needed. Other costs include lost productivity when adults fall sick and stay home from work, or when primary caregivers have to take care of sick children (and potentially lose wages).

Indoor air pollution: Data on population using fuelwood for cooking in Nicaragua and on child mortality and prevalence of acute respiratory illnesses (ARIs) is used with odds ratios from international research evidence to estimate the premature deaths and cases of illness from ARIs in children and adults and chronic obstructive pulmonary disease (COPD) in adult women. For COPD mortality and morbidity incidence, WHO regional estimates are used in the absence of Nicaraguan data.

Urban air pollution: With Nicaraguan data on particulate matter and urban population figures, this analysis uses dose-response coefficients from international research evidence on long-term air pollution impacts on health to estimate the number of premature deaths and sickness attributed to urban air pollution. Using WHO methodologies, these health outcomes are then translated into disability adjusted life years (DALYs), and are also valued to arrive at cost estimates.

The cost of mortality for adults is based on the value of statistical life (VSL) as a high bound and the Human Capital Approach (HCA) as a low bound, while that for children is based on the HCA. In addition, treatment cost represents private sector (unsubsidized) health care services, while the value of time for adults (for lost work days due to sickness or caregiving) in Nicaragua is estimated at 75 percent of average hourly wages.

Source: Background report for this study (Strukova 2009).

Similar to other countries in Central America, the environmental health implications of poor water supply and sanitation and of indoor and urban air pollution dramatically impact Nicaragua's ability to achieve targets for reducing child mortality, improving maternal health, combating diseases, and other Millennium Development Goals (MDGs). Overall, the analysis carried out in this study shows that Nicaragua's economic costs associated with lack of water and sanitation and with indoor and urban air pollution amount to nearly 2.6 billion NIO, or 2.4 percent of the country's gross domestic product (GDP) (see Table ES 1). Among the three categories of environmental health risks, damages due to (i) inadequate water supply, sanitation and hygiene amounted to 0.92 billion NIO, or 0.9 percent of the country's GDP; (ii) indoor air pollution amounted to 870 million NIO, or 0.85 percent of GDP; and (iii) urban air pollution amounted to 780 million NIO, or 0.75 percent of the country's GDP.

Table ES 1: Aggregate Environmental Health Costs for Nicaragua

	NIO (billions)	Percent of GDP
Lack of water and sanitation	0.8–1.0	0.8–0.9
Indoor air pollution	0.8–0.9	0.7–0.9
Urban air pollution	0.3–1.2	0.3–1.2
Total	**1.9–3.1**	**1.8–3.0**

The costs of these environmental problems have been estimated in this report to help policy makers in Nicaragua appreciate the magnitude of these issues and better integrate environmental health considerations into economic development decision making. These costs include not only the medical costs of treatment and lost productivity due to sickness and caregiving, but also provide an estimate of the value of pain and suffering from premature death and disease. This analysis covers only a limited number of diseases attributed to the three environmental risk factors in question—inadequate water and sanitation, indoor air pollution, and urban air pollution—and therefore underestimates the economic burden these environmental risk factors place on Nicaragua. Furthermore, the study does not include the indirect impacts of poor water, sanitation and hygiene which are mediated through malnutrition.

Poor water quality, sanitation and hygiene: According to the latest WHO/UNICEF Joint Monitoring Program (JMP/2006), 90 percent of the urban population and 56 percent of the rural population in Nicaragua have access to improved sources of drinking water (piped water, public tap, borehole/tubewell, protected well, protected spring or rainwater). However, even in connected households, the quality of service is low (WSP 2008). In terms of sanitation, 56 percent of the urban population and 34 percent of the rural population have access to improved sanitation (are connected to public service or have a septic tank).[1] About 20 percent of urban and 30 percent of rural households disinfect drinking water (WSP 2008) in Nicaragua.

Applying an established methodology used by WHO and other international agencies and also used in this study, it is estimated that 240 children under age five in urban areas and 320 in rural areas die from diarrheal diseases attributed to poor water, sanitation and hygiene. Furthermore, among children under age five, more than a million annual cases of diarrhea in rural and urban areas, respectively, result from poor water, sanitation and hygiene. The estimated number of cases of diarrheal illness in children under age five is about 1.3 times higher in rural areas.[2]

The annual cost of diarrheal mortality and morbidity from inadequate water, sanitation and hygiene is estimated at 345 million NIO in urban areas and 455 million NIO in rural areas. The cost of morbidity includes the cost of illness (medical treatment, medicines and value of lost time). In addition, the cost of averting expenditures in Nicaragua—associated with the purchase of bottled water and disinfecting water through boiling or chlorination to avoid health risks—is estimated to range from 80 to 150 million NIO per year. The total estimated cost associated with inadequate water supply, sanitation and hygiene ranges from 830 million to 1 billion NIO per year, with a mean of 915 million NIO, amounting to 0.9 percent of the country's GDP.

Indoor air pollution: Acute respiratory infections (ARI) mainly affect women and children in rural areas in Nicaragua, where nine out of ten households (92 percent) burn fuelwood in inefficient stoves in poorly ventilated areas.[3] The vulnerable subgroups in the population include children under

1 These figures are comparable to the estimated shares of population in rural and urban areas with access to piped water and sanitation in all cases except for sanitation in rural areas (data from official Nicaraguan sources [ENACAL, FISE] and the 2009–2011 Updated National Human Development Plan). The figures for sanitation in rural areas are higher in the official statistics because all types of sanitation are included in these estimates, while this study excludes unimproved latrines.

2 These estimates are made by assuming the under-age-five child mortality rate of 31 and 40 per 1,000 live births in urban and rural areas, respectively, based on 2006 data provided by the 2006–2007 ENDESA survey, which inquired about deaths of children under age five during the five-year period prior to the survey. The same source reports that for the ten-year period prior to the survey, the mortality rate for children under age five 35 and 47 per 1,000 live births in urban and rural areas.

3 According to the 2006–2007 ENDESA survey, about 38 percent of households in urban and 92 percent in rural areas used fuelwood for cooking.

age five (ARI mortality and morbidity among children) and women over age 30 (COPD mortality and morbidity; ARI morbidity), because these subgroups are exposed to smoky kitchens.

Each year, an estimated 140 to 200 children under age five die from ARIs in rural areas, and an additional 40 to 70 children die in urban areas in Nicaragua. Among children under age five, more than half a million annual cases of acute respiratory infections in rural areas, and more than 200,000 cases in urban areas, can be linked to indoor air pollution. Among females over age 30, each year there are nearly 285,000 cases of indoor-air-pollution-related ARI morbidity in rural areas and nearly 162,000 cases in urban areas. Indoor air pollution also causes chronic obstructive pulmonary disease (COPD) in females over age 30: nearly 120 women die annually from COPD in urban and rural areas, and about 3,000 new cases of COPD can be attributed to indoor air pollution each year.

The total estimated annual cost of indoor air pollution ranges from 540 million 1.2 billion NIO with a mean cost of 870 million NIO. These costs accounted for about 0.8 percent of GDP in 2007. ARI in children represents the largest share (40 percent) of the costs. The rural poor are especially vulnerable and account for 56 percent of the total costs of indoor air pollution.

Urban air pollution: The total urban population exposed to air pollution was estimated to be about 1.95 million, or 62 percent of the total Nicaraguan population in 2007. Data relating to urban air quality concentrations are extremely limited and very dated. Furthermore, there is no emissions inventory, and very little city-specific data exist. Using the latest available data for 2001, adjusted using World Bank estimates, the annual average PM_{10} concentration for Managua was estimated at 67 $\mu g/m^3$, and in other Nicaraguan cities with populations over 100,000 at 43 $\mu g/m^3$. Urban air particulate pollution is estimated to cause around 420 premature deaths annually, although there is significant uncertainty about this estimate because of the limited data on emission levels and additional uncertainty in the estimation of mortality rates from illnesses related to urban air pollution in Nicaragua.[4] The number of new cases of chronic bronchitis is estimated at about 520 per year. Annual hospitalizations due to pollution are estimated at close to 630, and emergency room visits/outpatient hospitalizations at 26,500 per year.

In estimating the costs of health impacts from particulate matter in Nicaragua, health conditions such as premature mortality, hospital admissions, restricted activity days, and emergency visits have been considered. In the absence of proper data on treatment costs, informed estimates have been provided by medical experts in Managua. The mean estimated annual cost of urban air pollution due to PM ranges from 305 million to 1.25 billion NIO, with a mean of about 780 million NIO. The low and high estimates are obtained by applying the HCA and the VSL approaches to the valuation of the costs of mortality, respectively. This represents about 0.7 percent of the country's GDP. Around 70 percent of the costs are due to mortality, and the remaining 30 percent are associated with morbidity.

Prioritizing Interventions Through Cost-Benefit Analyses

Recognizing the importance of setting priorities, subsequent follow-up work included cost-benefit

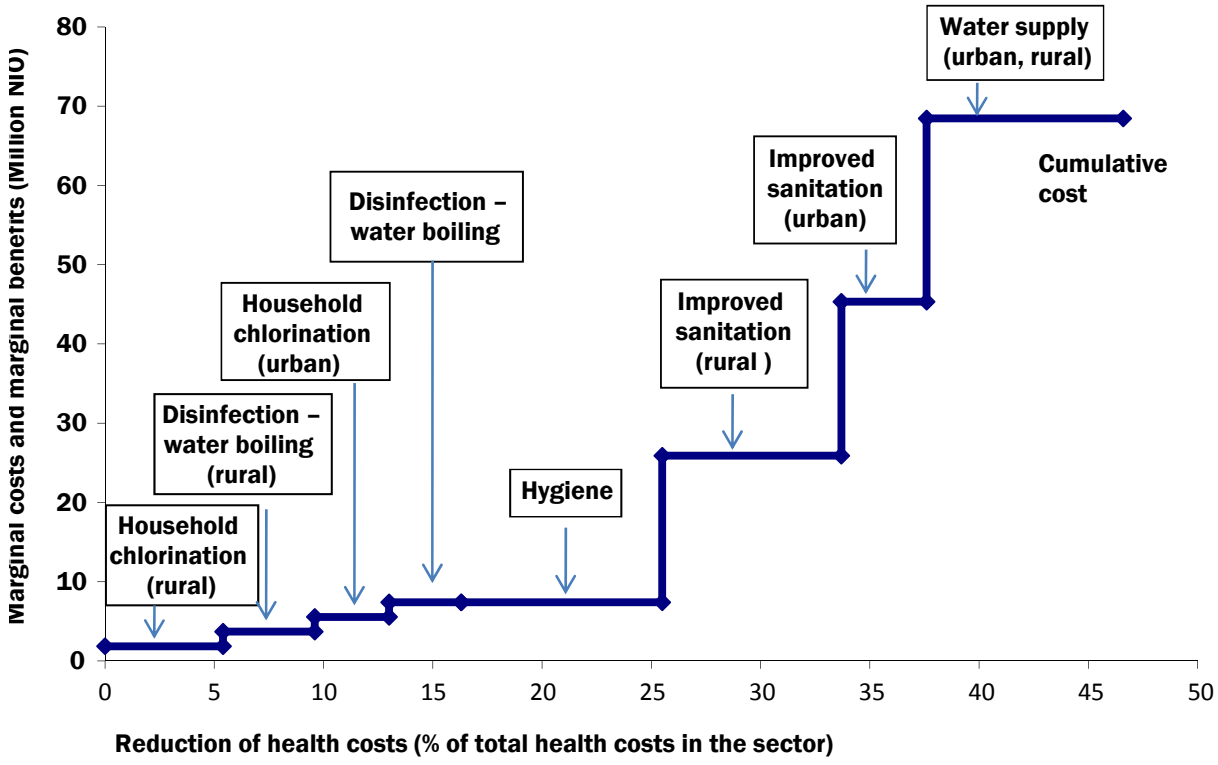
4 An estimate of the annual incidence of chronic bronchitis (CB) is required in order to apply the dose response coefficients, which translate air pollution measures into the incidence of illness. In the absence of data on CB incidence for Nicaragua, this study has used the CB rate from WHO (2001) and Shibuya et al. (2001) for the AMRO D region of WHO, which includes Nicaragua. For details, see Annex A.

analyses of various environmental health interventions to address inadequate water sanitation and hygiene, and indoor air pollution. These analyses would help the government determine the most cost-effective interventions to implement in terms of addressing key environmental health risks in Nicaragua.

Water, sanitation, hygiene: Interventions related to improving the quality and quantity of water supply, improving access to improved sanitation, and programs encouraging better hygiene practices (including hand washing) have potential health benefits. For Nicaragua, this study estimated the cost-benefit ratios for improvements in water supply and sanitation, hand-washing programs, and drinking water disinfection programs (both boiling and chlorination). The height of each segment of the cumulative cost curve equals the unit cost of an intervention per one percentage point reduction of health damages; the total area below each segment is equal to the total cost of this intervention (see Figure ES 2). Although several of these interventions have significant time-savings benefits, only health benefits were considered in this study. Several assumptions were also made relating to the sustainability of these programs from a behavioral perspective.

Findings from this analysis revealed that in terms of water, sanitation and hygiene interventions, highest priority should be given to drinking water disinfection and hand-washing programs (in rural and urban areas) because they had the lowest cost-benefit ratios.

Figure ES 2: Ranking of Interventions to Reduce Water Supply, Sanitation and Hygiene Cost in Nicaragua

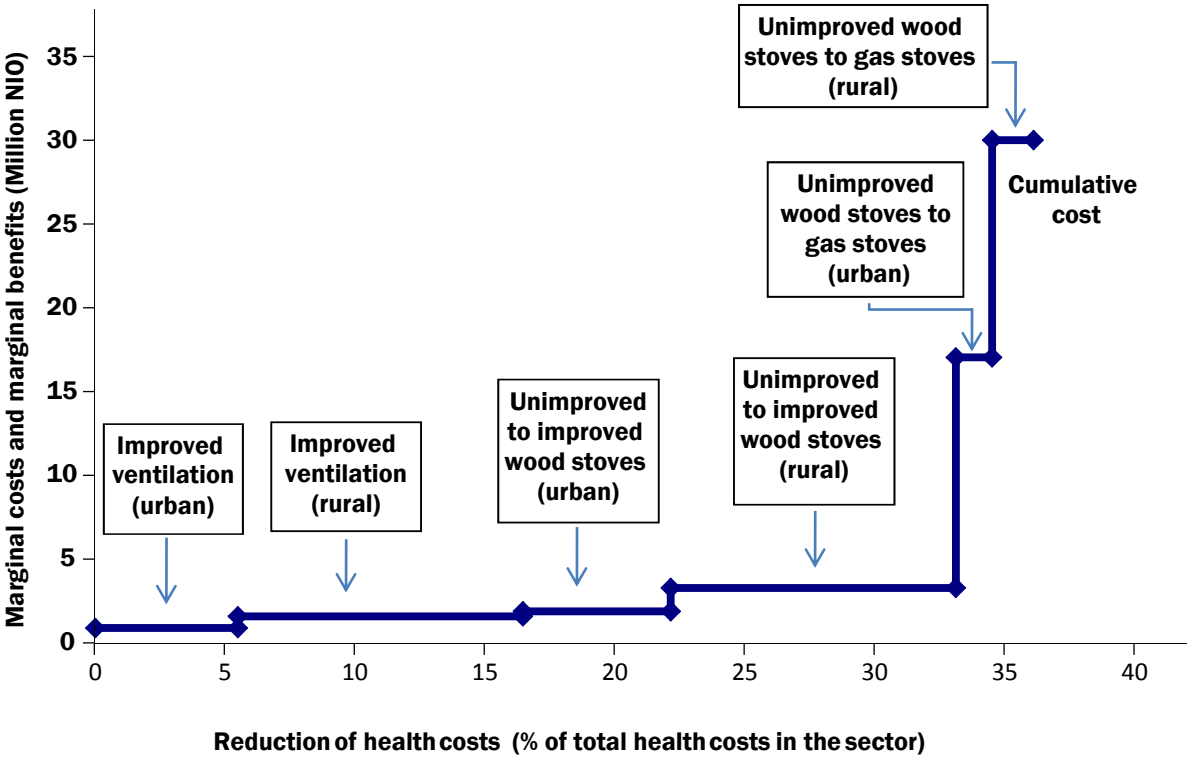


Indoor air pollution: Interventions are available to reduce indoor air pollution and associated health effects. These interventions typically include addressing (a) source of pollution, including moving from traditional stoves to improved stoves, and switching to cleaner fuels such as LPG; (b) the living environment, such as chimneys and smoke hoods (with flues); and (c) user behavior, such as keeping young children away from smoke. For Nicaragua, cost-benefit ratios were only estimated for interventions related to moving from unimproved to improved stoves, better ventilation, and switching to cleaner fuels (see Figure ES 3).

The analysis for Nicaragua recommends shifting households with unimproved stoves to improved ones, and improving ventilation. The relative attractiveness of other interventions (such as from unimproved stoves to LPG or from improved stoves to LPG) is much more uncertain and depends substantively on the costs and benefits used.

Urban air pollution: For urban air pollution, a similar cost-benefit analysis was not carried out because the paucity of air quality data is a significant constraint to prioritizing interventions to reduce urban air pollution in Nicaragua. The study recommends the development of an emissions inventory to identify the main sources of air pollution in Managua and León. Furthermore, the study recommends as a priority the development of an air quality monitoring system for Managua and León so as to monitor emissions in the main urban areas. Work recently initiated by the World Bank to develop an emissions inventory for Managua and León will contribute to the identification of relevant interventions to reduce urban air pollution in Nicaragua.

Figure ES 3: Ranking of Interventions for IAP Cost Reduction in Nicaragua



I. Overview

Environmental pollution and inadequate environmental services, such as improved water supply and sanitation, impose significant costs to Nicaragua's economy in the form of ill health, lost income, and increased poverty and vulnerability. While progress is being made on interventions to address environmental risks, much more attention and resources need to be invested in water supply coverage and in improved sanitation coverage. Indoor air quality, especially in rural areas where biomass is used for cooking, and outdoor air quality, especially in urban areas such as Managua, are growing concerns. These environmental health risks are especially important for the most vulnerable subgroups of Nicaraguan population, including children under age five, women, the elderly and the poor. This section provides overall estimates of the health costs of environmental pollution in Nicaragua.

In its 2009–2011 Updated National Human Development Plan (NHDP), the Government of Nicaragua (GoN) has placed strong emphasis on preventive health measures and on addressing the root causes of ill health. The Plan has identified a series of measures to help Nicaragua achieve the MDG targets on child mortality and the environment. Recognizing the crucial role of improving the urban and rural populations' access to improved water and sanitation services, the GoN has also set ambitious targets to expand the provision of these services. This strategy has been reflected in the investment plans for the water supply and sanitation sector. The NHDP states the targets to expand access to public water supply in rural areas from 56 percent in 2007 to 64 percent by 2011, and to expand rural sanitation from 73 to 81 percent (including all types of sanitation and unimproved latrines). In urban areas, the targets are to increase access to public water supply from 72 to 86 percent, and to sanitation from 36 to 48 percent over the same period. In the area of air quality management, the GoN is preparing guidelines for an air quality policy, to be adopted in the future. The findings and recommendations of this study are directly relevant to the GoN's efforts to address the environmental causes of diseases.

As the evidence shows, the environmental health implications of poor water supply and sanitation and of indoor and urban air pollution dramatically impact Nicaragua's ability to achieve targets for reducing child mortality, improving maternal health, combating diseases, and other Millennium Development Goals (MDGs). Overall, the analysis shows that Nicaragua's economic costs associated with lack of water and sanitation and with indoor and

urban air pollution amount to nearly 2.6 billion NIO, or 2.4 percent of the country's gross domestic product (GDP) (see Table I.1). Among the three categories of environmental health risks, (i) damages due to inadequate water supply, sanitation and hygiene amounted to 0.92 billion NIO, or 0.9 percent of the country's GDP; (ii) indoor air pollution amounted to 870 million NIO, or 0.85 percent of GDP; and (iii) urban outdoor air pollution amounted to 780 million NIO, or 0.75 percent of the country's GDP.

Table I.1: Aggregate Environmental Health Costs for Nicaragua

	NIO (billion)	Percent of GDP
Lack of water and sanitation	0.8–1.0	0.8–0.9
Indoor air pollution	0.8–0.9	0.7–0.9
Urban air pollution	0.3–1.2	0.3–1.2
Total	**1.9–3.1**	**1.8–3.1**

In addition to the mean estimates, "low" and "high" estimates of annual costs are presented in Table I.2. The range for water supply, sanitation and hygiene is in large part associated with uncertainties regarding estimates of diarrheal child mortality and morbidity. In the case of urban air pollution, two different valuation techniques for estimating the social cost of mortality have been applied; these yielded the "low" and "high" estimates. The range for indoor air pollution is mainly from the uncertainty about the level of exposure to indoor smoke from the use of fuelwood, and thus a range has been applied for the level of health risk.

Table I.2: Annual Cost of Environmental Damage – Low and High Estimates (million NIO per year)

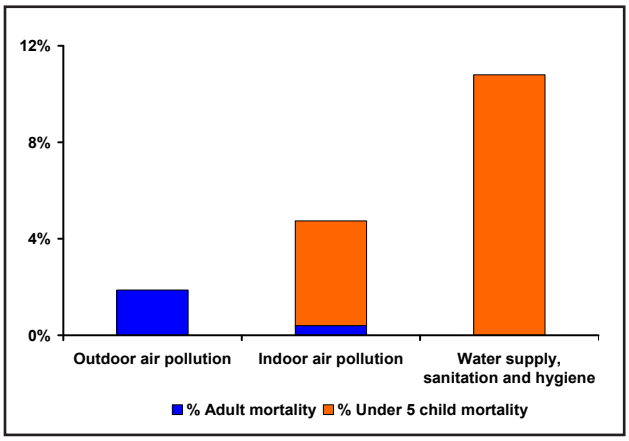
Environmental Categories	"Low"	Mean Estimate	"High"
Water supply, sanitation and hygiene	832	917	1,001
Indoor air pollution	772	872	972
Outdoor air pollution	309	779	1,249
Total costs	1,913	2,568	3,222
Costs as percent of GDP in 2007	1.8%	2.4%	3.1%

Distributional impacts: The costs of damages associated with environmental health are distributed unevenly across the population. Losses due to outdoor air pollution were estimated for the inhabitants of the cities with populations over 100,000; costs of inadequate water supply, sanitation and hygiene were estimated for the entire population of Nicaragua; indoor air pollution costs were estimated for households that use solid fuel for cooking (about 60 percent of households). Outdoor urban air pollution has the highest cost on a per-person basis, followed by damages due to indoor air pollution. Among the estimated cost items, inadequate water supply and sanitation has the lowest cost per capita.

Vulnerable subgroups: About 2 percent of adult mortality is attributed to outdoor and indoor air pollution, and about 15 percent of under-age-five child mortality is attributed to inadequate water supply, sanitation and hygiene and to indoor air pollution. Figure 1.1 presents the burden of mortality related to environmental causes as a percent of total mortality among adults and children under age five in Nicaragua.

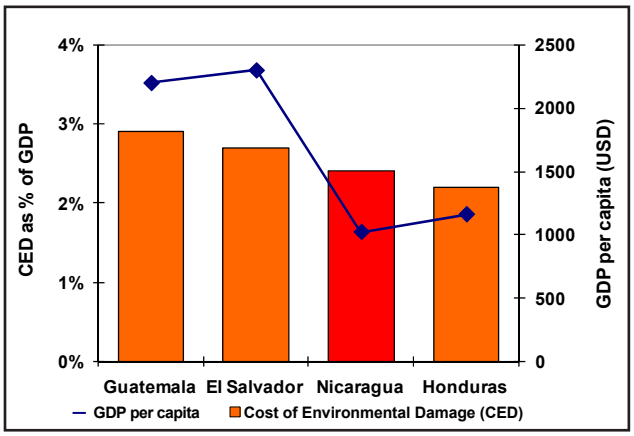
Central American Context: The cost of environmental degradation in Nicaragua is comparable with other countries at similar income levels. In all the selected countries in Central America, these costs range from two to three percent of the re-

Figure I.1: The Burden of Mortality Related to a Environmental Causes



spective country's GDP. In Nicaragua, the health cost of environmental damage—including costs of inadequate water, sanitation and hygiene, and costs of indoor and outdoor air pollution—amounts to 1.8–3.1 percent of the country's GDP.

Figure I.2: Health Cost of Environmental Damage in Selected Central American Countries



Source: CEA studies, World Bank 2005–2009.

The cost of environmental damage is equivalent to the benefits that society would enjoy if environmental quality were improved to a condition with no environmental risks to health, no negative impacts on productive assets from environmental degradation, and no damages to health, infrastructure and housing from natural disasters. The estimates of damage costs presented above can therefore be used as a starting point to evaluate the benefits of interventions to improve environmental quality and reduce environmental damage.

From a socioeconomic point of view, the well-being of society will improve if interventions that provide greater benefits than costs are implemented. A cost-benefit analysis would provide a sense of prioritization among various interventions. In terms of water supply, sanitation and hygiene, a cost-benefit analysis would involve looking at various interventions such as hand washing, drinking water disinfection, improved sanitation and water supply options, etc. Similarly, for indoor air pollution a cost-benefit analysis would consider alternative scenarios of indoor cooking that include the use of improved or unimproved stoves, and the use of solid or clean fuel (LPG). For outdoor air pollution, this analysis would assess the costs and benefits of various particulate matter (PM) emissions control options in urban areas. However, the identification of appropriate interventions is constrained by the lack of air quality monitoring data and the absence of an emissions inventory in Nicaragua.

In the following sections, this study provides estimates for the costs associated with environmental health risks from inadequate water, sanitation and hygiene, and from indoor and urban air pollution. Therefore, in order to help the GoN prioritize among available interventions, this study also attempts to undertake cost-benefit analyses for each of these environmental health risks in the context of Nicaragua.

II. Water, Sanitation, and Hygiene

According to the latest WHO/UNICEF Joint Monitoring Program (JMP/2006), 90 percent of the urban population and 56 percent of the rural population in Nicaragua have access to improved sources of drinking water (piped water, public tap, borehole/tubewell, protected well, protected spring or rainwater). However, even in connected households, the quality of service is low (WSP 2008). In terms of sanitation, 56 percent of the urban population and 34 percent of the rural population have access to improved sanitation (are connected to public service or have a septic tank).

Inadequate quantity and quality of potable water supply, sanitation facilities and practices, and hygiene conditions are associated with various illnesses both in adults and children. The major health effects of inadequate water quality and quantity, sanitation facilities and practices, and hygiene are diarrheal morbidity and mortality.[5] WHO estimates that about 90 percent of diarrheal illness is attributable to these factors (WHO 2002). While diarrheal illness is generally not as serious as some other waterborne illnesses, it is more common and affects a larger number of people.

Health impacts: The estimation for diarrheal mortality in Nicaragua is based on total child mortality. Nicaragua has relatively high child mortality in general, although the estimates are quite uncertain. According to the latest demographic and health survey (*Encuesta Nicaragüense de Demografía y Salud, ENDESA*), mortality among children under age five is 35 per 1,000 live births, using the 2006 child mortality rate as the starting point in the estimation (ENDESA 2006–2007). A similar estimate of child mortality in 1998 was 51 deaths for 1,000 live births (ENDESA 1998). The main reason for the uncertainty and year-to-year variation in the estimates is that not all births are registered (Alarcón, Robles 2007).

The estimated health effects from inadequate water, sanitation and hygiene are based on background health data, taking into account the WHO estimate that 88 percent of diarrheal illness in Nicaragua is attributable to water, sanitation and hygiene.[6] The percent of diarrheal cases among children under age five is estimated from ENDESA 2006–2007, and in the age group older than age five it is estimated from the *Encuesta de Hogares sobre Medición del Nivel de Vida*, EMNV (2005).[7]

5 Hygiene refers to personal hygiene (such as hand washing), domestic hygiene and food hygiene.

6 Estimated applying methodology presented in Fewtrell et al., 2007.

7 EMNV (2005) reports significantly lower diarrheal prevalence among people over 5 in comparison with other AMRO D countries. This lower diarrheal prevalence among people over 5 explains relatively low estimates of WSSH losses on Nicaragua. WHO GBD (2004) predicts higher rates of diarrheal illness in AMRO D than those reported in EMNV (2005).

The same method was applied to estimate treated cases because only the percentage of treated cases among children under age five was available from ENDESA 2006–2007.

Each year, an estimated 240 children under age five in urban areas and 320 in rural areas die from diarrheal diseases attributed to poor water, sanitation and hygiene. Furthermore, among children under age five, more than a million annual cases of diarrhea in rural and urban areas, respectively, result from poor water, sanitation and hygiene. The estimated number of cases of diarrheal illness in children under age five is about 1.3 times higher in rural areas.

Although the rural population in Nicaragua comprises about 44 percent of the total population, the estimated number of cases of diarrheal child mortality is about 40 percent higher there because the share of children in the population as well as the diarrheal prevalence are also substantially higher in rural areas. The larger share of children in the rural population, lower public awareness of the health benefits of drinking boiled water, and poorer access to energy are also determinants of higher diarrheal illness in rural children.

Table II.1: Estimated Annual Health Effects from Water, Sanitation, Hygiene

	Urban cases	Rural cases
Children (under age five – increased mortality	240	320
Children (under age five) – increased morbidity	1,000,000	1,200,000
Population over age five – increased morbidity	700,000	650,000

Economic costs: Inadequate access to water and sanitation leads to premature deaths and disease, which in turn impose costs on Nicaragua's economy. These costs include the expenses incurred to treat illness from diseases attributed to poor water and sanitation, doctor fees, laboratory tests, drugs, and bed charges when hospitalization is needed. Other costs include lost productivity when adults fall sick and stay home from work, or when primary caregivers have to take care of sick children (and potentially lose wages). Furthermore, the pain and suffering from premature death and illness can also be valued by calculating the burden of disease in disability adjusted life years (DALYs)[8] and by costing these DALYs at GDP per capita.

The annual cost of diarrheal mortality and morbidity from inadequate water, sanitation and hygiene is estimated at 345 million NIO in urban areas and 455 million NIO in rural areas (Table II.2). The cost of diarrheal child mortality is based on the Human Capital Approach (HCA) discussed in Annex A. The cost of morbidity includes the cost of illness (medical treatment, medicines, and value of lost time). About 50 percent of these costs are associated with the value of time lost to illness (including care giving), and 50 percent are from cost of treatment and medicines.

Avertive Expenditures: In the presence of perceived health risks, people often take averting measures to avoid these risks. If people perceive there is a risk of illness from the municipal water supply or from other sources of water supply that they use, some of them are likely to purchase bottled water for drinking purposes, boil their water, filter or chlo-

8 The Disability Adjusted Life Year (DALY) is a health gap measure that extends the concept of years of life lost due to premature death to include equivalent years of healthy life lost due to poor health or disability. DALYs for a disease or health condition are calculated as the sum of the years of life lost due to premature mortality (YLL) in the population and the years lost due to disability (YLD) for incident cases of the health condition.

Table II.2: Estimated Annual Cost of Diarrheal Illness (million NIO)

	Urban	Rural
Mortality: Children under age 5	135	185
Morbidity: Children under age 5, population over age 5	210	270
Total Annual Costs	**345**	**455**

rinate it. These averting expenditures associated with the purchase of bottled water and boiling the water account for the costs of health risks.

No reports were identified on the use of bottled water in Nicaragua. Bottled water use in Nicaragua was estimated at 23,000 m^3 (23 million liters) per year in 2004, with information on pricing and costs of production derived from Gómez 2008. According to surveys, nearly five to seven percent of urban households and one to three percent of rural households in Nicaragua boil their drinking water, either all the time or sometimes (WSP 2008). It is assumed that the average daily consumption of drinking water per person is 0.5 to 1.0 liters among households that use boiled water. The residential cost of energy is estimated based on data from experts, using the average stove efficiency for natural gas and wood fuel (see Annex A for details). Baseline data are presented in Table II.3. The annual cost of boiling water for these households is estimated at 20 million NIO per year.

About 20 percent of urban and 30 percent of rural households disinfect drinking water (WSP 2008) in Nicaragua. Chlorination is predominantly used to disinfect drinking water.[9] Braghetta (2006) cites the cost of chlorinating drinking water at the point of use in Nicaragua at US$10 per household per year. It is estimated that rural households spend 24 million NIO and urban households spend 15 million NIO annually for water chlorination. Data on filter use are sketchy. Although MINSA has a program for household filter distribution and about 80,000 filters are reported to have been distributed, there is no information on actual use. WSP (2008) estimates that about 5 percent of urban households use filters; this would translate into annual costs of about 7 million NIO.[10]

Table II.3: Baseline Data for Estimation of Costs Due to Water Boiling

Indicator	Data	Notes
% of households that boil their drinking water	1–7%	WSP 2008
Average daily consumption of drinking water	0.5–1.0	Liters per person per day
% of households using electricity (urban-rural)	0.9–0.3%	ENDESA 2006–2007
% of households using LPG (urban-rural)	65.6–7.3%	
% of households using fuel wood (urban-rural)	30.9–91.4%	
% of households using coal (urban-rural)	0.9–0.1%	
Energy requirement for heating water (100% efficiency)	4,200	Joules/ltr/1 degree C
Average stove efficiency for heating water	25–50%	Varies by type of stove
Average time of boiling water (after reaching boiling point)	10	Minutes

9 WSP (2008) reports that 90 percent in rural areas and 55 to 60 percent in urban areas of those who disinfect choose to chlorinate water. However, other sources, such as Ramírez (2008), indicate that water filtration is a significant source of disinfected water in Nicaragua.

Table II.4: Estimated Annual Household Avertive Expenditures

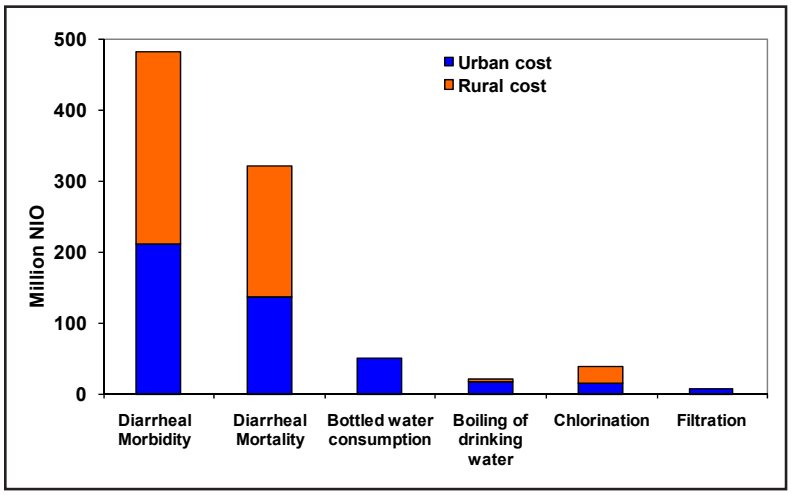
	Total Annual Cost (million NIO)	
	"Low"	"High"
Bottled water consumption	25	75
Boiling of drinking water	10	30
Chlorination	38	38
Filtration	7	7
Total annual cost	80	150

Total avertive expenditures for Nicaragua are estimated to range from 80 to 150 million NIO (Table II.4) per year. This represents about 10 to 17 percent of the total estimated annual cost associated with inadequate water supply, sanitation and hygiene.

The total estimated cost associated with inadequate water supply, sanitation and hygiene ranges from 830 million to 1 billion NIO per year, with a mean of 915 million NIO (Figure II.1). The damages include health impacts, mortality and morbidity and averting expenditures which mostly include household boiling of drinking water. The cost of health impacts represents an estimated 87 percent, and avertive expenditures represent about 13 percent of total costs. While rural areas account for 52 percent of total cost, urban areas account for the remaining 48 percent.

Inadequate water and sanitation as well as poor hygiene contribute directly to health risks (diarrheal diseases), especially in children under age five. However, given the linkages among environmental health, malnutrition and disease, there are additional malnutrition-mediated (indirect) health impacts associated with inadequate water and sanitation provisions and with improper hygienic practices (Fewtrell, Prüss-Üstün et al. 2007). Furthermore, the consequences of malnutrition in children under age five, in terms of longer term cognition and learning impacts, can also be partly attributed to inadequate water, sanitation and hygiene. Recent analyses in Ghana and Pakistan have shown that by adding these indirect impacts (both in the short term and long term), the health costs attributed to poor water, sanitation and hygiene nearly double (World Bank 2008). Estimating these additional impacts requires much more detailed analyses; it is recommended as follow-up work but has not been included within the scope of this study.

Figure II.1: Annual Costs of Inadequate Water, Sanitation and Hygiene (million NIO)



10 Filter distribution and pricing data are from communications with B. Castro. MINSA, March 2009.

Water, Sanitation, and Hygiene Interventions

Interventions related to improving the quality and quantity of water supply, improving access to improved sanitation, and programs encouraging better hygiene practices (including hand washing) have potential health benefits. Based on studies from several countries around the world, estimates of the benefits associated with different interventions to reduce damage arising from unsafe water and sanitation have been developed (see Annex A for details). These international studies estimate the percentage reductions in the incidence of diarrheal morbidity and mortality following interventions to improve the infrastructure that provides drinking water or basic sanitation, or interventions that improve personal hygiene. The results are applied to available Nicaraguan health data and to estimates of the costs of providing such improvements in rural and urban areas of Nicaragua.

A. Cost-Benefit Analysis of Water and Sanitation Improvements

Providing piped water supply to all rural households is likely to be very expensive. A realistic objective might be to at least provide improved water supply (protected wells or boreholes) and sanitation facilities (improved pit latrines or pour-flush latrines). The aim of the infrastructure interventions is to improve water supply and sanitation, largely in rural areas. Two programs are analyzed: one that provides 1.5 million people with improved sanitation, and one that provides 1.2 million people with an improved water supply both in rural and urban areas.

The annualized investment costs per capita are estimated at about US$12–19 for improved sanitation and US$30–40 for improved water supply, using information about incremental service increase and corresponding investment needs from the *Estrategia Sectorial de Agua Potable y Saneamiento 2005.* This is based on a ten percent annual discount rate, an annual five percent for operation and maintenance (O&M) and five percent for promotion/water source protection costs, and US$6 in annual sewage costs.[11]

Benefits associated with improvements in water supply and sanitation include reductions in mortality and morbidity from diarrheal diseases (see Table II.5). Improved water supply is estimated to avert 200,000 diarrheal cases (and 40 child deaths) per year in rural areas, and 70,000 diarrheal cases (and 12 child deaths) per year in urban areas. Similarly, improvements in sanitation are estimated to avert 300,000 diarrheal cases (and 60 child deaths) per year in rural areas, and 100,000 diarrheal cases (and 17 child deaths) per year in urban areas. Details on the assumptions and calculations can be found in Annex B. The morbidity costs, based on the costs of treatment and value of lost time, are US$8–14 per case of diarrhea. The mortality costs are calculated based on the Human Capital Approach (HCA).

The analysis estimates that interventions (programs) that improve sanitation in Nicaragua will have a benefit-to-cost ratio greater than 1.0 when the time savings of improved water are included. For water supply programs, the benefit cost ratio is less than 1. For water supply/sanitation programs in urban areas, the costs are higher and the benefits are lower due to lower diarrheal mortality among children under age five and lower diarrheal prevalence. Marginal cost[12] would be higher than marginal benefits[13] (health damage reduction) for all four investment programs considered.

11 Per capita investment costs represent average costs in South America (WHO/UNICEF 2000).
12 Approximated by average cost per one percent of WSSH cost reduction.
13 Value of one percent of WSSH cost reduction, estimated at about 9 million NIO.

Table II.5: Costs and Benefits of Reductions in Diarrheal Morbidity and Mortality

	Rural Areas		Urban Areas	
	Improved Sanitation Facilities	Improved Water Supply	Improved Sanitation Facilities	Improved Water Supply
Population (million) receiving improved sanitation	1.0		0.5	
Population (million) receiving improved water supply		0.9		0.2
% reduction in diarrheal illness /person (Fewtrell and Colford 2004)	32%	25%	32%	25%
Diarrheal cases (million) averted per year	0.3	0.2	0.1	0.07
Deaths in children averted per year	60	40	17	12
Annual Health Benefits of Improved Services (US$ million)	*4*	*3*	*2*	*1*
Annualized Costs of Service Provision (US$ million)	*12*	*24*	*9*	*10*
Benefit-Cost Ratio (health benefits only)	**0.35**	**0.1**	**0.2**	**0.1**
Marginal cost (million NIO per 1% reduction) in WSSH health cost	26	69	45	70

B. Benefit-Cost Analysis of Hygiene Improvements

In many studies, the single most effective hygiene intervention is found to be hand washing after defecation, before preparing meals, and before eating. For Nicaragua, this analysis estimates the benefits and costs of hand-washing programs in both rural and urban areas. The costs of improved hand-washing practices include (i) the costs of program preparation and implementation, and (ii) the private (household) costs associated with increased water and soap consumption. Benefits from a hand-washing program include the percentage reduction in diarrheal illness per child. These benefits are dependent on the effectiveness and sustainability of the hand-washing program in terms of behavioral change at the household and individual levels. Assumptions made, and details of methodology, can be found in Annex B.

In terms of the sustainability of the hand-washing programs, benefit-cost ratios are estimated for three scenarios of behavioral change (low, medium, high). The analysis estimates that the benefit-cost ratios for hand-washing programs in Nicaragua range from 4.5 in the "low" scenario to about 0.6 in the "high" scenario. These ratios are higher for the urban population since medical treatment costs and annual wages are higher in urban areas. Apart from children under age five, the general population over age five can also benefit from a hand-washing program. However, the benefit-cost ratios are found to be below one, primarily due to the substantially lower diarrheal incidence rates in the sub-population above age five.

C. Benefit-Cost Analysis of Drinking Water Disinfection

The benefit-cost analysis for drinking water disinfection interventions (boiling water, which is more common in Nicaragua, and chlorination programs) has also been estimated. There are no estimates of program costs to promote drinking water disinfection at point-of-use; therefore, the same costs as for hand-washing programs (and three scenarios of effectiveness ranging from 10 to 20 percent) have been applied. The program costs are estimated per household, while the private cost of boiling drinking water is estimated at US$5 per year for urban households using commercial fuels and about US$3 for rural households using fuelwood collected by household members. The cost of water

Table II.6: Benefits and Costs of a Hand-Washing Program (Rural and Urban)

	Rural Households with Children Under Age 5			Urban Households with Children Under Age 5		
	Low	Med	High	Low	Med	High
Program target (million households)*	0.3	0.3	0.3	0.3	0.3	0.3
Program response (% of households with behavioral change)	10%	15%	20%	10%	15%	20%
Percent reduction in diarrheal illness per child (Fewtrell and Colford 2004)	45%	45%	45%	45%	45%	45%
Total program cost (US$ million)	0.1	0.4	1.7	0.1	0.4	1.6
Private costs of water and hygiene products per year (US$ million)	0.1	0.2	0.2	0.1	0.2	0.2
Total costs from hand-washing program	*0.2*	*0.6*	*1.9*	*0.2*	*0.6*	*1.8*
Cases of diarrheal illness averted per year (thousands)	30	45	60	30	50	60
Deaths in children averted per year	9	13	18	9	14	19
Total benefits from hand-washing program	*0.5*	*0.8*	*1.0*	*0.7*	*1.0*	*1.4*
Benefit-Cost Ratios						
LOW: If behavioral change lasts 1 year	2.2	1.4	0.6	2.9	1.9	0.8
MEDIUM: If behavioral change lasts 2 years**	3.0	**2.1**	1.0	3.9	**2.8**	1.3
HIGH: If behavioral change lasts 3 years**	3.4	2.6	1.3	4.5	3.4	1.7
Marginal cost for medium scenario (million NIO per 1% of WSSH health cost reduction)		10			7	

* There are about 0.6 million rural children under age five in Nicaragua. It is assumed there is one child under age five in each household (thus the program target is 0.6 million households). However, the estimated benefit-cost ratio is higher for households with more than one child under age five. There are about 0.4 million urban children under age five in Nicaragua. It is assumed there is one child under age five in each household (thus the program target is 0.4 million households). However, the estimated benefit-cost ratio is higher for households with more than one child under age five.** Benefits and costs in the second and third years are discounted at an annual rate of 10 percent.

chlorination is estimated at US$3 per household based on an average drinking water consumption of 0.75 liters per person per day (Lantagne et al. 2005).

In rural areas of Nicaragua, disinfection programs are estimated to avert 110,000 to 220,000 cases of diarrhea and 25 to 50 deaths in children per year. The benefit-cost ratio for the central estimate in water boiling programs is 1.9 and for water chlorination 4.8, corresponding to a 15 percent program response rate with drinking water disinfection sustained for two years. Even for the "high" program cost, and with improved hand washing only sustained for one year, the benefit-cost ratio is 3.2. Benefit cost ratios are lower, but well above 1 in urban areas. In urban areas, the disinfection programs are estimated to avert 70,000 to 130,000 cases of diarrhea and 10 to 25 deaths in children per year. Drinking water chlorination programs in both rural and urban areas have high benefit-cost ratios, because associated private costs are low. Detailed tables for disinfection in urban areas, as well as for chlorination programs in both rural and urban areas, are in Annex B.

Table II.7: Benefits and Costs of a Rural Drinking Water Boiling Program

	"Low"	"Medium"	"High"
Target population – rural population not practicing disinfection (millions)	1.5	1.5	1.5
Target households (millions)	0.3	0.3	0.3
Program response (% of households with behavioral change)	10%	15%	20%
Percent reduction in diarrheal illness per person (Fewtrell and Colford 2004)	47%	47%	47%
Program costs (US$ million)	0.1	0.3	1.4
Private costs of boiling drinking water per year (US$ million)*	0.3	0.4	0.5
Total costs of boiling drinking water	*0.4*	*0.7*	*1.9*
Cases of diarrheal illness averted per year (thousands)	45	65	90
Deaths in children averted per year	<15	<20	25
Total benefits from boiling drinking water (US$ million)	*0.7*	*1.1*	*1.5*
Benefit-Cost Ratios			
LOW: If behavioral change lasts 1 year	1.9	1.5	0.7
MEDIUM: If behavioral change lasts 2 years**	2.2	1.9	1.1
HIGH: If behavioral change lasts 3 years**	2.3	2.1	1.4
Marginal cost for medium scenario (million NIO per 1% of WSSH health cost reduction)		5	

* Estimated based on efficiency of LPG and wood stoves, cost of LPG, fuelwood collection time of 30 minutes per day and 10 percent of fuelwood used for water boiling, and per-person water consumption of 0.75 liter per day.

** Benefits and costs in the second and third years are discounted at an annual rate of 10 percent.

Summary Assessment of Interventions Relating to Water, Sanitation and Hygiene

As part of this analysis, interventions relating to sanitation and water supply, various forms of disinfection (boiling water and chlorination, as well as hand-washing programs) were examined. The results for these interventions can be summarized in terms of their contribution to reduced environmental damages and the costs per one percent of health damage reduction (marginal cost).

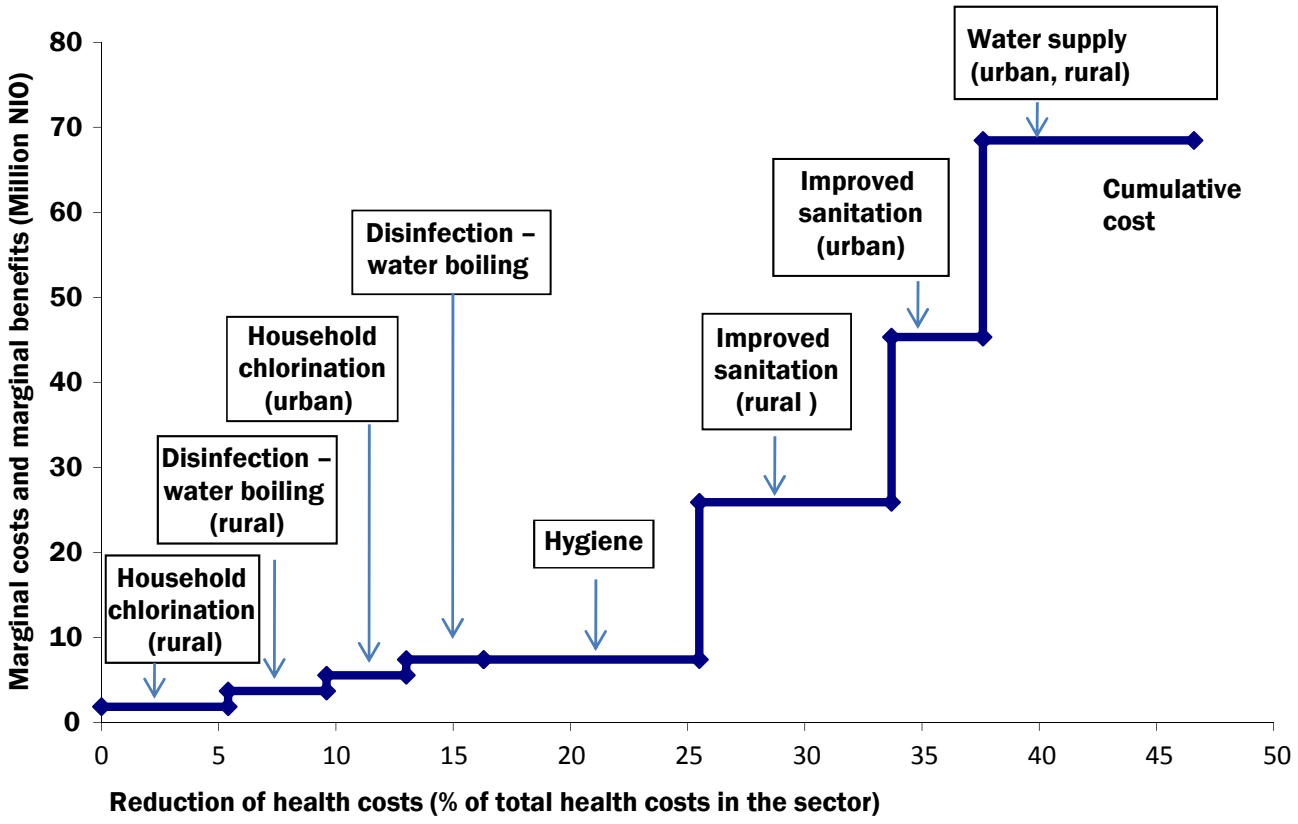
The length of each segment depicted in Figure II.2 represents percentage point reduction of health damage (morbidity, mortality) from the implementation of a corresponding intervention. The height of each segment of the cumulative cost curve equals the unit cost of an intervention per one percentage point reduction of health damages. The total area below each segment is equal to the total cost of this intervention. For example, the first intervention to reduce water pollution is chlorination of water at the point of use in rural areas. It is depicted by the first segment of Figure II.2. This intervention reduces five percent of total health damage associated with inadequate water supply, sanitation and hygiene at the cost of 2 million NIO per one percentage point of this damage reduction. The total cost of this intervention is 10 million NIO. The segments are ranked in the order of increasing unit costs.

The disinfection and hygiene programs are estimated to have the greatest potential health benefits, but only if at least 20 percent of the population responds favorably to the program and improves hand-washing practices. Hygiene improvement and

disinfection of drinking water at point of use have a substantial potential to reduce diarrheal illness and mortality. However, the challenge is to develop and deliver programs that induce sustained behavioral response at a large scale while containing program costs at an affordable level.

The benefit-cost ratios for hand washing and drinking water disinfection are based on behavioral change being sustained for two years. The ratios would be higher (lower) if, as a result of promotion programs, households sustain improved behavior for longer (less) than two years. This figure does not consider the possible interaction effects between different interventions (i.e., how the impacts of a first intervention affect those of a second intervention), because data constraints preclude a sound analysis of such effects.

Figure II.2: Ranking of Interventions to Reduce Water, Sanitation and Hygiene Costs in Nicaragua



Recommendations for Actions on Water, Sanitation, and Hygiene

From the analysis presented here, it is clear that in Nicaragua, most measures to improve the water supply and sanitation facilities in rural areas yield benefits in excess of costs under most assumptions. The programs are also justified because the benefits are concentrated primarily among the poor. The highest priority should be given to the drinking water disinfection and hand-washing programs in both rural and urban areas.

III. Indoor Air Pollution

About 2.4 billion people worldwide burn biomass (wood, crop residues, charcoal and dung) for cooking and heating. The smoke created from burning these fuels turns the kitchens of the world's poorest countries into death traps. Indoor air pollution from the burning of solid fuels kills over 1.6 million people, predominantly women and children, each year (World Bank 2002b). Smoke in the home is one of the world's leading child killers, claiming the lives of nearly one million children each year (ITDG 2004). The strongest links between indoor smoke and health are for lower respiratory infections, chronic obstructive pulmonary disease (COPD), and cancer of the respiratory system. Of all the respiratory diseases associated with indoor smoke, lower respiratory infections account for about 37.5 percent, COPD accounts for 22 COPD, and cancer of the respiratory system accounts for about 1.5 percent globally (WHO 2002b).

Rural energy use: Indoor air pollution is associated with use of traditional fuels (mainly cotton stalks in Nicaragua). About 92 percent of the rural population and 32 percent of the urban population use solid fuel for cooking in Nicaragua (ENDESA 2006–2007). WHO (Desai et al. 2004) suggests using a ventilation coefficient of 0.25 for households that use improved stoves or have outside kitchens. The national survey of solid fuel use in Nicaragua (ENDL 2006–2007) estimates that kitchens are located outside the house in 50 percent of rural and 75 percent of urban households.

Health effects: Acute respiratory infections (ARIs) and COPD are the most common diseases associated with indoor air pollution in Nicaragua. The vulnerable subgroups in the population include children under age five (ARI mortality and morbidity among children) and women over age 30 (COPD mortality and morbidity; ARI morbidity), because these subgroups are exposed to smoky kitchens. The health estimates attributed to indoor air pollution are based on background health data on ARI and COPD prevalence, available from ENDESA 2006–2007 and international sources, taking into account odds ratios (see Annex A for details).

Table III.1: Estimated Annual Health Effects of Indoor Air Pollution

	Rural areas		Urban Areas	
	"Low"	"High"	"Low"	"High"
Mortality:				
Acute respiratory infections in children under age 5	140	200	40	70
Chronic obstructive pulmonary disease in women over age 30	45	70	20	50
Morbidity:				
Acute respiratory infections in children under age 5	586,900	1,049,800	208,000	627,200
Acute respiratory infections in women over age 30	284,800	412,700	161,800	273,900
Chronic obstructive pulmonary disease	1,280	2,060	530	1,160

Each year, an estimated 140 to 200 children under age five die from ARIs in rural areas, and an additional 40 to 70 children die in urban areas in Nicaragua. Among children under age five, more than half a million annual cases of acute respiratory infections in rural areas, and more than 200,000 cases in urban areas, can be linked to indoor air pollution. Among females over age 30, each year there are nearly 285,000 cases of indoor-air-pollution-related ARI morbidity in rural areas and nearly 162,000 cases in urban areas. Indoor air pollution also causes COPD in females over age 30: nearly 120 women die annually from COPD in urban and rural areas, and about 3,000 new cases of COPD can be attributed to indoor air pollution each year (Table III.1).

66. *Economic costs:* The total estimated annual cost of indoor air pollution ranges from 540 million to 1.2 billion NIO with a mean cost of 870 million NIO (Table III.2). These costs account for about 0.83 percent of GDP in 2007. ARI in children represents 40 percent of cost; respiratory child mortality represents 12 percent; COPD mortality in adult females and ARI morbidity in adult females represent 11 and 12 percent of the total costs, respectively. The rural poor are especially vulnerable and account for 56 percent of the total costs of indoor air pollution.

Table III.2: Estimated Annual Costs (million NIO) of Indoor Air Pollution in Nicaragua

	"Low"	"High"
Acute Respiratory Illness (ARI):		
Children (under age 5) – increased mortality	104	157
Children (under age 5) – increased morbidity	249	558
Adult females – increased morbidity	158	248
Chronic obstructive pulmonary disease (COPD):		
Adult females – increased mortality	12	212
Adult females – increased morbidity	17	30
Total	**539**	**1205**

In order to estimate the cost of COPD mortality for adults, the Value of Statistical Life (VSL) is used as the upper bound and HCA as the lower bound (see Annex A for details on this methodology). In the case of children, HCA is used to estimate the cost of mortality. The cost of morbidity includes the cost of illness (medical treatment and value of time lost due to illness).

Indoor Air Pollution Interventions

A wide range of interventions are available to reduce indoor air pollution and associated health effects. These interventions can be classified according to the level at which they are effective: (a) interventions on the source of pollution, including moving from traditional stoves to improved stoves,

and switching to cleaner fuels such as LPG; (b) interventions on the living environment, such as chimneys and smoke hoods (with flues); and (c) interventions on user behavior, such as keeping young children away from smoke. For purposes of this economic analysis for indoor air quality in Nicaragua, only those interventions relating to the source of pollution have been considered, that is, moving from unimproved to improved stoves, better ventilation, and switching to cleaner fuels.

Five intervention scenarios considered for Nicaragua represent stylized situations commonly found in most developing countries representing reduction of pollution loads from solid fuel use. However, actual pollution exposure can vary substantially in each scenario, and depends on additional factors such as household ventilation as well as other characteristics and household behavior (Table III.3).

Table III.3: Interventions

Scenarios:	*Description:*
From I (50% HH) to II	From unimproved stove inside to better ventilation
From I (50% HH) to III	From unimproved stove inside to improved stoves
From III to V	From improved stove to LPG
From IV to VI	From unimproved stove and LPG mix to LPG only
From V to VI	From improved stove and LPG mix to LPG only

In the benefit-cost analyses of selected interventions, improved ventilation and replacement of unimproved stoves with and improved ones in individual households are found to have substantially higher benefits than costs. The benefit-cost ratio is estimated at above 3 for all four of these interventions. The benefit-cost ratio is lower than 1 if there is switching to LPG due to high LPG prices. For households with improved stoves, the health benefits alone are not large enough to outweigh the cost of switching to LPG. Although promotion of improved stoves is a very attractive intervention, the merits of promoting LPG in individual rural households are uncertain. LPG prices would have to be reduced dramatically for the estimated benefits to exceed costs. Therefore, it appears that LPG will have a chance of success only in better-off households.

Summary Assessment of Interventions to Address Indoor Air Pollution

The range of interventions is summarized in terms of their contribution to reduced environmental damages and costs per one percent of health damage reduction (marginal cost)[14] (Figure III.1). Similar to the case of water pollution, the length of each segment depicted represents a percentage point reduction of health damage (morbidity, mortality) from the implementation of a corresponding intervention. The unit costs reflect only program costs and private household costs, without taking into account time and fuelwood savings.

Improved ventilation and household replacement of unimproved stoves with improved stoves results in the largest reduction in damages in rural areas. This is followed by households switching

14 Approximated by the average cost to implement intervention per one per cent of IAP cost reduction.

Table III.4: Benefits and Costs of Indoor Air Pollution Control in Nicaragua

	Rural Areas			*Urban Areas*		
	Better ventilation from unimproved stove inside	Improved stoves from unimproved stoves inside	LPG from improved stove	Better ventilation from unimproved stove inside	Improved stoves from unimproved stoves inside	LPG from improved stove
Population receiving intervention (million)	0.5	0.5	0.07	0.1	0.1	0.03
ARI cases averted/year (thousand)	400	400	50	80	80	20
ARI deaths in children averted/year	36	36	5	10	10	<5
COPD cases averted per year	110	110	20	50	50	15
COPD deaths averted per year	10	10	<5	<10	<10	<5
Annual health benefits (million NIO)	*96*	*96*	*14*	*50*	*50*	*10*
Program cost (million NIO)	13	13	2	4	4	1
Annualized stove cost (million NIO)	3	22	4	1	6	2
Annual cost of LPG (million NIO)	0	0	40	0	0	20
Total annual costs (million NIO)	*18*	*37*	*47*	*5*	*10*	*23*
Benefit-cost ratio (health benefits only)*	**6.0**	**2.7**	**0.3**	**10.6**	**4.9**	**0.5**
Marginal cost (million NIO per 1% of IAP health cost reduction)	1.5	3.2	30	0.8	1.8	17

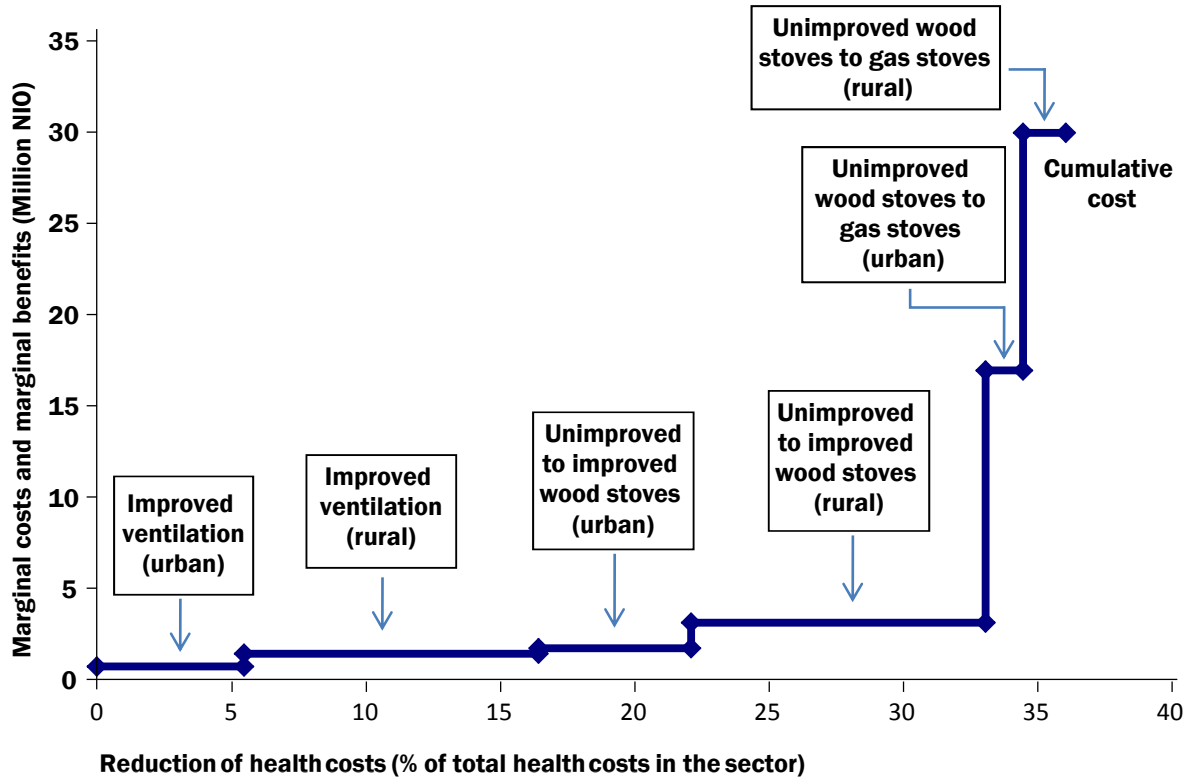
Note: *rounded off

to LPG alone from improved stoves in urban and rural areas. Each of these measures contributes a smaller amount of reduction in environmental damages; marginal costs for these two interventions slightly exceed marginal benefits. In total, the first four interventions reduce the cost of health effects by about 37 percent per year. This reflects better ventilation and switching to improved stoves in 43 percent of rural households and in 8 percent of urban households, and switching to LPG from improved stoves in 3 percent of rural and 1 percent of urban households.

Recommendations for Actions on Indoor Air Pollution

The analysis presented here recommends shifting households who have unimproved stoves to improved ones, and to improve ventilation. The relative attractiveness of other interventions (such as switching from unimproved stoves to LPG or from improved stoves to LPG) is much more uncertain and depends substantively on the costs and benefits used.

Figure III.1: Ranking of Interventions for Indoor Air Pollution Cost Reduction in Nicaragua



IV. Urban Air Pollution

Air quality: Managua, the capital of Nicaragua, has a population of about 1.2 million. It is located in the western part of Nicaragua on the southwestern shore of Lake Managua. Urban (outdoor) air pollution is emerging as a major problem in Nicaragua's urban centers, particularly in Managua. Total urban population exposed to air pollution is about 1.95 million, or 62 percent of the total Nicaraguan population[15] in 2007. Data relating to urban air quality concentrations are extremely limited and very dated (last available in 2001, see Table IV.1). There is no emissions inventory, and very little city-specific data are available. Furthermore, the estimates relating to health effects from urban air pollution relate to only Managua and other cities with populations over 100,000. Although the urban population in other smaller cities in Nicaragua is also exposed to ambient air pollution, these cities were not included in the analysis due to the lack of monitoring data and estimated concentrations.

MARENA provided the monitored data for annual average concentrations of major pollutants in Managua in 1995–2001. No monitoring of PM_{10} and TSP was conducted after 2001.

Table IV.1: Measured Average Annual Concentration of Pollutants in Managua (1996–2001)

	Units	1996	1997	1998	1999	2000	2001	Average	Standard
NO_2	$\mu g/m^3$	40	34	31	34	22	23	31	40
Ozone	$\mu g/m^3$	88	71	75	119	42	23	70	60
PM_{10}	$\mu g/m^3$	66	67	62	52	65	70	64	50
TSP	$\mu g/m^3$	n/a	288	341	241	300	253	285	75

Source: MARENA 2009

15 Estimated from http://www.mongabay.com/igapo/2005_world_city_populations/Nicaragua.html, adjusted to 2007 by applying the urban population growth rate in Nicaragua from http://www.makingcitieswork.org/files/pdf/latin-am-carribean/Nicaragua.pdf for all cities with populations over 100,000.

Table IV.2: Estimated Health Impact of Urban Air Pollution

Health end-points	*Total Cases*
Premature mortality	429
Chronic bronchitis	514
Hospital admissions	1,352
Emergency room visits/ Outpatient hospital visits	26,518
Restricted activity days	4,478,531
Lower respiratory illness in children	58,749
Respiratory symptoms	14,253,413

Vehicle growth: However, since the number of vehicles nearly doubled in Nicaragua in 2000–2007 (Figueroa de la Vega 2009) and the transportation fleet is a major polluting source in the urban areas, annual average concentrations of PM_{10} have not decreased since 2001. Using the latest available monitoring data, and then adjusting them in relation to World Bank estimates, the annual average PM_{10} concentration for Managua was estimated at 67 $\mu g/m^3$; in other Nicaraguan cities with populations over 100,000 it was estimated at 43 $\mu g/m^3$.[16]

Health impacts: The most significant health impact of outdoor air pollution has been associated with particulate matter and, to a lesser extent, with ground-level ozone. Particles smaller than 10 microns in size (PM_{10}), and especially those smaller than 2.5 microns ($PM_{2.5}$), penetrate deep into human lungs and cause health impacts such as acute respiratory infection (both upper and lower respiratory tract infections), COPD (especially bronchitis), asthma attacks, cardiovascular disease and lung cancer. Certain population subgroups, such as the elderly, children, and individuals with existing respiratory or cardiovascular diseases, are at increased risk from exposure to particulate matter.

The annual health effects of ambient particulate air pollution in Nicaragua are calculated using the information on applicable concentration-response coefficients that link annual average PM pollution with additional cardiopulmonary mortality and various morbidity end-points (for details of the methodology, see Annex A). Urban particulate air pollution is estimated to cause around 420 premature deaths annually. The number of new cases of chronic bronchitis is estimated at about 520 per year. Annual hospitalizations due to pollution are estimated at close to 630, and annual emergency room visits/outpatient hospitalizations at 26,500. Cases of less severe health impacts are also presented in Table IV.2. In terms of annual DALYs lost, mortality accounts for an estimated 45 percent, chronic bronchitis around 16 percent of the total, Restricted Activity Days (RADs) 20 percent, and respiratory symptoms 15 percent.

Economic costs: Increasing air pollution in Nicaragua's urban areas, especially in Managua, is imposing a negative economic impact from premature deaths, illness, medical costs and lost productivity. Costs of health impacts from particulate matter have been assessed, and health conditions such as premature mortality, hospital admissions, restricted activity days, and emergency visits have been considered. In the absence of proper data on treatment costs, informed estimates have been provided by medical experts in Managua.

The mean estimated annual cost of urban air pollution due to PM ranges from 305 million to 1.25 billion NIO, with a mean of is about 780 million NIO. This represents about 0.7 percent of the country's GDP. Around 70 percent of the cost is due to mortality, and the remaining 30 percent is associated with morbidity (Table IV.3). The cost of mortality, based on the Human Capital Approach (HCA) and the Value of Statistical Life (VSL), ranges from 1

16 www.worldbank.org/nipr/Atrium/mapping.html.url.

Table IV.3: Estimated Annual Cost of Health Impacts (Million NIO)

Health Categories	Total Annual Cost	% of Total Cost (Mean)
Mortality	55–1,000	68%
Morbidity:		
Chronic bronchitis	7	1%
Hospital admissions	6	1%
Emergency room visits/Outpatient hospital visits	15	2%
Restricted activity days (adults)	202	26%
Lower respiratory illness in children	20	3%
Respiratory symptoms (adults)	0	0%
Total costs of morbidity	250	32%
Total costs (mortality and morbidity)	305–1,250	100%

billion to 55 million NIO. The measure of the welfare cost of morbidity is often based on the willingness-to-pay (WTP) to avoid or reduce the risk of illness. It is often found to be several times higher than the cost of medical treatment and the value of time losses (Cropper and Oates 1992), and reflects the value that individuals place on avoiding pain and discomfort. However, there is an insufficient number of WTP studies from Central America. Thus, the Cost-of-Illness (COI) approach (mainly medical costs and value of time losses) has been applied to estimate morbidity (see Annex A).

Summary Assessment of Actions on Urban Air Pollution

Health effects of air pollution are a function of ambient air quality. Estimating the benefits of urban air pollution control therefore requires: (a) an emissions inventory, (b) a relationship between the inventory and ambient air quality, and (c) an estimate of emissions reductions from individual pollution control measures. Each of these three dimensions is complex, and estimates of the benefits and costs of control options therefore need to be accompanied by a careful sensitivity analysis of key parameters of the estimates. Because Nicaragua lacks an emissions inventory, it is difficult to conduct these related economic analyses.

At a general level, interventions to control primary and secondary particulate emissions from mobile sources can be broadly classified into: (a) market-based instruments, such as fuel pricing and taxation, vehicle taxation, and emission taxes; (b) vehicle technology standards and regulations, including in-fleet technology retrofitting, inspection and maintenance programs, as well as auto import regulations; (c) fuel quality improvements and fuel use regulations, such as low-sulfur diesel and conversion to compressed natural gas; and (d) traffic management and urban planning, including public transportation policies (Larsen 2005). Several of these measures may be potential options for the Government of Nicaragua to consider in light of worsening air quality in its cities.

Recommendations for Actions on Urban Air Pollution

Rapidly increasing urban populations and accompanying vehicle growth, coupled with inadequate regulations and monitoring, will impact the air quality in cities such as Managua unless appropriate actions are taken. The lack of adequate data on air quality in Nicaragua cities, and of subsequent analysis about the sources of urban pollution, constrain the analysis of potential interventions to address this issue.

An air quality indicator system should be established to monitor emissions in the main urban areas of Managua and León. Moreover, as part of improving the Nicaraguan air quality management system, a detailed and integrated emissions inventory for Managua and León should be developed. A World Bank analytical study (funded by TFESSD) is under way to carry out an emissions inventory for Managua and León. Results from this work will be very useful inputs to determine the specific kinds of interventions that can address urban air pollution.

V. Conclusions

Several key messages have emerged from the process of putting together this study and its results: (i) environmental health risks impose a significant burden on Nicaragua's economy, amounting to 2.6 billion NIO, or 2.4 percent of the country's GDP, and resulting in premature deaths and infections, especially in children under age five; (ii) cost-effective interventions to address these environmental health risks exist and should be prioritized in Nicaragua; (iii) country-specific health and environmental data are somewhat limited, especially in the case of air quality, and data collection and monitoring need to be further strengthened; and (iii) the capacity of MARENA and MINSA staff to carry out environmental health costing analyses needs to be strengthened through proper training.

Diarrheal and other waterborne diseases result from inadequate water, sanitation and hygiene in Nicaragua. The significant economic burden attributed to health costs from these diseases can be alleviated through various water, sanitation and hygiene interventions. For Nicaragua, water disinfection and hygiene programs are estimated to have the greatest potential health benefits, and it is recommended that the government invest in such programs, in both in rural and urban areas. However, infrastructure investments to expand access to water and sanitation are also extremely important, especially in rural Nicaragua, because they also provide significant non-health benefits (convenience, time-savings, etc.).

Interventions that aim to improve air quality through improved cookstoves, switching to cleaner fuels, and better ventilation can help reduce the incidence of respiratory diseases in Nicaragua, especially among women and young children. This analysis recommends that the GoN invest in improved cookstove programs, especially for the numerous rural households where unimproved stoves are currently being used. Switching to cleaner fuels (such as LPG) is also recommended; however, the GoN needs to review the relative costs of these fuels to ensure affordability.

Rapidly increasing urban populations and accompanying vehicle growth, coupled with inadequate regulations and monitoring, are continuing to impact the air quality in cities such as Managua. However, the lack of adequate data and the absence of

an emissions inventory make it difficult to identify the appropriate interventions for improving urban air quality in Nicaragua. The analysis endorses the ongoing work to carry out an emissions inventory for Managua and León, and recommends that the GoN take a more integrated approach to air quality management.

Finally, discussions with the GoN and other stakeholders have provided feedback about the usefulness of such analyses in helping to identify the appropriate interventions to address environmental health risks and contribute to a healthier Nicaragua. As part of this study, the Bank team helped to build capacity within MINSA and MARENA to carry out such environmental health costing work in future exercises. Apart from the ongoing analytical work on developing an emissions inventory, the GoN has also expressed interest in a study that would estimate health costs associated with dengue and identify appropriate environmental management solutions for Nicaragua.

Annex A.

Methodology for Health Cost Estimation

This annex provides technical details on the methodology used to estimate health impacts and subsequent costs associated with environmental health risks (urban air pollution, inadequate water supply and sanitation, and indoor air pollution).

Methodology: Urban Air Pollution

Particulate Matter Pollution

Research in the United States in the 1990s and most recently by Pope et al. (2002) provides strong evidence that it is even smaller particulates ($PM_{2.5}$) that have the greatest health effects. Gaseous pollutants (SO_2, NO_x, CO and ozone) are generally not thought to be as damaging as fine particulates. However, SO_2 and NOx may have important health consequences because they can react with other substances in the atmosphere to form particulates.

Dose Response Coefficients

In order to estimate health impacts, we have used work by Ostro (1994), Abbey et al. (1995) and Pope et al. (2002). Ostro and Abbey et al. used dose response coefficients to analyze morbidity effects and provide estimates of dose response of PM (PM_{10}) to chronic bronchitis. A survey of the current status of worldwide research shows that the risk ratios or dose-response coefficients by Pope et al. (2002) are likely to be the best available evidence of the mortality effects of ambient particulate pollution ($PM_{2.5}$). These coefficients were applied by WHO in the World Health Report 2002, which provided a global estimate of the health effects of environmental risk factors. The mortality and morbidity coefficients from the above studies are presented in Table A.1.

Table A.1: Urban Air Pollution Dose-Response Coefficients

Annual Health Effect	Dose-response Coefficient	Per 1 µg/m³ annual average ambient concentration of:
Mortality (% change in cardiopulmonary and lung cancer mortality)	0.8%	$PM_{2.5}$
Chronic bronchitis (% change in annual incidence)	0.9%	PM_{10}
Respiratory hospital admissions (per 100,000 population)	1.2	PM_{10}
Emergency room visits (per 100,000 population)	24	PM_{10}
Restricted activity days (per 100,000 adults)	5,750	PM_{10}
Lower respiratory illness in children (per 100,000 children)	169	PM_{10}
Respiratory symptoms (per 100,000 adults)	18,300	PM_{10}

Source: Pope et al. (2002) for the mortality coefficient. Ostro (1994) and Abbey et al. (1995) for the morbidity coefficients.

Pope et al. (2002) provide the most comprehensive and detailed research study to date on the relationship between air pollution and mortality. The study confirms and strengthens the evidence of the long-term mortality effects of particulate pollution found by Pope et al. (1995) and Dockery et al. (1993). Pope et al. (2002) used ambient air

quality data from metropolitan areas across the United States for 1979–1983 and 1999–2000, and information on certified causes of mortality of adults from the American Cancer Society (ACS) database over a period of 16 years. The ACS database has individual specific information for more than one million adults that was obtained through questionnaires. The study could therefore control for a large set of factors that may also affect variations in mortality rates across metropolitan areas, such as age, smoking behavior, education, marital status, body weight, occupational risk factors and dietary indexes.

The study found a statistically significant relationship between levels of $PM_{2.5}$ and mortality rates, controlling for all the factors discussed above. All-cause mortality was found to increase by 4–6 percent for every 10 μg/m^3 increase in $PM_{2.5}$. The increase in cardiopulmonary mortality was 6–9 percent, and 8–14 percent in lung cancer. No statistically significant relationship was found between levels of $PM_{2.5}$ and all other causes of mortality (see Table A.2).

The share of cardiopulmonary and lung cancer deaths in total mortality sometimes varies substantially across countries. Therefore, it may reasonably be expected that the risk ratios for cardiopulmonary and lung cancer mortality provide more reliable estimates of mortality from $PM_{2.5}$ than the risk ratio for all-cause mortality when the risk ratios are applied to countries other than the United States. The former two risk ratios are therefore used in this report. The mortality coefficient in Table A.1 is a combination of the cardiopulmonary and lung cancer mortality risk ratios in Table A.2.

In order to use the mortality coefficients in Table A.1 to estimate mortality from urban air pollution in Nicaraguan cities, baseline data on total annual cardiopulmonary and lung cancer deaths are required. Data from the Nicaraguan Ministry of Health, combined with WHO data by cause of deaths, were also used. Data from the above two sources showed an average rate of 30 percent of total deaths due to cardiopulmonary and lung cancer. To estimate the mortality effects, following the procedure used by the 202 World Health Report (WHO), a threshold level of 7.5 μg/m^3 of $PM_{2.5}$ has been applied, below which it is assumed there are no mortality effects. No threshold level has been applied for morbidity.

Table A.2: Mortality Risk Associated with a 10 μg/m^3 Change in $PM_{2.5}$

	Adjusted Relative Risk Ratios (RR)		
Cause of Mortality	**1979–1983**	**1999–2000**	**Average**
All-cause	1.04	1.06	1.06
Cardiopulmonary	1.06	1.08	1.09
Lung cancer	1.08	1.13	1.14
All other cause	1.01	1.01	1.01

Reproduced from Pope et al. (2002).

An estimate of annual incidence of chronic bronchitis (CB) is required in order to apply the CB coefficient in Table A.1. In the absence of data on CB incidence for Nicaragua, we have used the rate from WHO (2001) and Shibuya et al. (2001) for the AMRO D region of WHO, of which Nicaragua is a part. Therefore, it has not been possible to use city-specific CB incidence rates. Other morbidity

health end-points considered are hospital admissions of patients with respiratory problems, emergency room visits (or hospital outpatient visits), restricted activity days, lower respiratory infections in children, and respiratory symptoms. The coefficients are expressed as cases per 100,000 in the absence of incidence data for Nicaragua, though it would be preferable to have incidence data and use coefficients that reflect the percentage change in incidence. Increases in asthma attacks among asthmatics have also been related to air pollution in many studies. But these data are on the population subgroup that is asthmatic and the frequency of asthma attacks is not readily available for Nicaragua.

Table A.3: DALYs for Health Effects

Health Effect	DALYs lost per 10,000 cases
Mortality	75,000
Chronic bronchitis (adults)	22,000
Respiratory hospital admissions	160
Emergency room visits	45
Restricted activity days (adults)	3
Lower respiratory illness in children	65
Respiratory symptoms (adults)	0.75

Note: DALYs are calculated using a discount rate of 3 percent and full age weighting based on WHO tables. Estimates of DALYs for the morbidity end-points are from Larsen (2004a, b).

The health effects of air pollution are then converted to disability adjusted life years (DALYs) to facilitate a comparison to health effects from other environmental risk factors. DALYs per 10,000 cases of various health end-points are presented in Table A.3.

Table A.4 presents the disability weights and average duration of illness used in this report to calculate DALYs, as presented in Table A.5. The weights for lower respiratory illness (LRI) and chronic bronchitis (CB) are average disability weights.[17] Disability weights for the other morbidity end-points are not readily available, and are estimated by Larsen (2004a) based on weights for other comparable illnesses.[18] Average duration of CB is estimated based on age distribution in Nicaragua and age-specific CB incidence in Shibuya et al. (2001). Years lost to premature mortality from air pollution is estimated from age-specific mortality data for cardiopulmonary and lung cancer deaths, and have been discounted at three percent per year. Average duration of illness for the other health end-points is from Larsen (2004a).

Table A.4: Calculation of DALYs Per Case of Health Effects

	Disability Weight	Average Duration of Illness
Mortality	1.0	(7.5 years lost)
Lower respiratory Illness – children	0.28	10 days
Respiratory symptoms – adults	0.05	0.5 days
Restricted activity days – adults	0.1	1 day
Emergency room visits	0.30	5 days
Hospital admissions	0.40	14 days*
Chronic bronchitis	0.2	20 years

* Includes days of hospitalization and recovery period after hospitalization.

17 See: http://www.dcp2.org/pubs/GBD
18 The disability weight for mortality is 1.0.

Estimated Health Impacts

The total annual costs associated with the health effects described above were computed from the total cost per case (see Table A.5) and the number of estimated cases. For morbidity, the cost of illness alone has been estimated. In the case of respiratory symptoms, the estimated cost per occurrence is zero and hence the total annual estimated cost due to respiratory symptoms in Table A.5 is zero.

Table A.5: Estimated Unit Cost by Health End-point

Health categories	Cost-of-Illness Per Case (NIO)
Chronic bronchitis	13,060
Hospital admissions	4,800
Emergency room visits/ Outpatient hospital visits	560
Restricted activity days (adults)	330
Lower respiratory illness in children	45
Respiratory symptoms (adults)	0

The baseline data used to estimate the cost per case of illness is presented in Table A.6. The opportunity cost of time lost because of illness for adults is estimated based on urban wages. The average urban wage in Nicaragua is about 5,000 NIO per month.[19] In the case of both income-earning and non-income-earning individuals, 75 percent of the average urban wage rate has been imputed as the opportunity cost of time lost due to illness. In the case of non-income-earning individuals, the above rate is justified because most of these individuals provide a household function that has a value associated with it; equally, they could choose to join the paid labor force.

Overall, there is very little information about the frequency of doctor visits, emergency visits and hospitalization for CB patients in developing countries. However, Schulman et al. (2001) and Niederman et al. (1999) provide some information on frequency of doctor visits, emergency visits and hospitalization for CB patients in the United States and Europe.[20] In the absence of country-specific data, results from the above studies have been applied to Nicaragua. Lost workdays per year are estimated based on frequency of estimated medical treatment plus an additional seven days for each hospitalization and one extra day for each doctor visit and emergency visit. These days are added together to reflect the total time needed for recovery from illness.

To estimate the cost of a new case of CB, the medical cost and value of time losses have been discounted over a period of 20 years of illness. An annual real increase of two percent in medical cost and value of time lost has been applied to reflect an average expected increase in annual labor productivity and real wages. The costs are discounted at three percent per year, a rate commonly applied by WHO for health effects.

19 http://www.bcn.gob.ni/estadisticas/indicadores/3-4.htm
20 CB is a major component of COPD, which is the focus of the referenced studies.

Table A.6: Baseline Data for Estimation of Cost of Health Impact Due to Air Pollution

	Baseline	Source:
Cost Data for All Health End-Points:		
Cost of hospitalization (NIO per hospitalization)	500	Per consultations with medical service providers and health authorities
Cost of emergency visit (NIO) – urban	200	
Cost of doctor visit (NIO) (mainly private doctors) – urban	150	
Value of time lost to illness (NIO per day)	180	75% of urban wages in Nicaragua
Chronic Bronchitis (CB):		
Average duration of Illness (years)	20	Based on Shibuya et al. (2001)
% of CB patients being hospitalized per year	1.5%	From Schulman et al. (2001) and Niederman et al. (1999)
Average length of hospitalization (days)	10	
Average number of doctor visits per CB patient per year	1	
% of CB patients with an emergency doctor/hospital outpatient visit per year	15%	
Estimated lost work days (including household work days) per year per CB patient	2.6	Estimated based on frequency of doctor visits, emergency visits, and hospitalization
Annual real increases in economic cost of health services and value of time (real wages)	2%	Estimate
Annual discount rate	3%	Applied by WHO for health effects
Hospital Admissions:		
Average length of hospitalization (days)	6	Estimates
Average number of days lost to illness (after hospitalization)	4	
Emergency Room Visits:		
Average number of days lost to illness	2	
Restricted Activity Days:		
Average number of days of illness (per 10 cases)	2.5	
Lower Respiratory Illness in Children:		
Number of doctor visits	1	
Total time of caregiving by adult (days)	1	Estimated at 1–2 hours per day

Methodology: Inadequate Water Supply, Sanitation and Hygiene

Inadequate water supply, sanitation and hygiene result in a variety of diseases, such as diarrhea, that result in deaths (predominantly in children under age five) as well as illness. Esrey et al. (1991) provide a comprehensive review of studies documenting this relationship for diseases such as schistosomiasis (bilharzia), intestinal worms, diarrhea, etc. Fewtrell and Colford (2004) provide a meta-analysis of studies of water supply, sanitation and hygiene that updates the findings on diarrheal illness by Esrey et al. (1991). Water, sanitation and hygiene factors also influence child mortality. Esrey et al. (1991) find in their review of studies that the median reduction in child mortality from improved water and sanitation is 55 percent. Shi (1999) provides econometric estimates of the impact of potable water and sewerage connection on child mortality, using a data set for about 90 cities around the world. Literacy and education level are also found to be important determinants of parental protection of child health against environmental risk factors. Esrey and Habicht (1988) report from a study in Malaysia that maternal literacy reduces child mortality by about 50 percent in the absence of adequate sanitation, but only by 5 percent in the presence of good sanitation facilities.

Literacy is also found to reduce child mortality by 40 percent if piped water is present, suggesting that literate mothers are better at taking advantage of water availability for hygiene purposes to protect child health. Findings from the Demographic and Health Surveys from various developing countries further confirm the role of literacy in child mortality reduction. Rutstein (2000) provides a multivariate regression analysis of infant and child mortality in developing countries, using Demographic and Health Survey data from 56 countries from 1986 to 1998. The study finds a significant relationship among infant and child mortality rates and piped water supply, flush toilet, maternal education, access to electricity, medical services, oral rehydration therapy (ORT), vaccination, dirt floor in household dwelling, fertility rates and malnutrition. Similarly, Larsen (2003) provides a regression analysis of child mortality, using national data for year 2000 from 84 developing countries representing 95 percent of the total population in the developing world. A statistically significant relationship between child mortality and access to improved water supply, safe sanitation, and female literacy is confirmed.

Baseline health data for estimating the health impacts of inadequate water supply, sanitation and hygiene are presented in Table A.7. WHO estimates that 12 percent of child mortality was due to diarrhea in 2006. This is used for diarrheal mortality estimation. In the case of diarrheal morbidity, it is very difficult or practically impossible to identify all cases of diarrhea because a substantial share of cases are not treated or do not require treatment at health facilities, and therefore are never recorded. Furthermore, those cases that are treated by private doctors or clinics are often not reported to public health authorities. Therefore, household surveys provide the most reliable indicator of total cases of diarrheal illness. At the same time, the surveys only reflect diarrheal prevalence at the time of the survey. Because there is often high variation in diarrheal prevalence across seasons of the year, extrapolation to an annual average will result in either an over- or underestimate of total annual cases; correcting this bias is often difficult without knowledge of seasonal variations.

ENDESA 2006–2007 provides data on diarrheal prevalence (preceding two weeks) in children under age five, at rates of 13.2 percent in urban areas and 17.6 percent in rural areas. This rate is used to estimate the number of annual cases per child under age five, and then the total annual cases in all children under five. The procedure applied is to

multiply the two-week prevalence rate by 52/2.5 to arrive at an approximation of the number of annual cases per child. The prevalence rate is not multiplied by 26 two-week periods (i.e., 52/2), but multiplied by 52/2.5 for the following reason: the average duration of diarrheal illness is assumed to be three to four days. This implies that the two-week prevalence captures a quarter of the diarrheal prevalence in the week prior to and a quarter in the week after the two-week prevalence period.

Table A.7: Baseline Data on Health

	Urban	Rural	Source:
Under-age-5 child mortality rate in 2006 (per 1000 live births)	31	40	ENDESA 2006–2007
Diarrheal 2-week prevalence in children under age 5	13.2%	17.6%	ENDESA 2006–2007
Estimated annual diarrheal cases per child under age 5	2.8	3.7	Estimated from ENDESA 2006–2007
Estimated annual diarrheal cases per person (> age 5)	0.3	0.3	Estimated from EMNV 2005 and Fewtrell et al. 2007
% of diarrheal cases attributable to inadequate water supply, sanitation and hygiene	87%	88%	Estimated from Fewtrell et al. 2007

Since ENDESA does not provide information on diarrheal illness in the population above age five, estimations from another survey (EMNV 2005)[21] and approximations from Fewtrell et al. 2007 were used. The survey provides data on the prevalence of diarrhea by age during last 30 days.

Diarrheal illness sometimes requires hospitalization. However, there are no available centralized records in Nicaragua that provide data on the annual number of diarrheal hospitalizations. Thus, the number of hospital admissions due to diarrhea was estimated using information on hospitalization rates provided in Baschieri and Falkingham (2007). A hospitalization rate of 0.5 percent was applied to all cases of diarrhea estimated from ENDESA 2006–2007 to equal the figure on total number of hospitalizations due to diarrheal diseases.

The burden of disease methodology is used to estimate the number of DALYs lost because of inadequate water supply, sanitation and hygiene (see Table A.8). The disability weight for diarrheal morbidity is 0.119 for children under age five and 0.086 for the rest of the population, and the duration of illness is assumed to be the same (i.e., three to four days). However, the DALYs per 100,000 cases of diarrheal illness are much higher for the population over age five. This is because DALY calculations involve age weighting that attaches a low weight to young children and a higher weight to adults, corresponding to physical and mental development stages.[22] For diarrheal child mortality, the number of DALYs lost is 34. This reflects an annual discount rate of three percent of life years lost.

21 EMNV 2005 estimates are somewhat higher than those in other LAC countries for populations over age five. We applied these estimates in this report. This explains relatively lower health losses in Nicaragua associated with inadequate WSSH than in other LAC countries.

22 It should be noted that some researchers elect not to use age weighting, or report DALYs with and without age weighting.

Table A.8: Calculation of DALYs Per Case of Health Effects

	Urban	Rural	Source:
DALYs per 100,000 cases of diarrhea in children under age 5	40	40	Estimated from WHO tables using age weighting and an average duration of illness of 4 days, and age weighting and 3% discount rate for mortality
DALYs per 100,000 cases of diarrhea in persons > age 5	130	130	
DALYs per case of diarrheal mortality in children under age 5	34	34	

Baseline data used for the estimation of the cost of morbidity are presented in Table A.9. The percentage of diarrheal cases in the population older than five years treated at medical facilities is estimated from the percentage of treated cases among children (ENDESA 2006–2007) and adults (EMNV 2005). The cost of medical services reflects the cost of estimated private health care (WHO-CHOICE) and is a better indication of the economic cost of health services than public services, which are subsidized in Nicaragua.

Table A.9: Baseline Data for Estimating Health Effects Due to Lack of Improved Water Sanitation and Hygiene

	Urban	Rural	Source:
% of diarrheal cases treated at medical facilities (children < 5 years)	46%	41%	ENDESA 2006–2007
% of diarrheal cases treated with ORS (children < 5 years)	97%	95%	ENDESA 2006–2007
% of diarrheal cases (children < 5 years) treated with use of pharmacy	46%	41%	ENDESA 2006–2007
% of diarrheal cases treated at medical facilities (population > 5 years) and with medicines	45%	40%	Estimated from EMNV 2005
Average cost of health services (NIO per visit)	150	130	Per consultations with pharmacies, medical service providers and health authorities
Average cost of medicines for treatment of diarrhea (NIO)	70	70	
Average cost of ORS per diarrheal case in children (NIO)	10	10	
Average duration of diarrheal illness in days (children and adults)	4	4	Assumption
Hours per day of caregiving per case of diarrhea in children	2	2	Assumption
Hours per day lost to illness per case of diarrhea in adults	2	2	Assumption
Value of time for adults (caregiving and ill adults) NIO/hour	20	10	75% of urban and rural wages in Nicaragua
% of diarrheal cases attributable to inadequate water, sanitation and hygiene	87%	88%	Estimated from Fewtrell et al. 2007

The value of time lost for adults is imputed based on urban and rural wages. The analysis used 75 percent of urban and rural wages in Nicaragua as the imputed value for both income-earning and non-income-earning adults. It may be noted here that non-income-earning adults are engaged in a household function that has value and they also have an opportunity to join the paid labor force.[23]

Methodology: Indoor Air Pollution

There are two main steps in quantifying the health effects of indoor air pollution. The first step is to estimate the number of people or households exposed to pollution from solid fuels, and to measure the extent of pollution, or concentration. The second step is to quantify the health impacts from the exposure based on epidemiological assessments. Once the health impacts are quantified, the value of this damage can be estimated.

Data from ENDESA 2006–2007 on household use of fuels for cooking is used for this estimation. According to this survey, about 38 percent of urban and 92 percent of rural households used fuelwood for cooking in 2006–2007 in Nicaragua.

Desai et al. (2004) provide a review of research studies around the world that have assessed the magnitude of health effects of indoor air pollution from solid fuels. The odds ratios for ARI and COPD are presented in Table A.11. The odds ratios represent the risk of illness for those who are exposed to indoor air pollution, compared to the risk for those who are not exposed. The exact odds ratio depends on several factors such as concentration level of pollution in the indoor environment and the amount of time individuals are exposed to the pollution. A range of "low" to "high" ratios is presented in Table A.11, which reflects the review by Desai et al. (2004).

Studies around the world have also found linkages between indoor air pollution from traditional fuels and increased prevalence of tuberculosis and asthma. It is also likely that indoor air pollution from such fuels can cause an increase in ischemic heart disease and other cardiopulmonary disorders. As discussed in the methodology for urban air pollution, Pope et al. (2002) and others have found that the largest effect of urban fine particulate pollution on mortality is for the cardiopulmonary disease group. Because indoor smoke from traditional fuels is high in fine particulates, the effect on these diseases might be substantial. However, more research is required in order to draw a definite conclusion about the linkage and magnitude of effect.

The odds ratios in Table A.11 have been applied to young children under the age of five (for ARI) and adult females (for ARI and COPD) to estimate the increase in mortality and morbidity associated with indoor air pollution.[24] It is these population groups who suffer the most from indoor air pollution. This is because they spend much more of their time at home, and/or more time cooking than older children and adult males.

To estimate the health effects of indoor air pollution from the odds ratios in Table A.11, baseline data for ARI and COPD need to be established (see Table A.12). Data on COPD mortality and especially on the incidence of morbidity, according to international disease classifications, are not readily available for Nicaragua. Regional estimates from WHO (2001) and Shibuya et al. (2001) for the AMRO D region are therefore used.[25]

23 Some may argue that the value of time based on wage rates should be adjusted by the unemployment rate to reflect the probability of obtaining paid work.

24 Although Desai et al. (2004) present odds ratios for lung cancer. This effect of pollution is not estimated in this report because the incidence of lung cancer among rural women is generally very low. The number of cases in rural Nicaragua associated with indoor air pollution is therefore likely to be minimal.

25 Nicaragua belongs to the AMRO-D region of WHO.

Table A.11: Health Risks of Indoor Air Pollution

	Odds Ratios (OR)	
	"Low"	"High"
Acute respiratory illness (ARI)a	1.9	2.7
Chronic obstructive pulmonary disease (COPD)	2.3	4.8

Source: Desai et al. (2004).

The national average of the two-week prevalence rate of ARI in children under age five reported in ENDESA 2006–2007 was used to estimate total annual cases of ARI in children under age five. The procedure applied is to multiply the two-week prevalence rate by 52/3 to arrive at an approximation of the annual cases of ARI per child.[26] The EMNV 2005 provides information on ARI prevalence in the last month by age in adults. ARI mortality in children under age five is 14 percent of total estimated child mortality (WHO 2006).

Estimated Health Impacts

Annual new cases of ARI and COPD morbidity and mortality (D_i) from fuelwood smoke were estimated from the following equation:

$$D_i = PAR * D_i^B \quad ; \quad (A.1)$$

where D_i^B is baseline cases of illness or mortality, i (estimated from the baseline data in Table A.12), and PAR is given by:

$$PAR = PP*(OR-1)/(PP*(OR-1)+1) \quad (A.2)$$

where PP is the percentage of population exposed

Table A.12: Baseline Data for Estimating Health Impacts of Indoor Air Pollution

	Urban	Rural	Source
Female COPD mortality rate (% of total female deaths)	1.4–2.1%	1.4–2.1%	WHO GBD (2004) and Shibuya et al. (2001)
Female COPD incidence rate (per 100,000)	94	94	
ARI 2-week prevalence in children	28%	30%	ENDESA 2006–2007
Estimated annual cases of ARI per child under age 5	4.9	5.2	Estimated from ENDESA 2006–2007
Estimated annual cases of ARI per adult female (> 30 years)	1.7	2.6	Estimated from EMNV 2005
ARI mortality in children under age five (% of child mortality)	14%	14%	WHO 2006

26 A factor of 52/3 is applied for the following reason: the average duration of ARI is assumed to be about seven days. This implies that the two-week prevalence captures half of the ARI prevalence in the week prior to and the week after the two-week prevalence period.

Table A.13: Calculation of DALYs per Case of Health Effects From Indoor Air Pollution

	Baseline		*Source*
	Urban	Rural	
DALYs per 100,000 cases of ARI in children under 5	165	165	Estimated from WHO tables
DALYs per 100,000 cases of ARI in female adults (>30)	700	700	
DALYs per case of ARI mortality in children under 5	34	34	
DALYs per case of COPD morbidity in adult females	2.25	2.25	
DALYs per case of COPD mortality in adult females	6.8	6.8	

to fuelwood smoke (38 percent of urban and 92 percent of rural households according to ENDESA 2006–2007), and OR is the odds ratios (or relative risk ratios) presented in Table A.11.

The methodology described above is used to estimate the number of DALYs lost associated with cases of ARI and COPD attributed to indoor air pollution. The disability weight for ARI morbidity is the same for children and adults (0.28), and the duration of illness is also assumed to be the same (seven days). However, the DALYs per 100,000 cases of ARI are much higher for adults. This is because DALY calculations involve age weighting that attaches a low weight to young children, and a higher weight to adults that corresponds to physical and mental development stages.[27] For ARI child mortality, the number of DALYs lost is 34. This reflects an annual discount rate of three percent of life years lost.

DALYs lost per case of COPD morbidity and mortality are based on life tables and age-specific incidence of the onset of COPD reported by Shibuya et al. (2001) for the AMRO-D region. A disability weight of 0.2 has been applied to COPD morbidity.[28] A discount rate of three percent is applied to both COPD morbidity and mortality.

Estimating Costs

Treatment costs are estimated based on costs of health care services offered by the private sector, because these are likely to better reflect the true economic costs. The percentage of ARI cases in the age group older than five years treated at medical facilities is estimated from EMNV (2005).

The time lost in the case of adults is valued at 75 percent of average hourly wages. There is very little information about the frequency of doctor visits, emergency visits and hospitalization for COPD patients in developing countries. Since such data are not available for Nicaragua, data derived from Schulman et al. (2001) and Niederman et al. (1999) on the United States and Europe are used in this analysis. The lost workdays per year are estimated based on the frequency of estimated medical treatment, an additional seven days for each hospitalization and one extra day for each doctor visit and emergency visit. These days are added to reflect time needed for recovery from illness.

To estimate the cost of a new case of COPD, the medical cost and value of time losses are discounted over a 20-year duration of illness. An annual real increase of two percent in medical costs and value of time has been applied to reflect an average expected increase in annual labor produc-

27 It should be noted that some researchers elect not to use age weighting, or report DALYs with and without age weighting.
28 See: http://www.dcp2.org/pubs/GBD

Table A.14: Baseline Data for Estimation of Costs of Health Impacts From Indoor Air Pollution

	Rural	Urban	*Source*
% of ARI cases treated at medical facilities (children < 5 years)	60%	68%	ENDESA 2006–2007
%age of cases with use of pharmacy (children < 5 years)	60%	68%	ENDESA 2006–2007
Cost of medicines for treatment of acute respiratory illness (population < 5 years) (NIO)	70	70	Per consultations with pharmacies
% of ARI cases treated at medical facilities (females > 30 years)	30%	30%	EMNV (2005)
% of COPD patients being hospitalized per year	1.5	1.5	Assumption based on Schulman et al. (2001) and Niederman et al. (1999)
% of COPD patients with an emergency doctor/hospital outpatient visits per year	15	15	
Avg. number of doctor visits per COPD patient per year	1	1	
Estimated lost workdays (including household work days) per year per COPD patient	2.6	2.6	Estimated based on freq. of doctor visits, emergency visits and hospitalization
Cost of doctor visit (NIO per visit)	150	130	Per consultations with pharmacies, medical service providers and health authorities
Cost of hospitalization (NIO per day)	500	500	
Cost of emergency visit (NIO per visit)	200	200[29]	
Average duration of ARI in days (children and adults)	7	7	Assumption
Hours per day of caregiving per case of ARI in children	2	2	Assumption
Hours per day lost to illness per case of ARI in adults	3	3	Assumption
Value of time for adults (caregiving and ill adults) – NIO/ hour	10	20	75% of wages in Nicaragua
Average length of hospitalization for COPD (days)	10	10	Larsen (2004b)

tivity and real wages. The costs are then discounted at three percent per year, a rate commonly used by WHO for health effects.

Baseline data used to estimate the cost of morbidity are presented in Table A.14. The treatment costs are based on costs of private sector health care services, because these are likely to better reflect economic cost. Cost of mortality is discussed below. The percentage of ARI cases in the age group older than five years, treated at medical facilities, is estimated using EMNV (2005). The time lost due to illness in the case of adults is valued at 75 percent of the average hourly wage for urban and rural workers. The rationale for this valuation of time is discussed in the previous sections.

Methodology: Valuation of Mortality

Two distinct methods of valuation of mortality are commonly used to estimate the social cost of premature death: the Human Capital Approach (HCA) and the Value of Statistical Life (VSL). Although both approaches are being used, the VSL approach has

29 These costs include charges for a bed and costs of medicines including what the government incurs for these services

been more commonly used in the last few decades. In this report, the HCA has been applied as a lower bound and the VSL approach as the higher bound in estimating the cost of adult mortality. However, the HCA has been used in the case of child mortality.

Human Capital Approach

The HCA is based on the economic contribution of an individual to society over the lifetime of the individual, and death results in an economic loss that is approximated by the loss of all future income of the individual. Future income is discounted to reflect its value at the time of death. The discount rate commonly applied is the rate of time preference. Thus the social cost of mortality, according to the HCA, is the discounted future income of an individual at the time of death. If the risk of death, or mortality risk, is evenly distributed across income groups, average expected future income is applied to calculate the social cost of death. Mathematically, the present value of future income is expressed as follows:

$$PV_0(I) = \sum_{i=k}^{i=n} I_0(1+g)^i/(1+r)^i \qquad \text{(A.3)}$$

where PV_0 (I) is present value of future income (I) in year 0 (year of death), g is annual growth in real income, and r is the discount rate (rate of time preference). As can be seen from (1), the equation allows for income to start from year k, ending in year n. In the case of children, we may have i {20, 65}, assuming the lifetime income on average starts at age 20 and ends at retirement at age 65. An annual growth of real income and the discount rate used in this study are two percent and three percent, respectively.

Two important issues are often raised with respect to the application of the HCA. The first issue relates to the application of this valuation approach to individuals who do not participate in economic activities, i.e., to individuals such as the elderly, family members taking care of the home, and children who do not earn an income. One may think of an extension of the HCA that recognizes the value of non-paid household work at the same rate as the average income earner, or at a rate equal to the cost of hiring a household helper. In this case, the HCA can be applied to the death of non-income earners and children (whether or not children will become income earners or take care of the home during their adult life). In the case of the elderly, the HCA would not assign an economic value to older individuals who have either retired from the workforce or do not make significant contributions to household work. This obviously is a serious shortcoming of the HCA approach.

The second issue regarding the HCA is that the social cost of mortality is limited to the economic contribution of an individual or the value of household work if the individual takes care of the home. Alter-

Table A.15: Cost of Mortality (per death) Using HCA

	Average Number of Years Lost	Thousand NIO
Adults:		
Mortality from urban air pollution	7	132
Mortality from indoor air pollution	6.8	128
Children:		
Mortality from indoor air pollution	65	580
Mortality from diarrheal illness	65	580

native approaches (such as the value of statistical life) to the valuation of mortality, or social cost of mortality, have therefore been developed and have increasingly been applied in the past few decades.

The estimated cost of mortality in Nicaragua based on HCA, using Eq. A.3, is presented in Table A.15. Average annual income is approximated by GDP per capita, at about 18,800 NIO per year.

Value of Statistical Life (VSL)

While the HCA involves valuation of the death of an individual, the VSL is based on valuation of mortality risk. Everyone in society is constantly facing a certain risk of dying. Examples of such risks are occupational fatality risk, risk of traffic accident fatality, and environmental mortality risks. It has been observed that individuals adjust their behavior and decisions in response to such risks. For instance, individuals demand a higher wage (a wage premium) for a job that involves a higher-than-average occupational risk of fatal accident, individuals may purchase safety equipment to reduce the risk of death, and/or individuals and families may be willing to pay a premium or higher rent for properties (land and buildings) in a cleaner and less polluted neighborhood or city.

Therefore, by observing individuals' choices and willingness to pay for reducing mortality risk (or minimum amounts that individuals require to accept a higher mortality risk), it is possible to measure or estimate the value to society of reducing mortality risk, or, equivalently, to measure the social cost of a particular mortality risk. For example, if a certain health hazard has a mortality risk of 1/10,000, i.e., one individual (on average) for every 10,000 individuals dies every year from that particular health hazard. If each individual on average is willing to pay 10 NIO per year for eliminating this mortality risk, then every 10,000 individuals are collectively willing to pay 100,000 NIO per year for eliminating the mortality risk. This is the VSL for eliminating the mortality risk. Mathematically it can be expressed as:

$$VSL = WTP_{Ave} * 1/ R \qquad (A.4)$$

where WTP_{Ave} is the average willingness to pay (NIO per year) per individual for reducing the mortality risk of magnitude R. In the example above, R=1/10.000 (or R=0.0001) and WTP_{Ave}= 10 NIO. Thus, if 10 individuals die each year from the health risk illustrated above, the cost to society is 10* VSL = 10*100,000 NIO = 1 million NIO.

Estimating VSL

The main two approaches used to estimate the VSL are the revealed preference and stated preference analyses. Most of the studies that use revealed preferences are hedonic wage studies, which estimate labor market wage differentials associated with differences in occupational mortality risk. The stated preference studies use contingent valuation methods (CVM), which estimate individuals' willingness to pay for mortality risk reduction.

Mrozek and Taylor (2002) provide a meta-analysis of VSL estimates from labor market studies from around the world. They identify a "best-practice" sample and control for industry characteristics other than occupational mortality risk that also affects inter-industry wage differentials. The study concludes that a lower estimate of US$2 million for VSL can be reasonably inferred from labor market studies when "best practice" assumptions are used. However, it should be noted that the VSL range inferred by Mrozek and Taylor (2002) is substantially lower than average VSL estimated in some other meta-analyses where the mean VSL is as high as US$6 million. As a higher bound for VSL, a mean estimate of VSL meta- analysis of US$5.4 million was applied. The latest meta-analysis of VSL estimates is by Kochi et al. (2006) and uses the empirical Bayes pooling method to combine and compare estimates of VSL data from 40 se-

lected studies published between 1974 and 2002, containing 197 VSL estimates.

Benefit Transfer

No studies on VSL have been undertaken in Nicaragua; the overwhelming majority of VSL studies have been conducted in countries with substantially higher income levels. Hence, the VSL estimates from these countries must be adjusted through a benefit transfer to suit the conditions in Nicaragua. One commonly used approach in benefit transfer is to use income elasticities.[30] Viscusi and Aldi (2002) estimate an income elasticity of VSL in the range of 0.5 to 0.6 from a large sample of VSL studies. However, the range in income elasticity is influenced by three unusually high estimates of VSL from labor market data in one state in India. Leaving out these three studies provides an income elasticity of about 0.80.

However, the most appropriate income elasticity to use for low-income countries such as Nicaragua remains uncertain because the income level in Nicaragua falls far outside the range of income in the sample of countries from which the income elasticities of VSL are estimated in the empirical literature. A prudent approach might be to apply an elasticity of 1.0 in order to reduce the risk of overstating the cost of mortality in Nicaragua.

Table A.16 presents the VSL for Nicaragua from benefit transfer based on the range of VSL reported by Mrozek and Taylor (2002) as the lower bound, and that reported by Kochi et al. (2006) as the upper bound, and an income elasticity of 1.0. These figures are substantially higher than the ones from the HCA, especially for adult mortality due to urban air pollution and indoor air pollution. A comparison is presented in Table A.17.

Table A.16: Estimated Value of Statistical Life in Nicaragua

	"High"	"Low"	*Source:*
Average VSL in high-income countries (US$ million)	5.4	2	Kochi et al. (2006), Mrozek and Taylor (2002)
Average GDP/capita in high-income countries (US$)	30 000	30 000	World Bank*
GDP per capita in Nicaragua (US$ in 2007)	1020	1020	WDI 2009
Income elasticity	1.0	1.0	
Estimated VSL in Nicaragua (million NIO)	3.39	1.26	Benefit transfer

* Weighted average GDP per capita, based on the sample in Mrozek and Taylor (2002).

Table A.17: A Comparison of HCA and VSL Estimates Applied to Nicaragua

	Ratio of VSL/HCA
Adult mortality	18
Children mortality	4

30 The income elasticity is the percentage change in VSL per percentage change in income.

Annex B.

Methodology for Cost-Benefit Analysis

I. Introduction

The objective of this report is to provide estimates of benefits and costs of water-sanitation-hygiene improvements and control of indoor air pollution from solid fuels.

A full range of potential interventions could conceptually be evaluated in terms of their benefits and costs to society. However, data and resource limitations constrain the level of detail and the number of interventions that can be evaluated practically in a relatively short period of time. Interventions evaluated in this report are therefore confined to a relatively small number of interventions, and are aggregated to a level that reflects the limited data, time and resource availability for the study. Nevertheless, it is hoped that the interventions evaluated in this report by and large are consistent with interventions that are generally believed to be the most effective in improving environmental conditions. The report can also be utilized for further assessment of the effectiveness, benefits and costs of interventions at local levels in the areas of inadequate water supply, sanitation and hygiene, and indoor air pollution that produce the major relative health damage associated with environmental factors in Nicaragua.

Environmental cost-benefit analysis (CBA), the primary focus of this report, is extensively used in environmental policy, for example in the United States. It has also been undertaken in developing countries, but most often for a particular environmental issue. In contrast, this report provides an opportunity to compare benefits and costs of interventions that span several environmental issues or categories. However, it should be recognized that the estimated benefits and costs represent orders of magnitude and gross averages at the national level. They should therefore be subject to sensitivity analysis and can undoubtedly be improved by more extensive data collection and in-depth analysis.

II. Water, Sanitation and Hygiene

This section presents the damage cost of inadequate water supply, sanitation and hygiene and provides estimates of the benefits and costs of interventions to reduce this damage cost.

Effectiveness of Improved Water, Sanitation and Hygiene

In a seminal review of international studies, Esrey et al. (1991) reported mean estimates of reductions in diarrheal illness around the world from improvements in water supply, sanitation and household hygiene practices. Since then, Curtis and Cairncross (2003) presented results from a meta-analysis of studies that have investigated reductions in diarrheal illness from hand washing. In 2004, Fewtrell and Colford provided a systematic review and meta-analysis of water, sanitation and hygiene interventions on diarrheal illness.

The main results of Fewtrell and Colford (2004) are presented in Table B.1 for developing countries. The relative risk ratio (RR) is in relation to a non-intervention situation. The percentage reduction in diarrheal illness from intervention is therefore 1.0-RR. The relative risk ratio for hand-washing intervention in Table B.1 is very similar to the results from the meta-analysis by Curtis and Cairncross (2003).

The single most effective hygiene intervention is hand washing after defecation, before preparing meals, and before eating. This intervention is therefore reported in Table B.1. Improved sanitation refers to facilities for safe and hygienic removal of excreta, such as flush toilets, pour-flush latrines, ventilated improved pit latrines (VIP) and simple pit latrines. Unimproved sanitation includes open pit latrines, public latrines, service or bucket latrines, and the absence of any facilities. Improved water supply refers to house connections, standpipes, boreholes, protected wells or springs, and collected rain water. Unimproved water supply includes unprotected wells or springs, open surface water and rivers, and water provided by vendor or tanker trucks. In terms of water quality improvement, the studies reviewed by Fewtrell and Colford that have assessed the reduction in diarrheal illness from source water treatment are not very conclusive. The pooled study results suggest a mean reduction in diarrheal incidence of 10 percent, but with no statistical significance. In contrast, point-of-use drinking water treatment (i.e., household drinking water treatment) seems very effective in reducing diarrheal illness. Point-of-use treatment refers to non-chemical (e.g., boiling of water) and chemical treatment (e.g., chlorination) and seems to be most effective in rural areas.

Table B.1: Summary of Meta-Analysis by Fewtrell and Colford (2004)

Intervention	Relative Risk (RR)	Confidence Interval (95%)
Improved hygiene (hand washing)	0.556	0.334–0.925
Improved sanitation	0.678	0.529–0.868
Improved water supply	0.749	0.618–0.907
Water quality improvement (source treatment)	0.891	0.418–1.899
Water quality improvement (point-of-use treatment; rural)	0.534	0.392–0.727
Water quality improvement (point-of-use treatment; urban)	0.771	0.725–0.819
Water quality improvement (point-of-use chemical treatment)	0.605	0.443–0.828
Water quality improvement (point-of-use non-chemical treatment)	0.534	0.379–0.752

Note: Summarized from Table 22 in Fewtrell and Colford (2004).

To evaluate the benefits and costs of the interventions in Table B.1, it is important to distinguish between interventions that involve changes in household behavior and interventions that involve infrastructure or hardware improvements. Interventions that involve changes in household behavior are improved hygiene and water treatment at point-of-use. While public authorities can promote these behaviors, actual changes in behavior is beyond their control. It is therefore important to explicitly account for this behavioral component in a benefit-cost analysis. With regard to infrastructure or hardware (water supply and sanitation facilities), improvements are predominantly functions of provision and are likely to be utilized by households if design and service delivery reflect demand and provide convenience. Uncertainties regarding behavioral change in relation to water supply and sanitation therefore tend to be less important in a benefit-cost analysis than for hygiene improvement and point-of-use treatment of drinking water.

A Benefit-Cost Analysis Framework

Prüss et al. (2002) provided a framework for estimating the burden of disease from water, sanitation and hygiene. This is presented in Table B.2. Prüss et al. applied this framework to estimate the global burden of diarrheal disease, but it can also be applied conveniently to estimate the benefits and costs of improved water supply and sanitation.

According to the Global Burden of Disease 2002 (WHO), diarrheal incidence (cases per person per year) in most developing regions of the world is three to five times higher than in North America and high-income countries in Europe, and as much as six times higher in Sub-Saharan Africa. These figures are relatively consistent with Table B.2 and suggest that most developing countries are somewhere in the range of Scenario 4 to Scenario 6. These figures represent averages, and it should be made clear that there are larger variations within each developing country, with some parts of the population being closer to Scenario II.

Prüss et al. derived the relative risks of diarrheal illness from international literature (Table B.3).

Table B.2: Selected Exposure Scenarios

Scenario/ Situation	Description	Pathogen Load	Relative Risk (RR)
VI	NO IMPROVED WATER SUPPLY AND NO BASIC SANITATION in a country that is not extensively covered by those services, and where water supply is not routinely controlled	Very High	11.0
Vb	IMPROVED WATER SUPPLY and no basic sanitation in a country that is not extensively covered by those services, and where water supply is not routinely controlled	Very High	8.7
Va	BASIC SANITATION but no improved water supply in a country that is not extensively covered by those services, and where water supply is not routinely controlled	High	6.9
IV	IMPROVED WATER SUPPLY AND BASIC SANITATION in a country that is not extensively covered by those services, and where water supply is not routinely controlled	High	6.9
IIIc	IV and improved access to drinking water (generally piped to household)	High	-
IIIb	IV and improved personal hygiene	High	4.5
IIIa	IV and drinking water disinfected at point of use	High	3.8
II	Regulated water supply and full sanitation coverage, with partial treatment for sewage, corresponding to a situation typically found in developed countries	Medium to Low	2.5
I	Ideal situation, corresponding to the absence of transmission of diarrheal disease through water, sanitation, and hygiene	Low	1.0

Based on Prüss et al. 2002.

Prüss et al. derived the relative risks of diarrheal illness from international literature (Table B.3).

Table B.3: Reductions in Diarrheal Illness Used by Prüss et al.

Scenario Progression		Reduction in Diarrheal Illness	Source
From VI to Vb	Providing improved water supply	20.8%	Esrey (1996)
From VI to Va	Providing basic sanitation facilities	37.5%	Esrey (1996)
From VI to IV	Providing improved water supply and basic sanitation facilities	37.5%	Esrey (1996)
From IV to IIIb	Improved personal hygiene	35%	Huttly et al. (1997)
From IV to IIIa	Disinfection of drinking water at point of use	45%	Quick et al. (1999)
From IV to II	Regulated water supply and full sanitation coverage, with partial treatment of sewage	65%	Combined results from Huttly et al. (1997) and Quick et al. (1999)
From II to I	Absence of transmission of diarrheal disease through water, sanitation and hygiene	60%	Using results from Mead et al. (1999)

Benefit-Cost Analysis of Water and Sanitation Improvements

The framework by Prüss et al. (2002) is applied in this report to estimate the benefits and costs of interventions to reduce diarrheal illness and diarrheal mortality in Nicaragua. The relative risks in Table B.2, or reductions in diarrheal illness in Table B.3, are modified to reflect the more recent findings of relative risks in the meta-analysis study by Fewtrell and Colford (2004), and the meta-analysis study of hand washing by Curtis and Cairncross (2003).

The first modification to the framework presented by Prüss et al. is to distinguish between households that disinfect their drinking water at point of use and those households that do not disinfect their drinking water. This distinction is made for each of the scenarios from III to VI. The second modification is to distinguish between households with piped water supply that is treated at source (water treatment plant) and those with piped water that is not treated at source. Scenario IIId is therefore added in Table B.4.

To allow for a comparison to Table B.2, the relative risk for Scenario VI without point-of-use disinfection is also 11.0 in Table B.4. The relative risks in Vb and Va is derived by multiplying the relative risk in VI by the relevant relative risk ratios in Table B.1. As in Prüss et al., there is no difference between Va and IV. The difference between IV and IIId is a relative risk ratio of 0.9, reported in Fewtrell and Colford (2004) for household water supply connection. The difference between IIId and IIIc is the relative risk ratio of 0.891 presented in Table B.1.

The difference between with and without point-of-use disinfection for Scenarios VI to IIId is a relative risk ratio of 0.53. This corresponds to the relative risk ratio for rural water supply in Table B.1. This

ratio may be considered more appropriate to apply than the urban relative risk ratio because Scenarios IV–VI are typically found in rural areas, and water quality in Scenarios IIId to VI is on average likely to involve higher disease risk than urban treated piped water supply. The relative risk for Scenarios IIIc and IIId is assumed to be the same if drinking water is disinfected at point of use.

Scenario II is not included in Table B.4. Scenario II is the situation typically found in developed countries (see Table B.2). The provision of this level of service (including partial sewage treatment) to the entire urban and rural population in developing countries is likely to be very costly. The benefit-cost analysis in this report therefore focuses on improved water supply and basic sanitation for those segments of the population without these services.

To estimate the health benefits of water and sanitation interventions, it is necessary to provide an estimate of the Nicaraguan population shares in each of the scenarios. Three sources of data from Nicaragua are used for this purpose, i.e., the ENDESA 2006–2007 household survey with data on the water and sanitation situation in urban and rural areas, Censos Nacionales (National Censuses) 2005, and WHO/UNICEF Joint Monitoring Program (JMP 2008) as well as household drinking water disinfection data, and data from Nicaraguan water supply authorities on the piped water network and water treatment plants (Estrategia Sectorial de Agua Potable y Saneamiento 2005).

The water supply and sanitation situation is presented in Tables B.5 and B.6. As discussed in relation to Tables B.2 to B.4, unimproved or no basic sanitation mainly refers to households with no sanitation facilities or with open pit latrines. Similarly, no improved water supply refers mainly to surface water, tanker trucks and unprotected well or spring water.

The latter was selected as the basis for the analysis. In order to use the data in Table B.6 to estimate the population shares in each of the scenarios in Table B.4, a set of allocation "rules" were applied. These "rules" are presented in Table B.7.

Table B.4: Exposure Scenario Application to Nicaragua

Scenario/ Situation	Description	WITHOUT Point-of Use Disinfection	WITH Point-of-Use Disinfection
		RR	RR
VI	No improved water supply and no basic sanitation	11.0	5.8
Vb	Improved water supply and no basic sanitation	8.2	4.4
Va	Basic sanitation but no improved water supply	7.5	4.0
IV	Improved water supply and basic sanitation	7.5	4.0
IIId	IV and water supply piped to household (no source treatment)	6.7	3.6
IIIc	IV and water supply piped to household (source treatment)	5.9	3.6

Modified from Prüss et al. 2002. Note: RR is relative risk of diarrheal disease.

Table B.5: Water Supply and Sanitation (% of Households): Different Sources

	ENDESA 2006–2007			Censos Nacionales 2005		
Water Service by:	**Total**	**Urban**	**Rural**	**Total**	**Urban**	**Rural**
Pipe inside HH	30.7	49.5	5.1	39.7	62.7	10.4
Pipe outside HH in lot	32.0	41.4	19.0	20.6	24.1	16.0
Public fountain	3.7	1.0	7.5	3.2	1.5	5.4
Public/private well	14.9	3.3	30.9	16.7	5.6	30.8
Purchase/tanker	0.8	1.0	0.8			
River, watershed	13.1	0.6	30.2	13.2	0.5	29.3
Other	4.8	3.2	6.5	6.7	5.6	8.1
Sanitation Service by:						
Toilet w/sewer connection	56.7	44.9	72.9	60.0	53.0	68.0
Sewage connection in HH	23.2	39.5	0.9	17.5	33.0	0.0
Toilet w/septic tank	7.7	12.1	1.7	6.0	11.0	2.0
River	0.2	0.3	0.1	0.5	0.3	0.1
No sanitation	12.2	3.2	24.4	16.0	3.0	30.0

Source: ENDESA 2006–2007; Resumen Censal (Census Summary) 2005

Table B.6: Water Supply and Sanitation in Nicaragua (% of Households) as in JMP 2006

		Total	Urban (58% of the population)	Rural (42% of the population)
Water	Broad definition	79	90	63
	House connections	60	84	27
Sanitation	Broad definition	47	56	34
	Sewerage	13	22	0

Source: WHO/UNICEF Joint Monitoring Program (JMP/2006).

Data from Nicaragua's 2005 Estrategia Sectorial de Agua Potable y Saneamiento (Sectoral Strategy for Drinking Water and Sanitation) were used to provide an estimate of the urban population share with piped water supply that is treated. According to these data, 100 percent of drinking water was disinfected at the source in urban and rural areas in 2005.

Table B.7: Scenario Allocation Rules

Scenario/ Situation	Allocation rule
VI	Lesser population share without improved water supply and without basic sanitation.
Vb	Diff. between population share w/o basic sanitation and w/o improved water, if difference is > 0.
Va	Diff. between population share w/o improved water supply and w/o basic sanitation, if difference is > 0
IV	Lesser population share with improved water supply and basic sanitation minus population share with piped water.
IIId	Population share with piped water supply.
IIIc	

Table B.8: Rural Water Supply and Sanitation in Nicaragua (% of Rural Population)

Scenario/ Situation	Description	Share of rural population
VI	No improved water supply and no basic sanitation	37%
Vb	Improved water supply and no basic sanitation	2%
Va	Basic sanitation but no improved water supply	0%
IV	Improved water supply and basic sanitation	34%
IIId	IV and water supply piped to household (no source treatment)	27%
IIIc	IV and water supply piped to household (source treatment)	

Table B.9: Urban Water Supply and Sanitation in Nicaragua (% of Urban Population)

Scenario/ Situation	Description	Share of urban population
VI	No improved water supply and no basic sanitation	10%
Vb	Improved water supply and no basic sanitation	6%
Va	Basic sanitation but no improved water supply	0%
IV	Improved water supply and basic sanitation	28%
IIId	IV and water supply piped to household (no source treatment)	56%
IIIc	IV and water supply piped to household (source treatment)	

Table B.10: Water Treatment at Point of Use in Nicaragua (% of Households)

Type of water treatment	Urban[31]	Rural
Boiling	5	1.5
Chlorination	10	40
Filtering	5	1.5

Source: Estimated based on World Bank 2008

The source does not provide the share of households using disinfection in relation to their type of water supply and sanitation. The data on disinfection are therefore applied uniformly to each of the scenarios.

Strukova (2009) presents the estimated number of diarrheal illness cases in Nicaragua based on the ENDESA 2006–2007 (Table B.11). The total number of annual cases was estimated at close to seven million, or 1.2 cases per person.

Table B.11: Estimated Annual Cases of Diarrheal Illness in Nicaragua in 2005

	National	Urban	Rural
2-week diarrheal prevalence (children < 5 years)	21.7%	13.2%	17.6%
2-week diarrheal prevalence (population > 5 years)	3.7%	1.2%	1.5%
Annual diarrheal cases in children under 5 (000)	2970	898	1212
Annual diarrheal cases in population > 5 (000)	3778	697	664
Total annual diarrheal cases	6748	1595	1876
Diarrheal cases per person (all population)	1.21	0.51	0.76

Source: Strukova 2009

Estimated cases of diarrheal illness per person per year in Nicaragua are estimated for Scenarios IIIc to VI from the relative risks in Table B.4, the scenario population distribution in Tables B.8–B.9, and the average diarrheal cases per person in Table B.11. Tables B.12–B.13 indicate that cases per person average 0.40 in households with piped water supply and basic sanitation that practice disinfection of drinking water, and 1.2 to 1.3 per year in households that do not have improved water supply, have no basic sanitation and do not practice drinking water disinfection.

31 For estimates of periurban settlements.

Table B.12: Estimated Annual Cases of Diarrheal Illness per Person in Urban Nicaragua

Scenario/ Situation	Description	WITHOUT Point-of Use Disinfection	WITH Point-of-Use Disinfection
VI	No improved water supply and no basic sanitation	1.31	0.69
Vb	Improved water supply and no basic sanitation	0.98	0.52
Va	Basic sanitation but no improved water supply	0.89	0.47
IV	Improved water supply and basic sanitation	0.89	0.47
IIId	IV and water supply piped to household (no source treatment)	0.8	0.42
IIIc	IV and water supply piped to household (source treatment)	0.71	0.42

Table B.13: Estimated Annual Cases of Diarrheal Illness per Person in Rural Nicaragua

Scenario/ Situation	Description	WITHOUT Point-of Use Disinfection	WITH Point-of-Use Disinfection
VI	No improved water supply and no basic sanitation	1.22	0.65
Vb	Improved water supply and no basic sanitation	0.92	0.49
Va	Basic sanitation but no improved water supply	0.83	0.44
IV	Improved water supply and basic sanitation	0.83	0.44
IIId	IV and water supply piped to household (no source treatment)	0.75	0.40
IIIc	IV and water supply piped to household (source treatment)	0.67	0.40

Providing piped water supply to all rural households is likely to be very expensive. A realistic objective might be to at least provide improved water supply (protected wells or boreholes) and sanitation facilities (improved pit latrines or pour-flush latrines). The aim of the infrastructure interventions is to improve water supply and sanitation, largely in rural areas. Two programs are investigated: one that provides 1.5 million people with improved sanitation, and one that provides 1.2 million people with an improved water supply both in rural and urban areas.

Using information about incremental service increase and corresponding investment needs from the 2005 Estrategia Sectorial de Agua Potable y Saneamiento (Sectoral Strategy for Drinking Water and Sanitation), annualized per capita investment costs are estimated at about US$12–19 for improved sanitation and US$30–40 for improved water supply. This is based on a ten percent annual discount rate, annual five percent O&M and five percent promotion/water source protection cost, and US$6 in annual sewage cost.[32] The population receiving improved water supply and sanitation is

32 Per capita investment costs represent average costs in South America (WHO/UNICEF 2000). O&M refers to operations and maintenance.

calculated from Tables B8 and B.9. Diarrheal cases averted are calculated from Table B.13. Deaths averted are calculated based on an estimated case fatality rate of 0.3 per 1,000 cases in children under age five, using data presented in Strukova 2009. The key assumptions in deriving the benefits relate to the costs of morbidity and mortality and to the value of time saved. The morbidity costs, based on the costs of treatment and value of lost time, are US$8–14 per case of diarrhea. The mortality costs are calculated based on the Human Capital Approach (HCA) as presented in Strukova 2009. However, there are strong reasons to believe that the HCA approach underestimates the value of a lost life; hence, the figures reported here should be taken as lower bounds. Finally, the programs generate savings in time, which is an important ingredient in the calculations. It is based on data for households more than a 15-minute walk from a water source, and time saved is valued at 75 percent of the average rural wage (Strukova 2009).

Table B.14: Benefits of Reductions in Diarrheal Morbidity and Mortality in Rural Nicaragua

	Improved Sanitation Facilities	Improved Water Supply
Population (million) receiving improved sanitation*	0.96	
Population (million) receiving improved water supply**		0.9
Percent reduction in diarrheal illness per person (from Fewtrell and Colford 2004)	32%	25%
Diarrheal cases (million) averted per year	0.3	0.2
Deaths in children averted per year	60	40
Annual health benefits of improved services (US$ million)	4	3
Annual value of time savings from improved services (US$ million)	26	5
Annualized cost of service provision (US$ million)	12	24
Benefit-cost ratio (health benefits only)	0.35	0.1
Marginal cost (million NIO per 1% of WSSH health cost reduction)	26	69
Benefit-cost ratio (health benefits and time savings)	2.6	0.32

The data reveal that programs to improve sanitation have a benefit-to-cost ratio greater than 1.0 when the time savings of improved water are included. For water supply program benefit cost ration is less than 1. For water supply/sanitation programs in urban areas the costs are higher and the benefits lower due to lower diarrheal mortality among children under age five and to lower diarrheal prevalence.

Marginal cost[33] would be higher than marginal benefits[34] (health damage reduction) for all four investment programs considered.

33 Approximated by average cost per one percent of WSSH cost reduction.
34 Value of one percent of WSSH cost reduction, estimated at about nine million NIO.

Table B.15: Benefits of Reductions in Diarrheal Morbidity and Mortality in Urban Nicaragua

	Improved Sanitation Facilities	Improved Water Supply
Population (million) receiving improved sanitation*	0.5	
Population (million) receiving improved water supply**		0.2
Percent reduction in diarrheal illness per person (from Fewtrell and Colford 2004)	32%	25%
Diarrheal cases (million) averted per year	0.1	0.07
Deaths in children averted per year	17	12
Annual health benefits of improved services (US$ million)	2	1
Annual value of time savings from improved services (US$ million)	16	2
Annualized cost of service provision (US$ million)	9	10
Benefit-cost ratio (health benefits only)	0.2	0.1
Marginal cost (million NIO per 1% of WSSH health cost reduction)	45	70
Benefit-cost ratio (health benefits and time savings)	1.9	0.3

Benefit-Cost Analysis of Hygiene Improvements

In many studies, the single most effective hygiene intervention is found to be hand washing after defecation, before preparing meals, and before eating. Curtis and Cairncross (2003) provide a meta-analysis of close to 20 hand-washing studies and report a mean reduction in diarrheal illness of about 47 percent. In their meta-analysis, Fewtrell and Colford (2004) report a mean reduction in diarrheal illness of about 45 percent from hand-washing interventions (Table B.1). About two-thirds of the studies reviewed in the two meta-analysis studies assessed the effect of hand washing on diarrheal illness in children under age five. The meta-analyses do not report the effect of hand washing on diarrheal illness in children under age five versus older children and adults. A pooled analysis of the studies reviewed in the two meta-analyses was therefore undertaken in this report, but no statistically significant difference in diarrheal reduction was found in children and adults. A reduction in diarrheal illness of 45 percent is therefore applied in the benefit-cost analysis in this report for all age groups.

A benefit-cost analysis of hygiene improvement (hand-washing programs) involves an assessment of several key parameters and outcomes. These are listed in Table B.16. The costs of improved hand washing practices are twofold. First, a program to encourage behavioral change (improved hand-washing) has a cost that should be fully captured. This includes the cost of program preparation and implementation. Second, improved hand-washing practices have a private cost that includes the cost of increased water and soap consumption. The most uncertain and critical parameter is the effectiveness of the hand-washing program in terms of changing household and individual behavior, and the lasting effect of changed behavior (sustainability). This is likely dependent on several dimensions and will vary from country to country. It will also depend on the design, duration and overall magnitude of the hand-washing program. The ex-

pected benefit of the program can be estimated from the diarrheal illness risk reductions reported in Curtis and Cairncross (2003) and Fewtrell and Colford (2004), and the monetized benefits (or costs avoided per case of diarrheal illness reduction) presented in Strukova 2009 for Nicaragua.

Table B.16: Key Parameters and Outcomes in a Benefit-Cost Analysis of Hand Washing

Key Parameters:	Outcomes:
Program cost	Overall cost of hand-washing program
Program effectiveness	Behavioral change in target population (% of population that improves or starts regular hand-washing)
Program sustainability	Lasting effect of the program
Private cost	Costs of hand washing in the group with behavioral change (increased water and soap expenditures)
Program benefits	Percent reduction in diarrheal illness from hand-washing in group with behavioral change Monetized benefits of reduced diarrheal illness

A review of three hand-washing programs that provide program costs and behavioral change is presented in Table B.17. The program in Guatemala was national in scope and targeted households with children under age five (Saade et al. 2001). The program in Thailand focused on all households in a set of rural villages and involved a different level of program intervention in two subsets of the villages (Pinford and Horan 1996). The program in Burkina Faso involved one city and targeted households with children under age three (Borghi et al. 2002). As seen in the table, the percentage of the target population that changed behavior (i.e., started regular hand washing or improved hand-washing practices) range from 10 to 18 percent, and costs per target household range from US$0.36 to US$5.03. While the studies are too few to draw a definite conclusion, the results do suggest that program costs per unit of behavioral change (per percentage point increase in population with behavioral change) may increase substantially if the objective is behavioral change in a large share of the target population. This issue may therefore have a major impact on the overall cost of hygiene programs that aim to achieve substantial reductions in the overall number of cases of diarrheal illness in a country.

The program cost per target household with behavioral change is the most relevant unit cost in Table B.17 for a benefit-cost analysis. This cost can then be compared to the reduction in (and thus the benefits of) diarrheal illness in the target population with behavioral change.

A benefit and cost analysis of rural and urban hand-washing programs is provided for diarrheal reduction in children under age five. The “low” to “high” scenarios for children represent: (a) a program effectiveness of 10–20 percent in terms of the percent of households (or primary caretakers of children) that start regular hand washing or improve hand-washing practices for the protection of child health; and (b) a program cost ranging from US$0.4 to US$5.0 per targeted household or primary caretaker (US$4.0–US$25.0 per household or primary caretaker with behavior change). This range of program effectiveness and costs is

Table B.17: A Review of Costs and Effectiveness of Hand-Washing Programs

	Guatemala	Thailand		Burkina Faso
Target area	National	25 rural villages		One City
Intervention level		"Low"	"High"	
Target population	HH w/children under age 5	All HHs	All HHs	HH w/children under age3
Number of target households	1,570,000	10,000	6,550	38,600
Duration of program implementation	1 year	3–4 months	3–4 months	3 years
Behavioral change (% of target population)	10%	11%	16%	18%
Program cost (US$)	561,400	5,960	7,715	194,000
Program cost per target household (US$)	0.36	0.60	1.18	5.03
Program cost per target household with behavioral change (US$)	3.58	5.42	7.36	27.92

Source: Derived from Saade et al. (2001), Pinfold and Horan (1996), and Borghi et al. (2002).

based on the figures in Table B.17. The "high' scenario corresponds to the experience in one city in Burkina Faso. However, it is possible that a national program will benefit from economies of scale and therefore achieve a 20 percent effectiveness at a lower unit cost than US$5.0 per primary caretaker of children under age five. It is therefore possible that the "high" scenario represents a higher bound of program cost. The diarrheal illness baseline data and cost of illness per case of diarrhea and diarrheal mortality are from Strukova (2009). Avoided cost of illness is the program benefit per case of reduced or averted diarrheal morbidity and mortality. Mortality is valued by the human capital approach, as in the section on water and sanitation improvement in this report. The percent reduction in diarrheal illness (45 percent) in children with caretakers who start regular hand washing or improve hand-washing practices is from Curtis and Cairncross (2003) and Fewtrell and Colford (2004), as presented in Table B.1. Regarding the private cost of hand washing, the quantity of increased water and soap consumption reflects the assessment of experts in Nicaragua. The rural and urban price of water is communicated by experts from Nicaragua, and the cost of soap is based on a spot survey of retail prices for soap in Nicaragua.

A benefit and cost analysis of rural and urban hand-washing programs is presented in Tables B.18–B.19. Three scenarios are provided for diarrheal reduction in children under age five.

The estimated reduction in annual cases of diarrheal illness is about 0.1 million in children under age five. With morbidity and mortality costs estimated in Strukova 2009, the total program benefit is about US$2 million. The total first year program cost is about US$1 million for the "medium" scenario.

The total estimated benefits and costs result in a benefit-cost ratio that ranges from 4.5 in the "low" scenario to about 0.6 in the "high" scenario. Benefit-cost ratios are higher for the urban population since medical treatment cost and annual wages are higher in urban areas.

Table B.18: Benefits and Costs of a Rural Hand-Washing Program

	Rural Households with Children Under Age 5		
	"Low"	"Medium"	"High"
Program Effectiveness			
Program target (million households)*	0.3	0.3	0.3
Program response (% of households with behavioral change)	10%	15%	20%
Percent reduction in diarrheal illness per child (Fewtrell and Colford 2004)	45%	45%	45%
Program Cost			
Total program cost (US$ million)	0.1	0.4	1.7
Private Costs			
Cost of water and hygiene products per year (US$ million)	0.1	0.2	0.2
Program Benefits			
Cases of diarrheal illness averted per year (thousands)	30	45	60
Deaths in children averted per year	9	13	18
Total annual health benefits (US$ million)	0.5	0.8	1.0
Benefit-Cost Ratios			
LOW: If behavioral change lasts 1 year	2.2	1.4	0.6
MEDIUM: If behavioral change lasts 2 years**	3.0	**2.1**	1.0
HIGH: If behavioral change lasts 3 years**	3.4	2.6	1.3
Marginal cost for medium scenario (million NIO per 1% of WSSH health cost reduction)		10	

* There are about 0.3 million rural children under the age of five in Nicaragua. It is assumed there is one child under five in each household (thus the program target is 0.3 million households). However, the estimated benefit-cost ratio is higher for households with more than one child under five. ** Benefits and costs in the second and third years are discounted at an annual rate of 10 percent.

Not only can children under age five benefit from a hand-washing program, but the population over age five can benefit as well. However, these programs were found to have lower than one benefit cost ratio. This low ratio, even at zero incremental program cost, is due to the fact that diarrheal incidence is on average substantially lower in this population group than in children under age five.

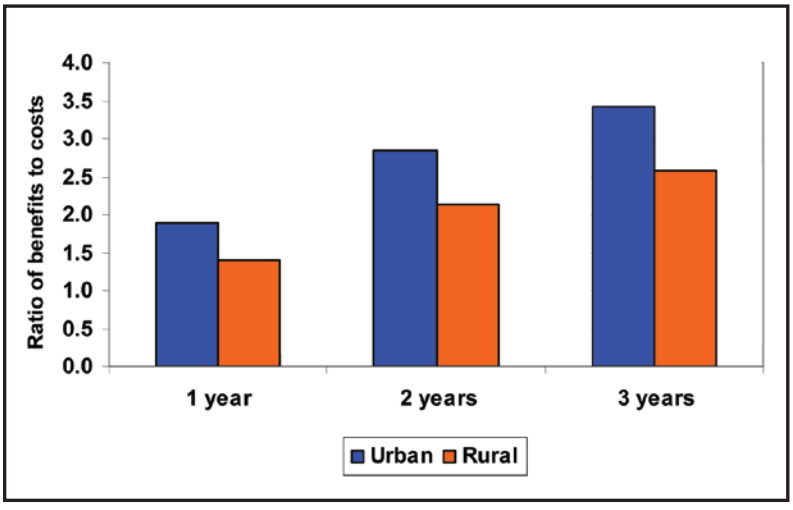
One very important aspect of the benefit-cost analysis presented above should be noted. It is implicitly assumed that the benefit of the program is only realized for one year, or that behavioral change (hand washing) only lasts one year. While it is difficult to assess the sustainability of behavioral change, benefit for only one year is clearly a very conservative assumption. If benefits are sustained for two years, the estimated benefit-cost ratios would increase. Note that the benefit-cost ratio does not change for the population over five years of age. This is because of the assumption that behavioral change takes place at no incremental program cost. Figure B.1 presents benefit-cost ratios for children for this target in a program with sustainability of behavioral change lasting from one to three years.

Table B.19: Benefits and Costs of an Urban Hand-Washing Program

	Urban Households with Children Under Age Five		
	"Low"	"Medium"	"High"
Program Effectiveness			
Program target (million households)*	0.3	0.3	0.3
Program response (% of households with behavioral change)	10%	15%	20%
Percent reduction in diarrheal illness per child (Fewtrell and Colford 2004)	45%	45%	45%
Program Cost			
Total program cost (US$ million)	0.1	0.4	1.6
Private Costs			
Cost of water and hygiene products per year (US$ million)	0.1	0.2	0.2
Program Benefits			
Cases of diarrheal illness averted per year (thousands)	30	50	60
Deaths in children averted per year	9	14	19
Total annual health benefits (US$ million)	0.7	1.0	1.4
Benefit-Cost Ratios			
LOW: If behavioral change lasts 1 year	2.9	1.9	0.8
MEDIUM: If behavioral change lasts 2 years**	3.9	2.8	1.3
HIGH: If behavioral change lasts 3 years**	4.5	3.4	1.7
Marginal cost for medium scenario (million NIO per 1% of WSSH health cost reduction)		7	

* There are about 0.4 million urban children under the age of five in Nicaragua. It is assumed there is one child under five in each household (thus the program target is 0.4 million households). However, the estimated benefit-cost ratio is higher for households with more than one child under five. ** Benefits and costs in the second and third years are discounted at an annual rate of 10 percent.

Figure B.1: Estimated Benefit-cost Ratios (20% Program Effectiveness Target)



It is important to note that some authors link hand washing and ARI prevention (Cairncross 2003). Although there is a lack of meta studies in this area, some evidence is already collected. Some suggest that about 20 percent of ARI could be reduced if a hand-washing program is implemented. If one takes this into account, then benefit from hygiene improvement may be increased at least 30 percent. It would make it by far the most efficient intervention. To take a conservative approach, we did not include this additional benefit while awaiting additional scientific evidence.

Benefit-Cost Analysis of Drinking Water Disinfection

Table B.10 presented data on the share of households in Nicaragua that disinfect drinking water. The source does not provide the share of households using disinfection in relation to their type of water supply and sanitation. The data on disinfection is therefore applied uniformly to each of the scenarios.

According to the survey, the most common method of disinfection is boiling water and is therefore the method considered in the benefit-cost analysis. Fewtrell and Colford (2004) report from their meta-analysis that disinfection of drinking water at point of use reduces diarrheal illness by an average of 47 percent in rural areas and 23 percent in urban areas.

In order to estimate the reduction in the number of cases of diarrheal illness, it is necessary to estimate the diarrheal incidence in the population share that does not practice point-of-use disinfection of drinking water. This is given by the following equation:

$$P_s d + (1-P_s)d(1-r) = d_A \qquad (B.1)$$

where P_s is the population share not practicing disinfection; d is diarrheal incidence in P_s; r is reduction in diarrheal incidence from disinfection; and d_A is the national average diarrheal incidence. This equation provides an estimated diarrheal incidence of 0.9 in the rural population not practicing disinfection, compared to a rural average of 0.8 from Strukova 2009, in urban areas an estimated diarrheal incidence is 0.54 for populations not practicing disinfection, compared to the urban average of 0.51 from Strukova 2009.

There are no estimates of program costs to promote drinking water disinfection at point of use. The same costs as for hand-washing programs (and for the same three scenarios of effectiveness ranging from 10 to 20 percent) have therefore been applied in the cost-benefit analysis. The program cost, instead of per primary caretaker of children, is now per household, with the assumption that one person in the household is primarily responsible for the boiling of drinking water. The private cost of boiling drinking water is estimated at US$5 per year for urban households using commercial fuels and about US$3 for rural households using fuelwood that is collected by the household members. Collection time is estimated at 75 percent of the average wage. The cost of water chlorination is estimated at about US$3 per household based on an average drinking water consumption of 0.75 liters per person per day (Lantagne et al. 2005). The disinfection program benefits are estimated the same way as for hand-washing programs.

In rural areas the disinfection programs are estimated to avert 110,000 to 220,000 cases of diarrhea and 25 to 50 deaths in children per year (Tables B.20 and B.22). The benefit-cost ratio for the central estimate in water boiling programs is 1.9 and for water chlorination is 4.8, corresponding to a 15 percent program response rate with drinking water disinfection sustained for two years. Benefit-cost ratios are lower, but well above one in urban areas. In urban areas the disinfection programs are estimated to avert 70,000 to 130,000 cases of diarrhea and 10 to 25 deaths in children per year. Drinking water chlorination programs both in

Table B.20: Benefits and Costs of a Rural Drinking Water Boiling Program

	"Low"	"Medium"	"High"
Program Effectiveness			
Target population – rural population not practicing disinfection (millions)	1.5	1.5	1.5
Target households (millions)	0.3	0.3	0.3
Program response (% of households with behavioral change)	10%	15%	20%
Percent reduction in diarrheal illness per person (Fewtrell and Colford 2004)	47%	47%	47%
Program Cost			
Total program cost (US$ million)	0.1	0.3	1.4
Private Costs			
Cost of boiling drinking water per year (US$ million)*	0.3	0.4	0.5
Program Benefits			
Cases of diarrheal illness averted per year (thousands)	45	65	90
Deaths in children averted per year	<15	<20	25
Total health benefits (US$ million)	0.7	1.1	1.5
Benefit-Cost Ratios			
LOW: If behavioral change lasts 1 year	1.9	1.5	0.7
MEDIUM: If behavioral change lasts 2 years**	2.2	1.9	1.1
HIGH: If behavioral change lasts 3 years**	2.3	2.1	1.4
Marginal cost for medium scenario (million NIO per 1% of WSSH health cost reduction)		5	

* Estimated based on efficiency of LPG and wood stoves, cost of LPG, fuelwood collection time of 30 minutes per day and 10% of fuelwood used for water boiling, and per person water consumption of 0.75 liter per day.
** Benefits and costs in the second and third years are discounted at an annual rate of 10 percent.

rural and urban areas have high benefit cost ratios since private program costs are low. Preliminary estimates for the filtration program suggest that the benefits of this program are at the same level as for chlorination, since annual maintenance costs are negligible and the diarrheal reduction rate is at the same level as for chlorination (for background data, see Ramírez 2008).

Preliminary estimates for the point-of-use filtration program suggest that the benefits of this program are at the same level as for chlorination, since annual maintenance costs are negligible and the diarrheal reduction rate is at the same level as for chlorination (for background data, see Ramírez 2008).

As in the case of the hand-washing program, one very important aspect of the analysis should be noted. It is implicitly assumed that the benefit of the disinfection program is only realized for one year, or that behavioral change (boiling of drinking water) only lasts one year. While it is difficult to assess the sustainability of behavioral change, benefits for only one year are clearly a very conservative assumption. If benefits are sustained for three years, the estimated benefit-cost ratios would increase in the same way as for hygiene programs.

Table B.21: Benefits and Costs of an Urban Drinking Water Boiling Program

	"Low"	"Medium"	"High"
Target households – urban population not practicing disinfection (millions)	0.5	0.5	0.5
Percent reduction in diarrheal illness per person (Fewtrell and Colford 2004)	23%	23%	23%
Program Cost			
Total program cost (US$ million)	0.2	0.2	2.7
Private Costs			
Cost of boiling drinking water per year (US$ million)*	0.2	0.4	0.5
Program Benefits			
Cases of diarrheal illness averted per year (thousands)	30	50	65
Deaths in children averted per year	<10	<10	<15
Total health benefits (US$ million)	0.6	0.9	1.2
Benefit-Cost Ratios			
LOW: If behavioral change lasts 1 year	1.2	0.9	0.4
MEDIUM: If behavioral change lasts 2 years*	1.6	1.2	0.6
HIGH: If behavioral change lasts 3 years*	1.8	1.4	0.8
Marginal cost for medium scenario (million NIO per 1% of WSSH health cost reduction)		8	

* Benefits and costs in the second and third years are discounted at an annual rate of 10 percent.

The different interventions discussed above can be summarized in terms of their contribution to reduced environmental damages and the costs per one percent of health damage reduction (marginal cost). This is done in Figure B.2. It shows the percent of reduction of environmental damage on the horizontal axis and the marginal cost as explained above on the vertical axis. The graph then plots the relative values of these two pieces of information for a number of interventions. The disinfection and hygiene programs are estimated to have the greatest potential health benefits, but only if at least 20 percent of the population responds favorably to the program and improves hand-washing practices. Hygiene improvement and disinfection of drinking water at point of use have substantial potential to reduce diarrheal illness and mortality, as indicated in Table B.3. However, the challenge is to develop and deliver programs that induce sustained behavioral response at a large scale, while containing program costs at an affordable level.

For sanitation, benefits exceed costs with time-saving benefits taken into account. Finally, the benefits of hand washing among adults are not presented at the graph above. These interventions were estimated to have significantly higher costs than benefits and corresponding benefit-cost ratios lower than one. All interventions that have marginal costs lower than marginal benefits could reduce total WSSH health costs by about 50 percent. The benefit-cost ratios for hand washing and drinking water disinfection are based on behavioral change being sustained for two years. The ratios would be higher (lower) if, as a result of promotion programs,

Table B.22: Benefits and Costs of a Rural Drinking Water Chlorination Program at the Point of Use

	"Low"	"Medium"	"High"
Program Effectiveness			
Target households (millions)	0.3	0.3	0.3
Percent reduction in diarrheal illness per person (Fewtrell and Colford 2004)	47%	47%	47%
Program Cost			
Total program cost (US$ million)	2.1	5.3	26.5
Private Costs			
Cost of chlorinating drinking water per year (US$ million)*	0.1	0.1	0.2
Program Benefits			
Cases of diarrheal illness averted per year (thousands)	70	100	130
Deaths in children averted per year	10	20	25
Total health benefits (US$ million)	0.9	1.4	1.9
Benefit-Cost Ratios			
LOW: If behavioral change lasts 1 year	4.5	3.3	1.2
MEDIUM: If behavioral change lasts 2 years**	6.1	4.8	2.0
HIGH: If behavioral change lasts 3 years**	6.9	5.7	2.6
Marginal cost for medium scenario (million NIO per 1% of WSSH health cost reduction)		2	

** Benefits and costs in the second and third years are discounted at an annual rate of 10 percent.

households sustain improved behavior for longer (less than) than two years. This figure does not consider the possible interaction effects between different interventions (i.e., how the impacts of a first intervention affect those of a second intervention), because data constraints preclude a sound analysis of such effects.

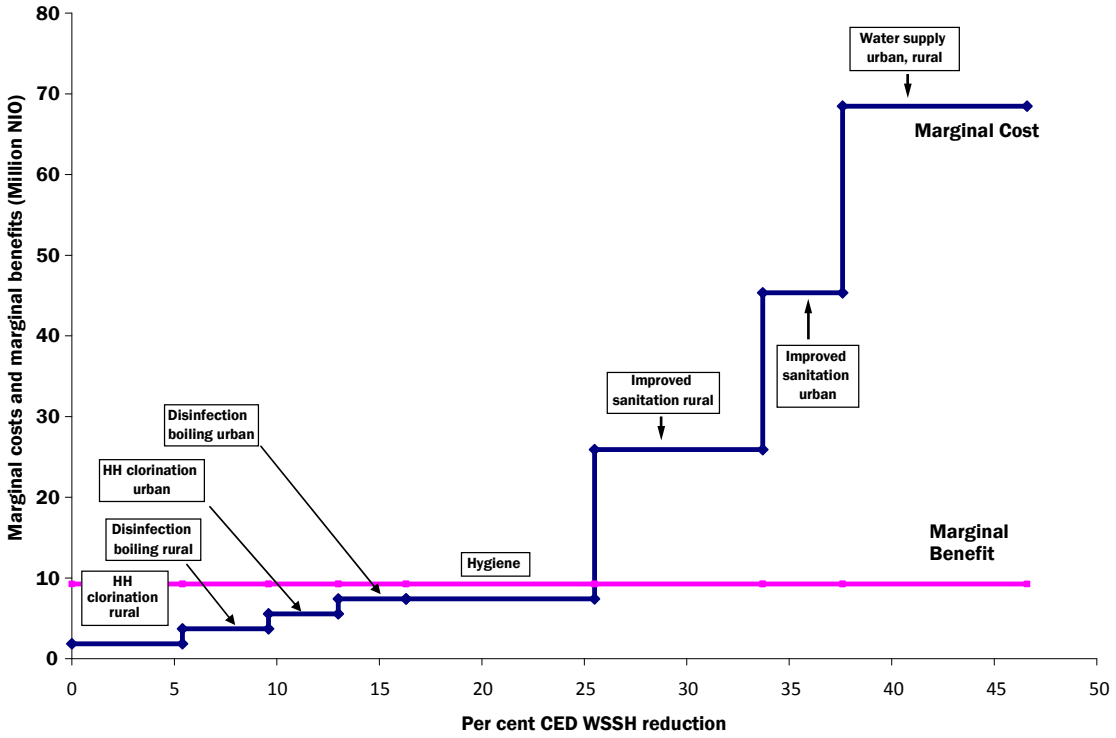
From the analysis presented here, it is clear that most measures to improve water supply and sanitation facilities in rural areas yield benefits in excess of costs under most assumptions. The programs are also justified because the benefits are concentrated primarily among the poor. These measures include drinking water disinfection, hand washing, improved rural water supply and safe rural sanitation. The highest priority should be given to the drinking water disinfection and hand-washing programs.

Table B.23: Benefits and Costs of an Urban Drinking Water Chlorination Program at the Point of Use

	"Low"	"Medium"	"High"
Target households – urban population not practicing disinfection (millions)	0.5	0.5	0.5
Percent reduction in diarrheal illness per person (Fewtrell and Colford 2004)	23%	23%	23%
Program Cost			
Total program cost (US$ million)	0.2	0.5	2.7
Private Costs			
Cost of chlorinating drinking water per year (US$ million)*	0.15	0.2	0.3
Program Benefits			
Cases of diarrheal illness averted per year (thousands)	30	50	65
Deaths in children averted per year	<10	<10	<15
Total health benefits (US$ million)	0.6	0.9	1.2
Benefit-Cost Ratios			
LOW: If behavioral change lasts 1 year	1.6	1.2	0.4
MEDIUM: If behavioral change lasts 2 years*	2.3	1.8	0.7
HIGH: If behavioral change lasts 3 years*	2.6	2.1	0.9
Marginal cost for medium scenario (million NIO per 1% of WSSH health cost reduction)		5	

*Benefits and costs in the second and third years are discounted at an annual rate of 10 percent.

Figure B.2: Ranking of Interventions to Reduce WSSH Cost in Nicaragua



III. Indoor Air Pollution

This section presents the damage cost of indoor air pollution and provides estimates of the benefits and costs of interventions to reduce this damage cost. The damage cost is from the health effects of smoke from solid fuels used in the household environment, as presented by Strukova (2009).

Health Effects of Indoor Air Pollution

It is well documented from studies around the world that indoor air pollution from solid fuels used for cooking and heating in the indoor environment has substantial respiratory health effects. Women and young children appear to be most affected because they tend to spend more time indoors and/or closer to the cooking areas. However, studies have also found health effects in men.

Smith et al. (2004) and Desai et al. (2004) report results of health effects from biomass smoke (fuelwood, etc.) and coal smoke based on a meta-analysis of available studies. The results are presented in Table B24. The relative risks (RRs) represent the risk of health effect or illness relative to the use of clean fuels such as LPG. The RR for households using LPG is therefore 1.0.

The strongest evidence of health effects is for acute lower respiratory illness (ALRI) in children under age five, COPD in adult females, and lung cancer in adult females from coal smoke. Smith et al. and Desai et al. do not report a relative risk ratio (RR) for acute respiratory illness in groups above age five. This is because most of the studies have concentrated on children under age five. However, Ezzati and Kammen (2002) from a study in Kenya

Table B.24: Relative Risks for Strong and Moderate Health Outcomes

Evidence	Health Outcome	Group	RR	CI
Strong	ALRI	Children <5 years	2.3	1.9–2.7
	COPD	Women >30 years	3.2	2.3–4.8
	Lung cancer (from coal smoke)	Women > 30 years	1.9	1.1–3.5
Moderate-I	COPD	Men > 30 years	1.8	1.0–3.2
	Lung cancer (from coal smoke)	Men > 30 years	1.5	1.0–2.5
Moderate-II	Lung cancer (from biomass smoke)	Women > 30 years	1.5	1.0–2.1
	Asthma	Children 5–14 years	1.6	1.0–2.5
	Asthma	All > 15 years	1.2	1.0–1.5
	Cataracts	All > 15 years	1.3	1.0–1.7
	Tuberculosis	All > 15 years	1.5	1.0–2.4

Source: Desai et al. (2004). Notations: RR= relative risk. CI= confidence interval. ALRI=acute lower respiratory infection. COPD=chronic obstructive pulmonary disease.

find that the RR for the 5–49 age group is quite similar to the RR for children under age five at various levels of pollution levels.

WHO recommends that ventilation level be taken into account while assessing exposure level in the household. Balakrishnan (2004) demonstrated that even with outdoor cooking, the exposure level is substantial. Even when cooking is done outside the house, the resulting indoor levels of PM and exposure of all family members greatly exceed health guidelines for ambient air. However, resulting PM concentrations are lower than with indoor cooking (Table B.25).

Table B.25: 24-Hour Exposure Concentrations for Cooks and Noncooks Among Solid Fuel Users Across Kitchen Configurations

Type of kitchen	N	Mean	Std. error of mean
Cooks			
Enclosed kitchen			
Enclosed indoor kitchen with partitions	76	520	56
Enclosed indoor kitchen without partitions	73	540	50
Separate enclosed kitchen outside the house	83	439	52
Outdoor kitchens			
Outdoor cooking	70	259*	23
Noncooks			
Enclosed kitchen			
Enclosed indoor kitchen with partitions	232	264	17
Enclosed indoor kitchen without partitions	155	280*	17
Separate enclosed kitchen outside the house	264	178	11
Outdoor kitchens			
Outdoor cooking	220	175*	10

* F-statistic significant at P<0.05 as compared to other kitchens.
* Significantly different as compared to noncooks in other types of enclosed kitchens

Source: Balakrishnan (2004)

Table B.25 shows that exposure concentrations are about 50 percent lower for cooks and 30 percent lower for non-cooks. Due to the non-linear character of the concentration-response function, WHO suggests the use of a 0.25 coefficient for the estimation of exposure to account for ventilation for the households with outside kitchens (Desai 2004).

A Benefit-Cost Analysis Framework

A benefit-cost analysis of interventions to reduce indoor air pollution from solid fuels represents a challenge for many reasons. The relative risks reported in Table B.24 represent averages from many studies, and do not necessarily reflect the pollution exposure situation in households using solid fuels in Nicaragua. Moreover, the pollution load from

solid fuels is not uniform across households. Some households use unimproved stoves or open fires while others use improved stoves with chimneys; some households use a combination of solid fuels and clean fuels such as LPG. Substantial numbers of households practice cooking outside the house. A benefit-cost analysis framework should therefore be flexible enough to accommodate these differences and allow for a sensitivity analysis of parameters that will influence the benefits and costs of interventions to reduce pollution loads and/or exposure.

For purposes of this report, six scenarios were selected that represent six stylized situations commonly found in most developing countries (Table B.26). These stylized situations represent the pollution loads from solid fuel use reasonably well. However, actual pollution exposure can vary substantially in each scenario and can depend on additional factors such as household ventilation practices, housing characteristics, and household behavior.Because data on these factors are not readily available at national level, a sensitivity analysis of relative risk will need to be undertaken in order to assess the likely influence of these factors on the benefit-cost ratios of interventions.

The next step is to assign population shares and relative risks to each of the stylized situations in Table B.26. According to ENDESA 2006–2007,[35] about 92 percent of the rural population in Nicaragua relies on fuelwood and charcoal as their main fuel for cooking. In urban areas, about 32 to 38 percent of the population relies on these fuels. There is a total annual fuelwood consumption of

Table B.26: Fuels, Stove Technology and Pollution Scenarios

Stylized Situation	Stylized Description	Relative Risk
I. Unimproved wood stoves or open fire with kitchen located inside the house	Low energy efficiency. No chimney or ventilation device. Very high indoor pollution load.	Very High
II. Unimproved wood stoves or open fire with kitchen located outside the house	Low energy efficiency. Natural ventilation. Relatively high pollution load.	High
III. Improved wood stoves	Relatively low energy efficiency. Chimney (or other ventilation device) taking much of the smoke outdoors. Still relatively high indoor pollution load if stove/chimney is not well maintained.	High
IV. Unimproved wood stoves and LPG (or other clean fuel)	Pollution load reduced in proportion to the use of LPG (relative to situation I.).	Medium
V. Improved wood stoves and LPG (or other clean fuel)	Pollution load reduced in proportion to the use of LPG (relative to situation II.).	Medium to Low
VI. LPG or other clean fuel	Absence of smoke from solid fuels.	Low

Note: The framework in this table is very similar to the exposure scenario framework presented in Prüss et al. (2002), which was applied in the water-sanitation-hygiene section of this report.

35 Estimates are slightly different in Censo 2005 and PROLENIA 2005.

2.6 million tons (Prolenia 2005) A total of nearly 0.6 million households use fuelwood and charcoal as their primary energy for cooking.

Very little information is available in Nicaragua to assign relative risks to each of the stylized situations in Table B.26. While some information is available from Prolenia 2005) and international literature, the situation-specific evidence is less firm than for water and sanitation. It is therefore necessary to apply a base case of relative risks to each of the stylized situations and perform a sensitivity analysis.

The base case for population shares and relative risks is presented in Table B.27. It is almost exclusively the rural population in Nicaragua that uses solid fuels as its main cooking fuel. Rural and urban population shares are applied in Table B.27. Shares of improved stoves and outdoor kitchens were estimated using Prolenia 2005.

An important factor is the reduction in "excess" risk from using improved stoves instead of unimproved stoves. While there is limited guidance from the international literature, several studies from around the world present measurements of particulate exposure from solid fuel use, particularly from cooking. Several results from Latin America are presented in Table B.28. The 24-hour average concentration levels from open fire or traditional stoves are many times higher than urban air quality standards in most countries. Improved stoves, such as the *plancha*, produce $PM_{2.5}$ or $PM_{3.5}$ levels that are often only 20 percent of concentration levels from an open fire, and are even found to be less than 10 percent of that of an open fire in a study in Guatemala by McCracken and Smith (1998). According to the figures in Table B.28, the reduction in $PM_{2.5}$ seems to even larger than reductions in PM_{10}. While the indoor concentration levels of PM can be substantially reduced by using improved stoves, it is not clear that the health benefits are proportional. The concentration levels of PM, even with an improved stove, are still substantially higher than those found in most outdoor urban environments.

Table B.27: Base Case Estimation of Scenario-Specific Relative Risks in Nicaragua

Stylized Situations	Rural			Urban		
	Pop. Share	RR for ARI	RR for COPD in Women	Pop. Share	RR for ARI	RR for COPD in Women
I. Unimproved wood stoves or open fire inside	43%	2.8	4.1	8%	2.8	4.1
II. Unimproved wood stoves or open fire outside	44%	1.9	2.6	24%	1.9	2.6
III. Improved wood stoves	3%	1.9	2.6	7%	1.9	2.6
IV. Unimproved stoves and LPG (or other clean fuel)	0%	1.5	2.5	5%	1.5	2.5
V. Improved stoves and LPG (or other clean fuel)	2%	1.0	1.8	5%	1.0	1.8
VI. LPG or other clean fuel	8%	1.0	1.0	76%	1.0	1.0
Weighed average risk of I to VI		2.2	2.0		1.3	1.0

Table B.28: Particulate (PM) Concentrations from Cooking Stoves

	Open fire/ Traditional Stove	Improved Stove	LPG	
24-hour $PM_{3.5}$	1,930	330		Guatemala. Albalak et al. (2001).
24-hour PM_{10}	1,210	520	140	Referenced in Albalak et al. (2001), adapted from Naeher et al. (2000).
24 hour $PM_{2.5}$	520	88	45	
24-hour $PM_{2.5}$	868	152		
PM_{10}	600–1,000	300	50	Mexico. Saatkamp et al. (2000)

Table B.29: Odds Ratios for ARI

PM_{10} (µg/m^3)	Children under age five	Age group 5–49
<200	1.0	1.0
200–500	2.42	3.01
500–1,000	2.15	2.77
1,000–2,000	4.30	3.79
2,000–3,500	4.72	
2,000–4,000		4.49
>3,500	6.73	
4,000–7,000		5.40
>7,000		7.93

Source: Ezzati and Kammen (2002).

Table B.29 provides the results of a study by Ezzati and Kammen (2002) that presents odds ratios for ARI in relation to PM_{10} indoor concentrations levels. A halving of PM_{10} levels from 1,000–2,000 to 500–1,000 µg/m^3 can correspond to the concentration levels associated with the use of an unimproved stove versus an improved stove. This reduction in concentration levels is associated with a reduction in the odds ratio of about 50 percent for children under age five and 25 percent for the 5–49 age groups. The 50 percent risk reduction has therefore been applied in the base case in Table B.27 for ARI to establish the relative order of magnitude of the RR in situation I and III.

With regard to chronic respiratory illness, Albalak et al. (1999) find a 60 percent reduced risk of chronic bronchitis from outdoor cooking with solid fuels compared to indoor cooking with the same fuels in a study from Bolivia. However, it should be noted that outdoor cooking is not free from fine particulate exposure. Studies have found that those engaged in outdoor cooking activities are exposed to elevated levels of pollution. Dennis et al. (1996) in a study from Bogotá find that individuals who did not use solid fuels in the household had an almost 75 percent lower prevalence rate of (chronic) obstructive airways disease than those who had lived in households with solid fuel use. Similar results were

found in a study from Mexico for chronic bronchitis, with an even greater difference in prevalence in individuals with longer life exposure to solid fuel pollution (Pérez-Padilla et al. 1996). In a cost-benefit analysis, a 50 percent "excess" risk reduction in COPD is applied for switching from open fire/traditional stove to an improved stove with chimney or to the transfer of a kitchen outdoors.

Using the parameter values discussed above, the estimated RRs are presented in Table B.27. Only COPD in women and ARI are included. While there is moderate evidence for an increased risk of COPD in men, this is not included in this report. For ARI, however, children under age five and women over age 15 are included, although ARI in adult women is not included in the meta-analysis results presented in Smith et al. (2004) and Desai et al. (2004). However, the study by Ezzati and Kammen (2002) provides some evidence of similar ARI risk ratios for children under age five and the 5–49 age group.

The population shares and the relative risk ratios in Table B.27 allow a base case estimation of the health benefits of interventions such as improved ventilation, improved stoves and switching to clean fuels (Table B.26). However, in order to estimate benefit-cost ratios, the costs of interventions need to be estimated. In addition to costs of improved stoves and LPG stoves (or stoves for other clean fuels), this involves an assessment of household energy consumption for cooking in order to estimate the recurrent cost of LPG requirements or other clean fuels. Moreover, for many households the time savings from less fuelwood collection may be an important benefit of switching to improved stoves or clean fuels. Fuelwood consumption must therefore be estimated for the various stylized situations or scenarios in Table B.27. A first step in estimating the costs of interventions is therefore to consider stove efficiencies.

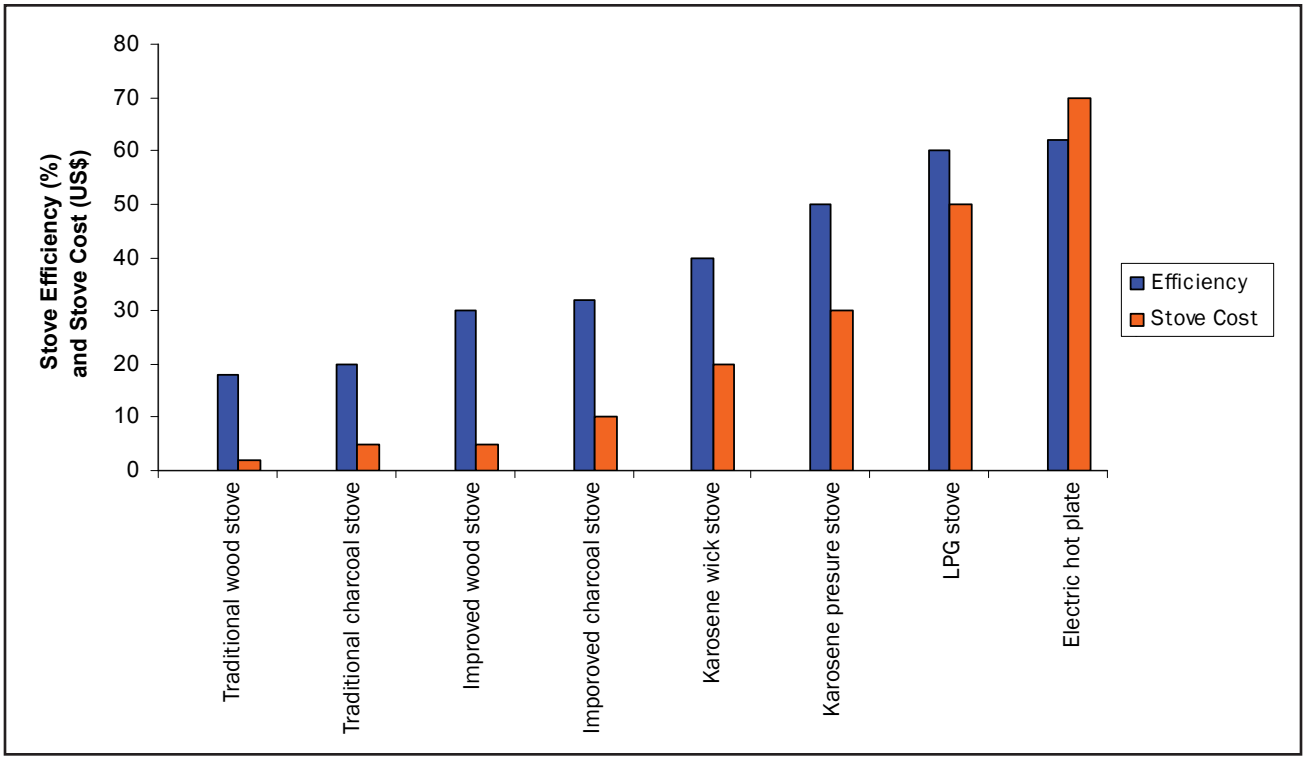
Stove Efficiency

Figure B.3 presents an energy efficiency ladder for stoves and their typical costs; this ladder is often cited in the research literature on fuel use and indoor air pollution (e.g., Baranzini and Goldemberg 1996; Luo and Hulscher 1999; and Saatkamp et al. 2000). The stove efficiency ladder provides a generic perspective on potential energy savings from improved wood and charcoal stoves and kerosene, LPG, and electric stoves in comparison to traditional stoves. According to Figure B.3, improved wood and charcoal stoves are about 50 percent more efficient than traditional stoves, and LPG and electric stoves are twice as efficient than improved wood and charcoal stoves.

A study of stove efficiency in Colombia was conducted by the National University of Colombia's Department of Physics. The results of the study were provided by UPME for the purposes of this report, and are presented in Figure B.4. The study estimated the stove efficiency for three different sizes of pots/kettles. The efficiency for electric plates was around 80 percent for all three pot sizes. LPG and natural gas stoves had an efficiency of 45 to 55 percent for the two smallest pot sizes. The efficiency for the largest pot size was more than 75 percent. For a "wood firebox," an improved wood stove, the efficiency was less than 10 percent for the two smallest pots, but about 30 percent for the largest pot. The efficiency of "fuelwood," or a traditional open stove, was less than 5 percent for the smaller pots, and 20 percent of the largest pot.

For the most part, the results from this Colombian study are consistent with the generic efficiency ladder in Figure B.4. A notable difference is the wood stove efficiencies for the two smallest pot sizes. However, a study of the *plancha* woodstove in Guatemala found an efficiency of around 10 percent, very similar to the efficiency of using open fire.

Figure B.3: Stove Efficiency and Capital Costs

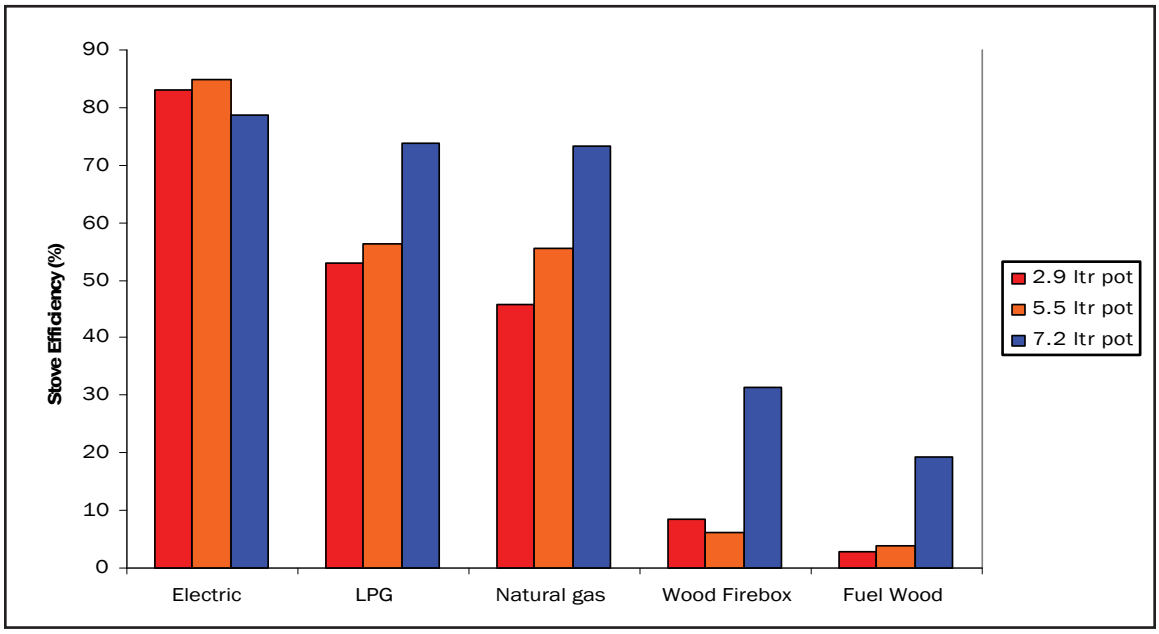


A modified version of the *plancha* had an efficiency of around 12 percent (Boy et al. 2000). McCracken and Smith (1998) found an efficiency of 13 to 14 percent for the *plancha* and open fire. Saatkamp et al. (2000) presented estimates of stove efficiencies in Jaracuaro, Mexico, and found that the efficiency of the *lorena* woodstove is not much different than that of traditional open stoves.

Trees, Water, & People (TWP), the Honduran Association for Development (AHDESA), and the Aprovecho Research Center are undertaking the "Micro-Enterprise Stove Project" to introduce safer and more environmentally friendly cook stoves for the people of Honduras. The team came together after Hurricane Mitch devastated Honduras in 1998 to adapt the Rocket stove technology to cooking conditions there. Working along with local Honduran women, Aprovecho stove technicians came up with the Justa stove design in 1999. Justa stoves save an average of 50 to 70 percent in firewood compared to traditional stoves. The Justa also removes about 90 percent of toxic smoke from the kitchen (Conway et al. 2006). In 2004, with a grant from the United States Environmental Protection Agency (US EPA), and with technical assistance from Aprovecho, TWP and AHDESA began developing commercial models based on the existing Rocket and EcoStove designs. Efficiency of the Justa stoves introduced through this project in Nicaragua was not estimated, but for the purpose of the study was considered in the same range as in Colombia.

The Justa woodstoves have been adopted by many communities in Latin America. While these stoves are often not very efficient, they are equipped with a chimney that removes the smoke from the indoor environment and therefore have important health and quality-of-life benefits. Several versions and offsprings of these stoves have also been developed in order to improve stove efficiency (Conway et al. 2006).

Figure B.4: Stove Efficiency From a Study in Colombia



Source: Study conducted by the National University of Colombia, Department of Physics.
The results of the study were provided by UPME.

Fuelwood Consumption

Among households that use fuelwood, there are typically three types of situations. Some households use open fire/traditional woodstoves. Others use improved woodstoves. Finally, some households use fuelwood in combination with LPG or another type of cleaner fuel. Based on data from UPME, it is estimated that the average household that uses fuelwood has a consumption of 3.01 tons per year. However, household consumption, for any given household size, will tend to vary depending on the efficiency of the woodstove and whether or not the household also uses other types of fuels for cooking.

Fuelwood consumption was estimated for different scenarios using the corresponding share of population with each stove type and stove efficiency from Figure B.4. The estimates are presented in Table B.30. These estimates are based on the assumption that the groups of households have on average the same demand for cooking energy.

Table B.30: Estimated Annual Household Consumption of Fuelwood

Technology:	Fuelwood consumption (tons)
Unimproved stoves	3.8
Improved stoves	2.6
Unimproved stoves and LPG stoves	1.9
Improved stoves and LPG stoves	1.3

It is important to assess the realism of fuelwood consumption in these four cases. Saatkamp et al. (2000) estimates fuelwood consumption in Jaracuaro, Mexico, in the range of 0.5–1.0 kg per meal per person for the *lorena* stove and open fire. For two meals a day and an average household size of five, this implies an annual fuelwood consumption

Table B.31: Annual Recurrent Cost of Complete Fuel Substitution

	Annual Cost Per Household (000 NIO)	
	LPG (25 lb bottles)	Electricity (urban only)
Unimproved stoves	2.8	2.5
Improved stoves	2.8	2.5
Unimproved stoves and LPG stoves	1.4	-
Improved stoves and LPG stoves	1.4	-

of 1.8–3.6 tons per year. For three meals a day, the annual consumption would be 2.7–5.4 tons per year. This is in the range of the estimated fuelwood consumption in Table B.30.

Cost of Interventions

Estimated annual recurrent costs of switching from fuelwood to commercial energy, or from a combination of fuelwood and LPG to LPG only, are presented in Table B.31. At current prices (in 2008) of energies in Nicaragua, LPG and electricity are found to be very close price options. Using electricity to replace fuelwood is found to be slightly less expensive than LPG, but it is difficult to ensure adequate access to electricity in rural areas. The cost is the same for households using unimproved and improved woodstoves (with 10 and 15 percent efficiency). This is because of the assumption that they have the same effective energy demand. LPG therefore seems to be the most viable option.

Table B.32: Baseline Parameters for Estimating the Cost of Fuel Substitution

Fuelwood	
Average gross energy content of fuelwood (MJ per kg)	19
Average net energy content of fuelwood (MJ per kg)	11
Propane (LPG)	
Average stove efficiency (propane)	55%
Average energy content of propane (Btu/gallon)	92,000
Cost per bottle (25 lb bottles) - NIO	175*
Electricity	
Average stove efficiency	80%
Cost of electricity (NIO./kWh)	2**

Sources: Energy contents of LPG and natural gas are based on data from UPME. Gross and net energy content of fuelwood (gross and net heating content) and stove efficiencies are from a study by the National University of Colombia and provided by UPME; * Instituto Nicaragüense de Energía (INE) 2008; **IPC-BCN, Canasta Básica 2008.

It should be noted that the estimated costs in Table B.31 are likely to represent underestimates of the costs of providing commercial energy to distant rural areas. Currently less than 1 percent of rural households in Nicaragua are already using LPG and other commercial energies, according to ENDESA 2006–2007. Thus, supplying these fuels to other rural households may not be substantially more expensive than to those households already using commercial fuels.

Table B.32 presents the baseline parameters that were used to estimate the cost of switching to commercial energy. These parameters are based on data from UPME and results of a study by the National University of Colombia, as well as Nicaraguan national statistics.

Capital costs and annualized costs of improved stoves and LPG stoves are presented in Table B.33. Capital costs are adapted from Prolenia (2005).[36] While simple improved stoves used in many developing countries are found to be quite inexpensive, as presented in Figure B.2, the type of improved stoves commonly used in Latin America is far more expensive, as indicated in Table B.33. Annualized costs are calculated by using a useful life of 10 years and an annual discount rate of 10 percent.

Table B.33: Cost Estimates of Improved Wood Stoves and LPG Stoves

	NIO	
Capital Cost:	Low	High
Traditional stove	170	
Improved stove	165	220
LPG stove	315	315
Annualized Cost:		
Traditional stove	26	
Improved stove	40	240

Benefit-Cost Analysis

Five intervention scenarios considered for Nicaragua represent four stylized situations commonly found in most developing countries. These stylized situations represent reduction of pollution loads from solid fuel use reasonably well. However, actual pollution exposure can vary substantially in each scenario, and can depend on additional factors such as household ventilation practices, housing characteristics and household behavior.

Table B.34: Interventions

Scenarios:	*Description:*
From I (50% HH) to II	From unimproved stove inside to better ventilation
From I (50% HH) to III	From unimproved stove inside to improved stoves
From III to V	From improved stove to LPG
From IV to VI	From unimproved stove and LPG mix to LPG only
From V to VI	From improved stove and LPG mix to LPG only

A benefit-cost analysis is undertaken for the three of five interventions presented in Table B.34. They are based on the stylized situations in Table B.26. The estimated benefits and costs of these interventions are presented in Table B.35 and B.36 for rural and urban areas. Avoided cases of ARI and COPD are estimated from the relative risk ratios in Table B.24 and baseline estimates of annual cases of ARI and COPD. Baseline cases are presented in Strukova (2009). The monetary benefits of avoided cases are calculated from the estimated unit costs of ARI and COPD morbidity and mortality, also presented in Strukova (2009). Unit costs of morbidity include medical treatment cost, and value of time losses (at 75 percent of wages). Child mortality is valued by using the human capital approach (HCA) of discounted life earnings losses. Adult mortality is

36 Some traditional stove prices are presented in Estufas Tradicionales (1995) http://www.gtz.de/de/dokumente/es-estufas-en-imag2-1995.pdf.

valued by the HCA as a lower bound and the value of statistical life (VSL) as a higher bound. VSL is derived from benefit transfer from the United States and other high-income countries using an income elasticity of 1.0, based on the mid-point value from the range of US$2 to US$5.4 million, as in Strukova (2009). The total health benefits of the interventions are greatly influenced by the choice of valuation techniques for adult mortality.

Annual costs of interventions include program cost, stove cost and LPG cost. LPG represents 80 to 90 percent of total cost in interventions (3). Interventions (4) and (5) from Table B.34 are not assessed since LPG costs greatly outweigh all benefits from morbidity and mortality reduction. A tentative estimate of the program cost of promoting and implementing improved stoves and LPG fuel switching, and sustaining a stove inspection and maintenance program, is also included in Tables B.35 and B.36. Only health benefits are included for the benefit-cost ratio estimation.

Improved ventilation and switching from unimproved and improved stoves in individual households is found to have substantially higher benefits than costs (Tables B.35 and B.36). The benefit-cost ratio is estimated at above 3 for all four of these interventions. The benefit-cost ratio is lower than 1 if there is switching to LPG due to high LPG prices. For households with improved stoves, the health benefits alone are not large enough to outweigh the cost of switching to LPG. Although promotion of improved stoves is a very attractive intervention, the merits of promoting LPG in individual rural households are uncertain. LPG prices would have to be reduced dramatically for the estimated benefits to exceed costs. Therefore, it seems that LPG will have a chance of success only in better-off households.

The various interventions are summarized in terms of their contribution to reduced environmental damages and costs per one percent of health damages reduction (marginal cost),[37] as was done for

Table B.35: Benefits and Costs of Indoor Air Pollution Control in Rural Nicaragua

	Better ventilation from unimproved stove inside	Improved stoves from unimproved stoves inside	LPG from improved stoves
Population receiving intervention (million)	0.5	0.5	0.07
ARI cases averted per year (thousand)	400	400	50
ARI deaths in children averted per year	36	36	5
COPD cases averted per year	110	110	20
COPD deaths averted per year	10	10	<5
Annual health benefits (million NIO)	96	96	14
Program cost (million NIO)	13	13	2
Annualized stove cost, (million NIO)	3	22	4
Annual cost of LPG (million NIO)	0	0	40
Benefit-cost ratio (health benefits only)	6.0	2.7	0.3
Marginal cost (million NIO per 1% of IAP health cost reduction)	1.5	3.2	30

37 Approximated by the average cost to implement intervention per one percent of IAP cost reduction.

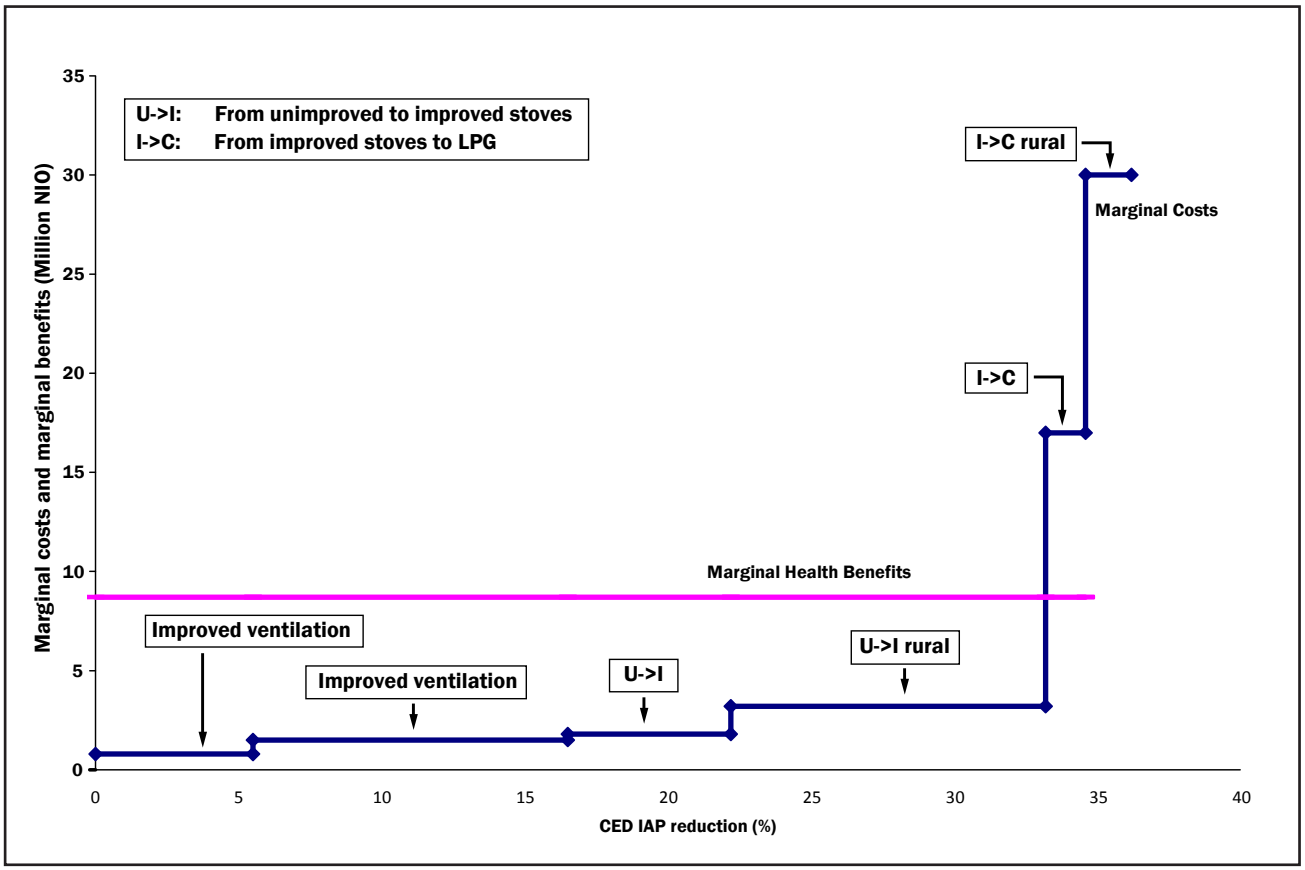
Table B.36: Benefits and Costs of Indoor Air Pollution Control in Urban Nicaragua

	Better ventilation from unimproved stove inside	Improved stoves from unimproved stoves inside	LPG from improved stove
Population receiving intervention (million)	0.1	0.1	0.03
ARI cases averted per year (thousand)	80	80	20
ARI deaths in children averted per year	10	10	<5
COPD cases averted per year	50	50	15
COPD deaths averted per year	<10	<10	<5
Annual health benefits (million NIO)	50	50	10
Program cost (million NIO)	4	4	1
Annualized stove cost, (million NIO)	1	6	2
Annual cost of LPG (million NIO)	0	0	20
Benefit-cost ratio (health benefits only)	10.6	4.9	0.5
Marginal cost (million NIO per 1% of IAP health cost reduction)	0.8	1.8	17

the water and sanitation programs (Figure B.5). Marginal cost reflects only program cost and private household cost, without taking into account time and fuelwood savings. Marginal benefit is approximated by the value of one percent of indoor air pollution cost reduction, estimated at 9 million NIO. Improved ventilation and household switching from unimproved to improved stoves have the largest reduction in damages in rural areas. This is followed by households switching to LPG alone from improved stoves in urban and rural areas. Each of these measures contributes a smaller amount of reduction in environmental damages; marginal costs for these two interventions slightly exceed marginal benefits. In total, the former four interventions reduce the cost of health effects by about 37 percent per year. This reflects better ventilation and switching to improved stoves in 43 percent of rural households, and eight percent of urban households; switching to LPG from improved stoves in three percent of rural and one percent of urban households.

The analysis presented here supports the unqualified recommendation to shift households that have unimproved stoves to improved ones and to improve ventilation. The results of other interventions, such as from unimproved stoves to LPG or from improved stoves to LPG, depend on the costs and benefits used. Therefore, a more detailed analysis needs to be carried out for such changes, looking at specific cases and taking into account other benefits.

Figure B.5: Ranking of Interventions for IAP Cost Reduction in Nicaragua



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