Modeling household solid fuel use towards reporting of the Millennium Development Goal indicator

Sumi Mehta
Health Effects Institute, 120 Second Avenue, Boston, MA 02129, USA
E-mail: smehta@healtheffects.org

Fiona Gore, Annette Prüss-Üstün, and Eva Rehfuess
Protection of the Human Environment, World Health Organization (WHO), 20, Avenue Appia CH-1211 Geneva 27, Switzerland

Kirk Smith
Environmental Health Sciences, University of California, Berkeley CA 94720, USA

Household use of solid fuels, such as dung, wood, agricultural residues, charcoal, and coal, is likely to be the largest indoor source of air pollution in developing countries. Combustion of solid fuels in inefficient stoves under poor ventilation conditions can result in large exposure burdens, particularly for women and young children, who spend the major part of their time at home. The importance of this public health and environmental issue is reflected in the inclusion of the percentage of households using solid fuels as an indicator towards the achievement of the Millennium Development Goal (MDG) for environmental sustainability. This article outlines the model used for completing missing country data for household use of solid fuels. Out of a total of 181 country data points reported, data were available for 94 countries. These included estimates from 42 countries where household solid fuel use was previously unknown, largely from the recently conducted World Health Survey. Based on the data available for these countries, using step-wise regression, a model to predict household solid fuel use based on rural population, gross national income (GNI) and geographic regional variables was developed. Thirty-five data points were estimated using this model. In general, household solid fuel use seems to be lower in 2003 than in 2000. Yet, even with increases in economic development and urbanization, drastic reductions in household solid fuel use are unlikely to occur in the absence of targeted programs to promote cleaner fuels.

1. Background

Cooking and heating with solid fuels, such as dung, wood, agricultural residues, charcoal, and coal, is likely to be the largest indoor source of air pollution in developing countries. Combustion of solid fuels in inefficient stoves under poor ventilation conditions can result in large exposure burdens, particularly for women and young children, who spend the major part of their time at home.

Because there is relatively little information on the indoor concentrations or exposures of these pollutants from solid fuel use, or on the baseline concentrations within similarly constructed households not using solid fuels, epidemiological evidence on the health effects of solid fuel use is based mainly on binary classifications of exposure, for example whether solid fuels were used for cooking or heating. Similarly, in the absence of detailed information on exposure to indoor air pollution from solid fuel use at the national level, binary classifications of household solid fuel use are used as a practical surrogate for exposure to indoor air pollution for burden of disease estimation, as well as to indicate progress towards the attainment of the Millennium Development Goal (MDG) for environmental sustainability.

In cases where data coverage is low or non-existent, it is necessary to predict solid fuel use. Previous estimates modeled missing country data for 2000 when survey data were available for only 52 countries [Smith et al., 2004]. This paper presents modeled estimates of household solid fuel use for countries where solid fuel use was unknown in 2003, now based on known data of 94 countries, including data from the recently conducted World Health Survey.

2. Data and methods

2.1. Available data on household solid fuel use at the national level

In many countries where large proportions of the population cook with solid fuels, household energy data are

widely, although not universally, available. In some cases, the data come directly from national census information or energy statistics, which state explicitly the number or fraction of households that rely predominantly on solid fuels for their energy. For example, information on the main fuel used for cooking is collected during the house listing of the decadal Census of India [GOI, 2001]. These data, disaggregated into urban and rural sectors, are available at the district level. (In India, a district, the administrative level below that of state, contains on average about two million people.)

In some countries, where censuses are infrequent and/or do not contain residential energy data, household surveys are an important information source. Some, such as Demographic and Health Surveys, are routinely conducted and report the main household cooking fuel. Less frequently conducted or one-time surveys are also a valuable source of information. For example, primary household energy estimates for 22 African countries, based on household welfare surveys with sample sizes ranging from 1,000 to over 14,000, are included in a database of African development indicators compiled by the World Bank [World Bank, 2000].

In other countries, including Indonesia and Thailand, data are available in the form of aggregate annual residential fuel consumption. In these cases, the percentage of households using solid fuels was estimated on the basis of the quantity of fuel consumed. We recognize that exposures from cooking and heating can be quite different because of different cooking technologies. In most cases, however, it was not possible to distinguish between the two end-uses.

The original global database of household fuel use used in the burden of disease project [Smith et al., 2004] was updated through a review of national census data and other household surveys. The updated database compiled by the World Health Organization, which includes information from 1990 to 2004, provides data for 94 countries. A bulk of this additional information comes from preliminary data of the World Health Survey conducted in 2003. All household fuel use is expressed as percent of households using each fuel type. (See Table 1.)

Admittedly, the compilation of data from various sources, with different methodologies and sample sizes, makes it difficult to characterize the uncertainty associated with the estimates for each country and region. Where more than one survey was available for a given country, the latest survey was selected. This was the case even for preliminary data (such as available from the World Health Survey), provided that the second latest survey was three years old or older. The differences between preliminary data and final estimates are likely to be minor compared to possible changes in solid fuel use over a three-year period. Where other survey results were available within two years of the latest preliminary survey results, however, the second latest survey was selected. No obvious inconsistencies were found where surveys were available for various years for the same country. Only nationally representative surveys were considered.

2.2. Statistical modeling to predict household solid fuel use at the national level

Using available national estimates of household solid fuel use, a stepwise linear regression model was used to predict national solid fuel use. A wide range of development indicators were tried as parameters in the modeling exercise, including average annual growth rates, per capita electricity and petroleum consumption, income (represented by gross national income[1] (GNI) per capita), Gini coefficient, adult female illiteracy, per capita fuelwood production, urbanization, and national traditional fuel consumption, and WHO Region (Table 2). All analysis was done using SPSS Version 8.0 (SPSS Inc., USA) and STATA 7.0 (Stata Corporation, USA).

For those countries where no census or survey data were available, estimates of household solid fuel use at the national level are based on the following assumptions.

1. As countries develop, people gradually shift up an energy ladder from solid fuels to cleaner fuels and cleaner cooking technologies. Although the picture may be more complex at local and household levels, it is assumed that this generally holds true over the long term on a regional scale.
2. In the 2000 round, Brazil, with a 1999 GNP per capita of US$ 4420, was the richest country in the original database to have a substantial proportion of households using solid fuels. Thus, to avoid extrapolating the model to areas where it may be inappropriate, estimates were only made for countries with 1999 GNP per capita less than $5,000. In other words, all countries with a GNP per capita greater than $5,000 are assumed to have made a complete transition to clean household cooking systems, either with cleaner liquid or gaseous fuels or electricity or, where solid fuel is still used for cooking/heating, to fully ventilated appliances. As recent surveys have indicated that much higher-income countries may still use significant proportions of solid fuels, estimates here are made for all countries with a 1999 GNP per capita less than US$ 10,500.
3. After a certain level of economic growth, it is assumed that countries will entirely shift away from using solid fuels in conditions with poor ventilation. Solid fuel use for heating may continue, especially in coal-rich and wood-rich regions. At higher levels of economic development, however, as this is essentially done using flues and chimneys, associated indoor air pollution exposures are limited.

The final model for the year 2000 (Table 3) included percentage rural population, location within the Eastern Mediterranean Region (EMR) and GNI per capita (log-transformed), and per capita petroleum use. As this was a linear regression model, beta are the regression coefficients for the variables included in the model. Location within EMR is likely important due to the fact that this encompasses a region with substantial oil and gas resources, and limited availability of solid fuel resources. To test for violations of regression assumptions, residuals were analyzed and plotted. Plots did not indicate any

Table 1. Available data on national estimates of household solid fuel use, 2003

Region[1]	Country	Households using solid fuel	Data source	Year	Reference
AfrD	Algeria	4 %	National energy statistics	1999	WRI, 2003
AfrD	Angola	100 %	National energy statistics	1999	IEA, 1999
AfrD	Benin	95 %	Household survey	2001	WBAHSD – Demographic and Health Surveys (DHS): Benin 2001
AfrD	Burkina Faso	96 %	Household survey	2003	WHS: Burkina Faso, 2003 (Preliminary data from WHS)
AfrD	Cameroon	83 %	Household survey	2001	WBAHSD – Enquête Camerounaise Auprès des Ménage (ECAM)
AfrD	Chad	97 %	Household survey	2003	WHS: Chad, 2003 (Preliminary data from WHS)
AfrD	Comoros	76 %	Household survey	2003	WHS: Comoros, 2003 (Preliminary data from WHS)
AfrD	Gabon	28 %	Household survey	2000	Macro, 2003
AfrD	Gambia	96 %	Household survey	1998	WBAHSD – National Household Poverty Survey, Gambia 1998
AfrD	Ghana	88 %	Household survey	2003	WHS: Ghana, 2003 (Preliminary data from WHS)
AfrD	Guinea	99 %	Household survey	1994/5	WBAD, 2000 citing Household Integrated Survey, Enquête intégrale budget et consummation, 1994/95
AfrD	Guinea-Bissau	95 %	Household survey	1993/4	WBAD, 2000 citing Inquerito ligeiro junto às familias, 1992
AfrD	Madagascar	98 %	Household survey	1999	WBAHSD – Enquête Prioritaire auprès des Ménages (EP)
AfrD	Mali	98 %	Household survey	2001	WBAHSD – Demographic and Health Survey (DHS)
AfrD	Mauritania	65 %	Household survey	2003	WHS: Mauritania, 2003 (Preliminary data from WHS)
AfrD	Mauritius	1 %	Household survey	2003	WHS: Mauritius, 2003
AfrD	Niger	98 %	Household survey	1995	WBAD, 2000 citing Household Priority Survey, Enquête permanente de conjuncture économique et sociale, 1995
AfrD	Nigeria	67 %	Household survey and census data	1992	WBAD, 2000 citing Consumer Expenditure Survey, 1992; Government of Nigeria, Social Statistics in Nigeria: 1990, Federal Office of Statistics, Lagos, Nigeria, 1990, p. 61
AfrD	Senegal	41 %	Household survey	2003	WHS: Senegal, 2003
AfrD	Sierra Leone	92 %	Household survey	1989/90	WBAD, 2000 citing Survey of Household Expenditure and Household Economic Activities (SHEHEA), 1989/90
AfrE	Botswana	65 %	National census	1991	GOB, 1991
AfrE	Burundi	100 %	Household survey	1998	WBAHSD – Enquête Prioritaire (EP)
AfrE	Central African Republic	99 %	Household survey	1993	WBAD, 2000 citing Household Priority Survey, 1993
AfrE	Congo	84 %	Household survey	2003	WHS: Congo, 2003 (Preliminary data from WHS)
AfrE	Côte d'Ivoire	74 %	Household survey	2003	WHS: Côte d'Ivoire, 2003 (Preliminary data from WHS)
AfrE	Dem. Rep. of Congo	100 %	National energy statistics	1999	WRI, 2003
AfrE	Eritrea	80 %	Household survey	1995	WBAHSD – Demographic and Health Survey (DHS)
AfrE	Ethiopia	96 %	Household survey	2003	WHS: Ethiopia, 2003
AfrE	Kenya	81 %	Household survey	2004	WHS: Kenya, 2004
AfrE	Malawi	98 %	Household survey	2003	WHS: Malawi, 2003
AfrE	Namibia	63 %	Household survey	2003	WHS: Namibia, 2003
AfrE	Rwanda	100 %	Household survey	2000	WBAHSD – Demographic and Health Survey (DHS)
AfrE	South Africa	18 %	Household survey	2003	WHS: South Africa, 2003
AfrE	Swaziland	68 %	Household survey	2003	WHS: Swaziland, 2003 (Preliminary data from WHS)

Table 1 (contd.)

Region[1]	Country	Households using solid fuel	Data source	Year	Reference
AfrE	Tanzania	96 %	Household survey	1992/3	WBAD, 2000 citing Human Resources Development Survey, 1993 (World Bank 2000).
AfrE	Uganda	97 %	Household survey	2000/2001	WBAHSD – Demographic and Health Survey (DHS)
AfrE	Zambia	86 %	Household survey	2001/2002	Macro, 2003
AfrE	Zimbabwe	73 %	Household survey	2003	WHS: Zimbabwe, 2003 (Preliminary data from WHS)
AmrB	Brazil	12 %	Household survey	2003	WHS: Brazil, 2003
AmrB	Columbia	15 %	Household survey	2000	Macro, 2003
AmrB	Dominican Republic	14 %	Household survey	2003	WHS: Dominican Republic, 2003
AmrB	Mexico	12 %	Household survey	2003	WHS: Mexico, 2003
AmrB	Uruguay	2 %	Household survey	2003	WHS: Uruguay, 2003
AmrD	Bolivia	25 %	Household survey	1998	Macro, 2003
AmrD	Ecuador	3 %	Household survey	2003	WHS: Ecuador, 2003 (Preliminary data from WHS)
AmrD	Guatemala	62 %	Household survey	2003	WHS: Guatemala, 2003 (Preliminary data from WHS)
AmrD	Haiti	96 %	Household survey	2000	Macro, 2003
AmrD	Nicaragua	58 %	Household survey	2001	Macro, 2003
AmrD	Peru	33 %	Household survey	2000	Macro, 2003
EmrB	Iran	2 %	National Energy Statistics	1999	WRI, 2003
EmrB	Lebanon	0 %	National energy statistics	1996/7	WRI, 2003
EmrB	Libya	3 %	National energy statistics	1996/7	IEA reports 1996/7 that the residential sector in Libya consumed 5236 TJ of biomass, but no coal [IEA,1999]
EmrB	Tunisia	5 %	Household survey	2003	WHS: Tunisia, 2003 (Preliminary data from WHS)
EmrB	United Arab Emirates	0 %	Household survey	2003	WHS: United Arab Emirates, 2003 (Preliminary data from WHS)
EmrD	Afghanistan	98 %	National energy statistics	1999	WRI, 2003
EmrD	Djibouti	6 %	Household survey	1996	WBAD, 2000 citing Household Priority Survey, Enquête Djiboutienne auprès des ménages. Indicateurs sociaux, 1996
EmrD	Egypt	2 %	Household survey	2000	Macro, 2003
EmrD	Iraq	2 %	National energy statistics	1999	WRI, 2003
EmrD	Morocco	4.8 %	Household survey	2003	WHS: Morocco, 2003
EmrD	Pakistan	72 %	Household survey	2004	WHS: Pakistan, 2004 (Preliminary data from WHS)
EmrD	Sudan	100 %	National energy statistics	1999	IEA, 1999
EmrD	Yemen	42 %	Household survey	1998	WBHBS, 2004
EurA	Croatia	12 %	Household survey	2003	WHS: Croatia, 2003
EurA	Czech Republic	2 %	Household survey	2003	WHS: Czech Republic, 2003
EurA	Slovenia	8 %	Household survey	2003	WHS: Slovenia, 2003 (Preliminary data from WHS)
EurA	Spain	2 %	Household survey	2003	WHS: Spain, 2003 (Preliminary data from WHS)
EurB	Armenia	26 %	Household survey	2000	WBDDHS
EurB	Bosnia and Herzegovina	51 %	Household survey	2003	WHS: Bosnia and Herzegovina, 2003 (Preliminary data from WHS)

Table 1 (contd.)

Region[1]	Country	Households using solid fuel	Data source	Year	Reference
EurB	Georgia	42 %	Household survey	2003	WHS: Georgia, 2003
EurB	Romania	23 %	Household survey	2002	WBFBS
EurB	Slovakia	2 %	Household survey	2003	WHS: Slovakia, 2003 (Preliminary data from WHS)
EurB	Tajikistan	75 %	Household survey	1999	WBLSMS
EurB	Turkey	11 %	National energy statistics	1999	WRI, 2003
EurB	Turkmenistan	0.2 %	Household survey	2000	Macro, 2003
EurC	Estonia	15 %	Household survey	2003	WHS: Estonia, 2003
EurC	Kazakhstan	5 %	Household survey	2003	WHS: Kazakhstan, 2003 (Preliminary data from WHS)
EurC	Latvia	10 %	Household survey	2003	WHS: Latvia, 2003 (Preliminary data from WHS)
EurC	Russian Federation	7 %	Household survey	2003	WHS: Russian Federation, 2003
EurC	Ukraine	6 %	Household survey	2003	WHS: Ukraine, 2003 (Preliminary data from WHS)
SearB	Indonesia	72 %	Agricultural census	2003	WBAC
SearB	Sri Lanka	67 %	Household survey	2003	WHS: Sri Lanka, 2003
SearB	Thailand	72 %	National energy statistics	1997	FAO, 1997
SearD	Bangladesh	88 %	Household survey	2003	WHS: Bangladesh, 2003
SearD	India	74 %	Household survey	2003	WHS: India, 2003
SearD	Myanmar	95 %	Household survey	2004	WHS: Myanmar, 2004
SearD	Nepal	80 %	Household survey	2003	WHS, 2003
WprB	Papua New Guinea	90 %	Household survey	1996	World Bank Household Survey (HHS) found under the LSMS website http://www.worldbank.org/html/ prdph/lsms/l
WprB	Cambodia	96 %	Household survey	2000	WBDDHS
WprB	China	80 %	National energy statistics	1996	GPRC, 1996
WprB	Lao People's Democratic Republic	97 %	Household survey	2003	WHS: Lao People's Democratic Republic, 2003 (Preliminary data from WHS)
WprB	Malaysia	1 %	Household survey	2003	WHS: Malaysia, 2003 World Health Organization
WprB	Philippines	47 %	Household survey	2003	WHS: Philippines, *2003 World Health Organization
WprB	Vietnam	70 %	Household survey	2003	WHS: Vietnam, 2003

Note

1. World Health Organization epidemiologic regions are defined by geographic location and patterns of adult and child mortality. A more detailed description is provided in Appendix A.

violation of assumptions of normalcy and constant variance. Collinearity and multicollinearity were assessed, and tolerance statistics were not suggestive of any multicollinearity.

Newly available household fuel use data and more recent values of development parameters were used in the model for the year 2003 to test whether the original model, based on limited data, still holds with a larger number of data points. The initial model turned out to be relatively robust and resulting estimates of the 2003 modeling were not very different from the 2000 predictions (Tables 3 and 4). Per capita petroleum use, however, was no longer a significant parameter in the 2003 predictions and was therefore dropped from the model. The importance of information on per capita petroleum use thus seems to be limited. See Table 5.

3. Results

This model was used to predict percentages of household solid fuel use in all countries with unknown solid fuel use patterns. For the recent MDG reporting on solid fuel use, for a total of 181 countries, 94 country data were compiled from surveys and 52 country data were assumed to have made the transition to clean fuels with less than 5 % of solid fuel use. For 35 countries missing data were estimated by the model described in this article. Missing values of explanatory variables (e.g., GNI per capita) were replaced with mean values for each variable. In order to force the percentage of solid fuel use to lie between 5 %

Table 2. Development parameters used to model household solid fuel use

Indicator	Source
Proportion of households using solid fuels (dependent variable)	Household Fuels Database [Smith and Desai, 2001]
Adult female illiteracy, 1998	[World Bank, 2001]
Average annual growth rate	[World Bank, 2003]
Dummy variables for six WHO sub-regions	World Health Organization
Electricity consumption, per capita, 1997 (kWh/year)	[World Bank, 2001]
Annual fuelwood production per capita (kg)	Transformation of fuelwood production, 1996
Annual fuelwood production (kg)	[United Nations, 1996]
Population 2000	[United Nations, 2003]
Gini coefficient	[World Bank, 2003]
GNI per capita ($, PPP)	[World Bank, 2003]
ln (GNI per capita, 1999)[1]	Transformation of GNI per capita
Petroleum use per capita (kg)	[United Nations, 1996]
ln (petroleum use per capita)	Transformation of petroleum use per capita
Rural population (%)	[United Nations, 2003]

Note

1. ln = natural logarithm

Table 3. Fuel prediction model, 2000[1]

	Unstandardized coefficients			95 % CI for beta		
	Beta	Std. error	t	Sig.	Lower	Upper
(Constant)	1.12	0.350	3.19	0.0025	0.414	1.82
Rural	0.661	0.214	3.09	0.0033	0.231	1.09
WHO Eastern Mediterranean Region	-0.248	0.0709	-3.50	0.0010	-0.390	-0.105
ln (GNI)	-0.104	0.0405	-2.56	0.0136	-0.185	-.0224
Per capita petroleum use	-0.0003	0.0001	-2.55	0.0143	-.0006	-.0001

Note

1. Dependent variable is the percentage of households using solid fuels.

Table 4. Fuel prediction model, 2003[1]

	Unstandardized coefficients			95 % CI for beta		
	Beta	Std. error	t	Sig.	Lower	Upper
(Constant)	1.543	0.2595	5.95	0.000	1.03	2.06
Rural	0.857	0.1243	6.90	0.000	0.61	1.104
WHO Eastern Mediterranean Region	-0.156	0.0568	-2.75	0.007	-0.27	-0.044
ln (GNI)	-0.181	0.0267	-6.76	0.000	-0.23	-0.128
Per capita petroleum use	-0.000453	0.0000339	-1.13	0.260	-0.000124	0.0000341

Note

1. Dependent variable is the percentage of households using solid fuels.

Table 5. Fuel prediction model without petroleum use, 2003[1]

	Unstandardized coefficients			95 % CI for beta		
	Beta	Std. error	t	Sig.	Lower	Upper
(Constant)	1.534	0.260	5.90	0.000	1.017	2.050
Rural	0.891	0.1214	7.38	0.000	0.651	1.131
WHO Eastern Mediterranean Region	-0.169	0.0559	-3.02	0.003	-0.280	-0.0580
ln (GNI)	-0.184	0.0267	-6.89	0.000	-0.237	-0.131

Note

1. Dependent variable is the percentage of households using solid fuels

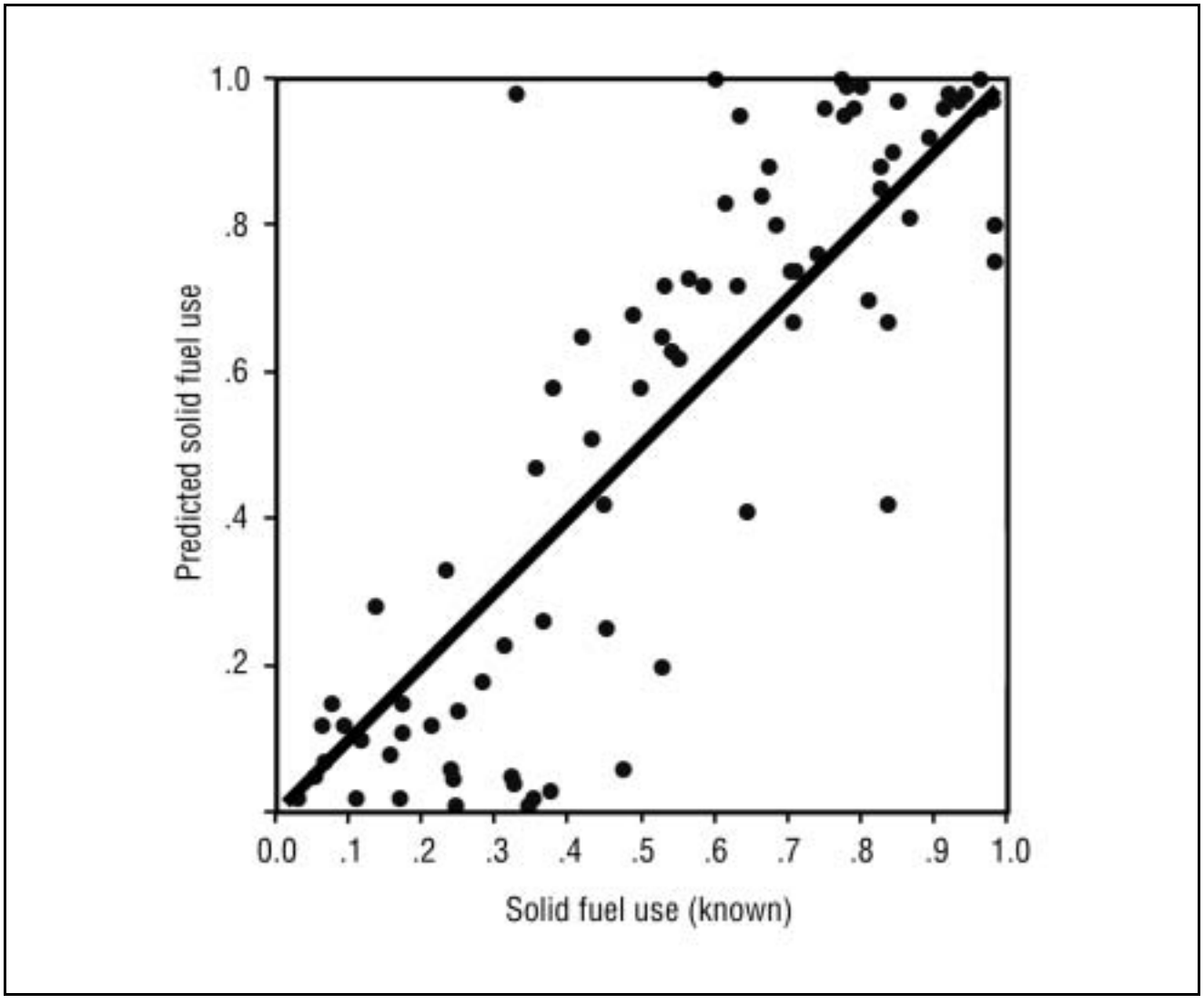

Figure 1. Proportion of households using solid fuels: known vs. predicted values of national household solid fuel use

and 95 %, all predicted values less than 0 or greater than 100 were converted to 5 % and 95 % respectively.

3.1. Comparison of known versus predicted values

The following graph of known versus predicted values of solid fuel use suggests that the model performs reasonably consistently across different proportions of solid fuel use (Figure 1). In other words, the model estimates fuel use as well for countries with low proportions of solid fuel use as it does for countries with high proportions of solid fuel use. There does, however, seem to be a tendency to slightly under-predict at higher proportions of solid fuel use, and to slightly over-predict at lower proportions. In addition, there does not seem to be a bias towards over- or underestimation of fuel use for countries where around

half the population uses solid fuels.

3.2. Comparison of 2000 and 2003 estimates

As the model used for 2003 incorporates year-specific information on annual income per capita and urban/rural population, it enables the statistical estimation of changes in household solid fuel use predicted to occur with annual changes in income and population growth. In general, known estimates of solid fuel use seem to be lower in 2003 than in 2000. It should be noted, however, that these differences are probably largely due to improvements in the underlying household solid fuel use data, and therefore do not necessarily reflect a decline over the three-year period from 2000 to 2003. In general, countries which have experienced economic development have slightly lower estimates of solid fuel use in 2003.

4. Discussion

Within just a few years, the knowledge base about solid fuel use has significantly increased, mainly due to the recent information gathered through the World Health Survey providing data for 42 countries with previously very scarce information. In 2000, fuel use was only available for 52 countries. In contrast, in this new round of reporting on the situation in 2003, solid fuel use estimates had to be modeled for only 35 countries.

Statistical estimations are not absolute reflections of reality. Small changes in estimates generated by the model may not necessarily indicate small changes in household solid fuel use. As previously mentioned, the compilation of data from various sources, with different methodologies and sample sizes, makes it difficult to characterize the uncertainty associated with the estimates for each country and region. Thus, while the model is a useful tool, there is no substitution for routine assessments of household solid fuel use.

Many of the nations with poor predictions (including Algeria, Afghanistan, the Congo, and Sudan) are experiencing serious civil unrest or war. This suggests that the economic and development indicators used here, and/or the known solid fuel use estimates, may not be robust under circumstances of political instability or insufficient governance.

If the prevalence of household solid fuel use is relatively high in a country, environmental health specialists should lobby for the addition of household fuel-related questions to national censuses or household surveys, preferably distinguishing among the principal categories, i.e., electricity, gas, coal, wood, charcoal, dung, and crop residues. For some locations, response categories may also need to include modern biofuels, such as biogas or ethanol, and solar energy. Although quantities of fuel and end-use information are often difficult to assess by minimally trained surveyors, experience from several Demographic and Health Surveys suggests that accurate information on the main fuel used for cooking and heating is easy to ascertain. The use of these questions will dramatically improve the reliability and consistency of information on household fuel use on a global scale.

It should be noted, however, that the percentage of households using solid fuels is an imperfect indicator of indoor air pollution, selected for convenience and current availability of data. This indicator does not address the issue of ventilation/household characteristics and most importantly, does not necessarily provide a good reflection of potential exposures resulting from solid fuel use. A useful indicator of indoor air pollution should not only report the main cooking fuel but also include aspects of ventilation, such as stove type and cooking location. Moreover, in many countries, particularly in sub-Saharan Africa, cooking is mostly done outdoors.

Indoor air pollution from solid fuel use remains a widespread and important risk factor in developing countries. Over 1.6 million deaths have been attributed to indoor air pollution from solid fuel use in 2000 alone [Smith et al., 2004]. A majority of these deaths are from acute respiratory infections in young children under five years of age. Shifting up the energy ladder towards "modern" or "cleaner" fuels is a way not only to achieve better health, but also to improve economic development prospects. In addition, the increased combustion efficiency that makes these fuels cleaner and more energy-efficient can also actually result in lower greenhouse gas emissions compared to poorly burned biomass fuels, even when renewably harvested [Smith and Desai, 2001]. In the absence of interventions or policies to increase access to cleaner fuels, however, drastic reductions in household solid fuel use are unlikely to occur. Governments and international development agencies should identify cost-effective, locally appropriate interventions, including access to cleaner fuels and improved ventilation [Mehta, 2004], to achieve better health and other important objectives related to sustainable development [Smith, 2002]. ■

Addendum: a request for help

The authors recognize that they have likely missed national surveys or other reliable sources of information on solid fuel use, as many of these are not available in the indexed literature archives, but in government and NGO reports and other "gray literature". Thus, we ask readers who know of such information missing in our database to share relevant references. Please send such information to Kirk Smith at krksmith@berkeley.edu and Eva Rehfuess at rehfuesse@who.int. Thank you.

Acknowledgements

The authors are thankful to the Department for the Protection of the Human Environment, World Health Organization, for supporting this work. We much appreciate the comments, advice, and leads to sources provided by Robert Bailis, Jonathan Sinton, and Maria Josefina Figueroa.

The views expressed in this paper are those of the authors and do not necessarily reflect the position of the World Health Organization, the Health Effects Institute or its sponsors.

Note

1. Unlike gross domestic product (GDP), gross national income (GNI) is a quantitative measure of the size and performance of an economy calculated using a three-year average of exchange rates, which makes it less sensitive to short-term fluctuations in exchange rates and policies. For more detailed information on how the GNIs used here were calculated, visit www.worldbank.org.

Prefatory note on references

The following abbreviations, some of which have been used in repeated references of which they form a part, are listed here for convenience to enable the reader to easily find the references of which they form part.

WBAD, 2000 = World Bank, 2000. Africa Database: 2000

WBAHSD = World Bank. World Bank Africa Household Survey Databank

WBAC = World Bank. World Bank Agricultural Census

WBDDHS = World Bank. World Bank Databank – Demographic and Health Survey

WBFBS, 2004 = World Bank. World Bank Family Budget Survey (FBS), 2004

WBHBS, 2004 = World Bank. World Bank Household Budget Survey (HBS), 2004

WBLSMS = World Bank. World Bank Living Standards Measurement Study (LSMS)

WHS = World Health Organization. World Health Survey

References

Food and Agricultural Organization (FAO), 1997. *Review of Wood Energy Data in RWEDP Member Countries,* FAO Field Doc. No. 47, 1997.

Government of Botswana (GOB), 1991. *Population; Housing Census,* CSO, Gabarone, Botswana, Table H10, p. 483.

Government of India (GOI), 2001. *Census of India.*

Government of People's Republic of China (GPRC), 1996. *China Energy Statistical Yearbook: 1991-1996,* Zhongguo Tongji Chubanshe (Chinese Statistical Publishing House), beijing.

International Energy Agency (IEA), 1999. *Energy Statistics of Non-OECD Countries 1996-1997,* Paris, The Organization for Economic Cooperation and Development (OECD) (International Energy Agency).

Macro International Inc. (Macro), 2003. *Household Energy Use in Developing Countries: A Multi-country Study* (Source: Demographic and Health Survey (DHS) specially tabulated by Macro International Inc. for the World Bank, Joint UNDP/World Bank Energy Sector Management Assistance Programme, 2003.

Mehta, S., and Shahpar, C., 2004. "The health benefits of interventions to reduce indoor air pollution from solid fuel use: a cost-effectiveness analysis", *Energy for Sustainable Development,* VIII(3), September, pp. 53-59.

Smith, K.R., 2002. "Indoor air pollution in developing countries: recommendations for research", *Indoor Air,* 12(3), pp. 198-207.

Smith, K., and Desai, M., 2001. "The contribution of global environmental factors to ill-health", in Martens, P., and McMichael, A., (eds.), *Environmental Change, Climate, and Health: Issues and Research Methods,* Cambridge University Press, Cambridge, UK.

Smith, K., Mehta, S., and Maeusezahl-Feuz, M., 2004. "Indoor air pollution from household use of solid fuels", in Ezzati, M., Lopez, A.D., Rodgers, A., and Murray, C.J.L., *Comparative Quantification of Health Risks: Global and Regional Burden of Disease Due to Selected Major Risk Factors, Vol. 2,* World Health Organization, Geneva, pp. 1435-1493.

United Nations, 1993. *Energy Statistics Yearbook,* United Nations, New York.

United Nations, 2003. *United Nations World Population Prospects,* United Nations, New York.

World Bank, 2000. *Africa Database: 2000* (CD-ROM) [hereafter WBAD, 2000]

WBAD, 2000 citing Consumer Expenditure Survey, 1992; Government of Nigeria, Social Statistics in Nigeria: 1990, Federal Office of Statistics, Lagos, Nigeria, 1990, p. 61.

WBAD, 2000 citing Household Integrated Survey, Enquête intégrale budget et consummation, 1994/95, 2000

WBAD, 2000 citing Human Resources Development Survey, 1993, 2000.

World Bank. World Bank Africa Household Survey Databank – Demographic and Health Survey (DHS), http://www4.worldbank.org/afr/poverty/databank/default.cfm, accessed 2004 [hereafter WBAHSD].

WBAHSD – Demographic and Health Survey: Benin 2001

WBAHSD – Enquête Camerounaise Auprès des Ménage (ECAM).

WBAHSD – Enquête Prioritaire (EP).

WBAHSD – Enquête Prioritaire auprès des Ménages (EP).

WBAHSD – Demographic and Health Survey (DHS)

World Bank. World Bank Agricultural Census, http://www.bps.go.id/index.shtml, accessed 2004 [WBAC].

World Bank. World Bank Databank – Demographic and Health Survey (DHS), http://www.measuredhs.com/countries/country.cfm, accessed 2004 [hereafter WBDDHS].

World Bank. World Bank Family Budget Survey (FBS), 2004 [WBFBS, 2004].

World Bank. World Bank Household Budget Survey (HBS), 2004 [WBHBS, 2004].

World Bank. World Bank Living Standards Measurement Study (LSMS), http://www.worldbank.org/html/prdph/lsms/, accessed 2004 [WBLSMS].

WBAHSD – National Household Poverty Survey, Gambia 1998, 2000

WBAD, 2000 citing Household Priority Survey, Enquête permanente de conjuncture économique et sociale, 1995, 2000.

WBAD, 2000 citing Household Priority Survey, 1993, 2000.

WBAD, 2000 citing Household Priority Survey, Enquête Djiboutienne auprès des ménages, Indicateurs sociaux, 1996, 2000.

WBAD, 2000 citing Inquerito ligeiro junto às familias, 1992, 2000.

WBAD, 2000 citing Survey of Household Expenditure and Household Economic Activities (SHEHEA), 1989/90, 2000.

World Bank, 2001. *World Development Indicators,* World Bank, Washington, DC.

World Bank, 2003. *World Development Indicators.* World Bank, Washington, DC.

World Health Organization. World Health Survey [hereafter WHS], 2003.

WHS: Bangladesh, 2003.

WHS: Bosnia and Herzegovina, 2003 (Preliminary data from WHS).

WHS: Brazil, 2003.

WHS: Burkina Faso, 2003 (Preliminary data from WHS).

WHS: Chad, 2003 (Preliminary data from WHS).

WHS: Comoros, 2003 (Preliminary data from WHS).

WHS: Congo, 2003 (Preliminary data from WHS).

WHS: Côte d'Ivoire, 2003. (Preliminary data from WHS)

WHS: Croatia, 2003.

WHS: Czech Republic, 2003.

WHS: Dominican Republic, 2003.

WHS: Ecuador, 2003 (Preliminary data from WHS).

WHS: Estonia, 2003.

WHS: Ethiopia, 2003.

WHS: Georgia, 2003.

WHS: Ghana, 2003 (Preliminary data from WHS).

WHS: Guatemala, 2003 (Preliminary data from WHS).

WHS: India, 2003.

WHS: Kazakhstan, 2003 (Preliminary data from WHS).

WHS: Kenya, 2004.

WHS: Lao People's Democratic Republic, 2003 (Preliminary data from WHS).

WHS: Latvia, 2003 (Preliminary data from WHS).

WHS: Malawi, 2003.

WHS: Malaysia, 2003.

WHS: Mauritania, 2003 (Preliminary data from WHS).

WHS: Mauritius, 2003.

WHS: Mexico, 2003.

WHS: Morocco, 2003.

WHS: Myanmar, 2004.

WHS: Namibia, 2003.

WHS: Pakistan, 2004 (Preliminary data from WHS).

WHS: Paraguay, 2003 (Preliminary data from WHS).

WHS: Philippines, 2003.

WHS: Russian Federation, 2003.

WHS: Senegal, 2003 (Preliminary data from WHS).

WHS: Slovakia, 2003 (Preliminary data from WHS).

WHS: Slovenia, 2003 (Preliminary data from WHS).

WHS: South Africa, 2003.

WHS: Spain, 2003 (Preliminary data from WHS).

WHS: Sri Lanka, 2003.

WHS: Swaziland, 2003 (Preliminary data from WHS).

WHS: Tunisia, 2003 (Preliminary data from WHS).

WHS: Ukraine, 2003 (Preliminary data from WHS).

WHS: United Arab Emirates, 2003 (Preliminary data from WHS).

WHS: Uruguay, 2003.

WHS: Vietnam, 2003.

WHS: Zimbabwe, 2003 (Preliminary data from WHS).

World Resources Institute (WRI), 2003. *Earth-Trends: The Environmental Information Portal,* January.

Appendix A. World Health Organization epidemiologic regions

Region	Sub-region	Mortality stratum	
		Child	Adult
Africa	AfrD	High	High
Africa	AfrE	High	Very high
The Americas	AmrA	Very low	Very low
The Americas	AmrB	Low	Low
The Americas	AmrD	High	High
Eastern Mediterranean	EmrB	Low	Low
Eastern Mediterranean	EmrD	High	High
Europe	EurA	Very low	Very low
Europe	EurB	Low	Low
Europe	EurC	Low	High
South-East Asia	SearB	Low	Low
South-East Asia	SearD	High	High
Western Pacific	WprA	Very low	Very low
Western Pacific	WprB	Low	Low