International Seminar on Bioenergy & Sustainable Rural Development

Casa de Gobierno
Paseo de la República 1500 Col. Oviedo Mota

Morelia, México
26-28 June 2003

SEMINAR PROCEEDINGS (Excerpt)

ANES

The International Seminar of Bioenergy and Sustainable Rural Development was held in Morelia, Mexico, from June 26 to 28 2003. It was organized jointly by the Latin American Thematic Network on Bioenergy (LAMNET), the Center for Ecosystem Research (CIECO) from the National Autonomous University of Mexico, the Food and Agriculture Organization of the United Nations (FAO), the National Association for Solar Energy (ANES) and the State Government of Michoacan, Mexico.

LAMNET - Latin America Thematic Network on Bioenergy
Coordination: WIP, Germany
Coordinator/ focal contact point:
Dr. Rainer Janssen (rainer.janssen@wip-munich.de)

Updated information on this workshop is available at http://www.bioenergy-lamnet.org, http://bioenergia.oikos.unam.mx and http://www.anes.org.

Workshop Organisation Support

Lic. Claudia Sánchez, Center for Ecosystem Research (CIECO), UNAM, México

M.S. Laura Hernández, Center for Ecosystem Research (CIECO), UNAM, México

Biol. Alan S. Cervantes, Center for Ecosystem Research (CIECO), UNAM, México

Biol. Adrián Ghilardi, Center for Ecosystem Research (CIECO), UNAM, México

Rodolfo Díaz, Center for Ecosystem Research (CIECO), UNAM, México

Dr. Javier Aguillón, Instituto de Ingeniería, UNAM, México

M. Arq. Ana Rosa Velasco, National Association for Solar Energy (ANES), México

Ing. Francesco Cariello, ETA-Florence, Italy

Dr. Giuliano Grassi, European Biomass Industry Association – EUBIA

Ing. Anton Hofer, WIP-Munich, Germany

Dr. Peter Helm, WIP-Munich, Germany

Editor of Workshop Proceedings

Dr. Rainer Janssen, WIP, Germany

Dr. Omar Masera, Center for Ecosystem Research (CIECO), UNAM, México

Dr. Eduardo Rincon, National Association for Solar Energy (ANES), México

Dr. Gustavo Best, Food and Agriculture Organization of the United Nations (FAO)

Published by: WIP-Munich
Sylvensteinstr. 2
81369 Munich, Germany
Phone: +49 89 720 127 35
Fax: +49 89 720 127 91
E-mail: wip@wip-munich.de
Web: www.wip-munich.de

International Seminar on Bioenergy & Sustainable Rural Development

WORKING GROUP 4: BIOMASS RESOURCES

International Seminar on Bioenergy and Sustainable Rural Development
- 5th LAMNET Project Workshop – Mexico 2003

ENVIRONMENTAL AND SOCIO-ECONOMIC IMPACTS OF CHARCOAL PRODUCTION IN KENYA

Rob Bailis
Energy and Resources Group - Renewable and Appropriate Energy Laboratory, University of California Berkeley
310 Barrows Hall, Berkeley CA 94720-3050, USA
Email: rbailis@socrates.berkeley.edu
Internet: http://socrates.berkeley.edu/erg/~rael

ABSTRACT

Every day, nearly seven thousand tons of charcoal is used in households and small commercial enterprises in Kenya. This charcoal is produced from roughly 80,000 m^3 of wood, which is harvested primarily from arid and semi-arid lands (ASAL) that constitute over two thirds of Kenya's land mass. Charcoal production and consumption on this scale has far-reaching environmental and socio-economic implications. However, not all of the impacts associated with charcoal are negative. While many people posit that the charcoal trade harmful to the environment because of the impacts that charcoal production can have on woodlands as well as the emissions that are associated with wood pyrolysis, there are also benefits associated with charcoal in the form of rural employment and reduced levels of indoor air pollution relative to fuel wood, the primary source of residential energy for rural Kenyans. In addition, charcoal can be produced from trees harvested on a sustainable basis or made from carbonized biomass waste products, which occur in abundance in many less developed countries. Focusing only on charcoal's negative attributes can lead to incoherent policies that are doomed to fail. This is evident in Kenya, where charcoal production and transportation is illegal, despite the daily deliveries of thousands of tons of charcoal to Nairobi and other cities and towns.

Charcoal's illegal status leads directly to corruption and bribes that producers and suppliers must pay to local officials and police in order to get their product to market; these costs are passed onto consumers. It also leaves the government out of the revenue steam because it does not impose stumpage fees or taxes at any point of the supply chain. Finally, despite current attitudes and practices, charcoal production is not inherently environmentally destructive – arid woodlands are resilient ecosystems that can support repeated harvests with proper management practices. The competing costs and benefits of different woodland management regimes, different methods of charcoal production, and improved stoves for end-use require careful analysis in order to create policies that best serve charcoal producers and users as well as the environment on which they depend. In this paper, I will review some of the current research on a range of issues associated with charcoal in Kenya. I will discuss the public health and social welfare issues associated with the charcoal life cycle. I will also examine the environmental impacts of charcoal and present an analysis of greenhouse gas (GHG) emissions associated with charcoal production and use.

BACKGROUND

Charcoal production - Charcoal is a wood product that is made by heating wood in the absence of sufficient air for full combustion to occur. Heating releases the wood's volatile compounds, leaving behind a relatively lightweight and clean-burning fuel that is 70-90% carbon. Charcoal can be produced by a range of methods, from simple earth kilns to brick or metal kilns and retorts that capture condensable volatile compounds or combust them as gases, using the heat generated to drive the charcoal-making process (FAO, 1987). In an earth-mound kiln, the most common method of making charcoal in sub-Saharan Africa, between five and ten tons of wood are needed to make 1 ton of charcoal: a mass-based conversion efficiency of 10-20%. In these circumstances, between 60-80% of the wood's energy is lost in the production process. The efficiency of the process depends on a number of variables: scale of production (production can range from less than a hundred kilos to tens of tons), moisture content and size of the wood, and time taken for the burn (which also depends on the scale of production, ranging from 2-10 days). The skill and techniques of the producers also affects the process, however this is harder to quantify and is difficult to separate from environmental and economic conditions.

Using special kilns or retorts can reduce energy losses to only 30 or 40%. However, this equipment is expensive relative to traditional methods. It is not likely to be widely adopted in developing countries without additional incentives, particularly in regions where wood is accessible for little or no financial cost, as is the case in Kenya's unregulated charcoal industry.

Charcoal consumption - Charcoal is the principal woodfuel in urban areas of many less developed countries. There are a number of reasons why people in dense urban settlements favor charcoal over wood: it has a higher energy density, it burns more cleanly (which reduces exposure to harmful pollutants), and it is easier to transport, handle, and store. Charcoal can be purchased in small amounts and charcoal-burning stoves are quite inexpensive, making it more attractive than LPG or electricity. In addition, many people favor charcoal because it is considered a more modern fuel than wood, and is thus a kind of status symbol. In Kenya, all of these factors play a role. In addition, there is growing evidence that charcoal, commonly considered an urban source of residential energy, is becoming an increasingly popular fuel among the rural population (Kituyi, Marufu et al., 2001a; Ministry of Energy, 2002). This will be discussed in detail below.

Charcoal in Kenya - Recent studies estimate that Kenyans produce and consume between 2.4 and 2.9 million tons of charcoal annually (Kituyi, Marufu et al., 2001b; Ministry of Energy, 2002). There is very little trade in charcoal, thus production and consumption are balanced. Kenya's level of consumption is one of the highest in the world.
Table **1** shows consumption data in the ten largest charcoal-using countries in the world listed in order of net consumption. Six of the top ten charcoal producing countries are in sub-Saharan Africa. Kenya ranks fourth in consumption behind Brazil, Nigeria and Ethiopia and it ranks second in consumption per capita after Zambia.[1]

[1] **Brazil, which leads the world in charcoal consumption, stands well apart from most other charcoal producing nations because, unlike countries in sub-Saharan Africa, charcoal is used as a major industrial input. While other countries listed in**
Table 1 rely heavily on charcoal as a residential fuel, charcoal contributes little to household energy needs in Brazil (see census data in Government of Brazil, 1991).

Table 1: Charcoal consumption statistics from the world's top-10 charcoal consumers (all data are for 2000)[a]

Country	Charcoal consumption (tons)	Population	Fraction of world consumption	Consumption per capita (kg per person)[b]
1. Brazil	12,063,000	170,100,000	31%	71
2. Nigeria	3,057,000	126,910,000	8%	24
3. Ethiopia	2,907,000	64,298,000	7%	45
4. Kenya	2,475,000	30,092,000	6%	82
5. India	1,654,000	1,015,923,000	4%	2
6. D. R. Congo	1,418,000	10,273,300	4%	28
7. Thailand	1,222,000	60,728,000	3%	20
8. Egypt	1,196,000	63,976,000	3%	19
9. Tanzania	1,165,000	33,696,000	3%	35
10. Zambia	1,040,000	10,089,000	3%	103
World total	*40,615,004*	6,054,117,000	*100%*	7

[a] Population data are from the World Bank's development database (http://devdata.worldbank.org/dataonline/). Charcoal data are from the UN Food and Agriculture Organization's (FAO) on-line statistical database (http://apps.fao.org/page/collections? subset=forestry) with the exception of Kenya. The FAO reports annual Production, Imports, and Exports, but not Consumption. The latter was calculated by assuming Consumption = Production + Imports – Exports (neglecting the possibility of stockpiling). Data for Kenya are taken from (Ministry of Energy, 2002). The FAO report Kenya's charcoal consumption for the year 2000 to be only 640,500 tons, however the recent national survey, based on household level observation estimates it to be roughly 2.4 million tons: nearly 300% higher. Many other discrepancies exist in national-level charcoal data. See, for example, (FAO-WETT, 2002), which lists a range of charcoal data and sources for 22 African countries. As with Kenya, some of the FAO's estimates differ by a factor of two or more with other sources of data.

[b] This indicates a national rate of consumption, rather than consumption among those people reporting use. Aggregate consumption figures like this can be misleading and are reported here simply for comparison across charcoal using countries. It is more important to quantify consumption among people reporting use, which will be discussed below.

Kenyan charcoal is produced by manual laborers who carbonize, on average, 80,000 m^3 of wood daily.[2] Production is scattered in thousands of locations, primarily in arid and semi-arid woodlands, which constitute over two thirds of Kenya's total land area. Recent years have seen changes in the origin of charcoal supplied to urban demand centers. As discussed above, charcoal in Kenya is primarily a household fuel. Rural and urban households together accounted for over 80% of charcoal consumption 2000. Commercial, industrial, and institutional consumers account for the balance; this includes restaurants, businesses, small-scale industries like metal workers, and schools.

[2] This is based on an annual charcoal consumption of 2.4 million tons in the year 2000 (Ministry of Energy, 2002). Kituyi et al. assuming that wood to charcoal conversion efficiency is 12% (based on the mass of charcoal produced per unit of air-dried wood). With air-dried wood (20% moisture content), one ton of charcoal requires roughly eight tons (or 12 m^3) of wood. Pennise et al. (Pennise, Smith et al., 2001) found that large earth kilns in Kenya, with initial charges of 15-25 tons of wood, can operate at over 25% efficiency (wet basis) with well-dried wood (less than 20% moisture). At that efficiency, producing one ton of charcoal requires less than 4 tons of wood. However, efficiencies from earth kilns measured in the field are normally somewhat lower. Kituyi et al. (Kituyi, Marufu et al., 2001b) assume 17% mass-based conversion efficiency for wood at 30% moisture, or 6 tons of wood per ton of charcoal produced.

As a result of rapid urban population growth and changing patterns of rural consumption, in the past two decades charcoal use has increased at a rate that far exceeds general population growth. Unfortunately, data is not available to observe the pattern of growth in detail, only to mark two points in the past two decades. Household energy surveys at the national scale are infrequent. The first such survey was performed by the Beijer Institute in 1980 with funding from Dutch and Swedish development organizations (O'Keefe, Raskin et al., 1984; Hosier, 1985). A second survey was completed in 1997 (Kituyi, Marufu et al., 2001a; Kituyi, Marufu et al., 2001b) and a third was done more recently, in 2000, with the results released in late 2002 (Ministry of Energy, 2002). During the long gap between the initial survey and the more recent work, there were a number of village and/or community-scale surveys, but nothing at a scale that indicates how the trend of charcoal consumption evolved on a national level. Despite the absence of interim data, the surveys reveal some interesting trends in household energy demand.

Table 2: Changes in Kenyan Charcoal Consumption: 1980-2000[a]

	1980	2000	% Change (1980-2000)
National Population (Millions of people)	16.6	30.1	81%
Urban	2.7	10.0	276%
Rural	14.0	20.1	44%
Inflation adjusted GDP per capita (2000 USD)	237	231	-3%
% of URBAN households reporting charcoal use	82%	82%	0%
Average per capita consumption in URBAN households reporting use (kg/cap-yr)	175	152	-13%
% RURAL households reporting charcoal use	16%	34%	113%
Average per capita consumption in RURAL households reporting use (kg/cap-yr)	110	156	42%
Total URBAN charcoal consumption	0.4	0.9	135%
Total RURAL charcoal consumption	0.3	1.1	308%
Commercial/institutional charcoal consumption	0.1	0.4	315%
National Charcoal consumption (Million tons)	0.8	2.5	223%
Real cost of charcoal (2000 KSh/kg) [b]	6-8	8-11	33-38%
Real cost of kerosene (2000 KSh/l)[c]	38	33	-13%

[a] Data for 1980 come from the Beijer Institute study and 2000 data come from the MoE survey report (Hosier, 1985; Ministry of Energy, 2002). Socio-economic data come from the World Bank's development database (http://devdata.worldbank.org/dataonline/).

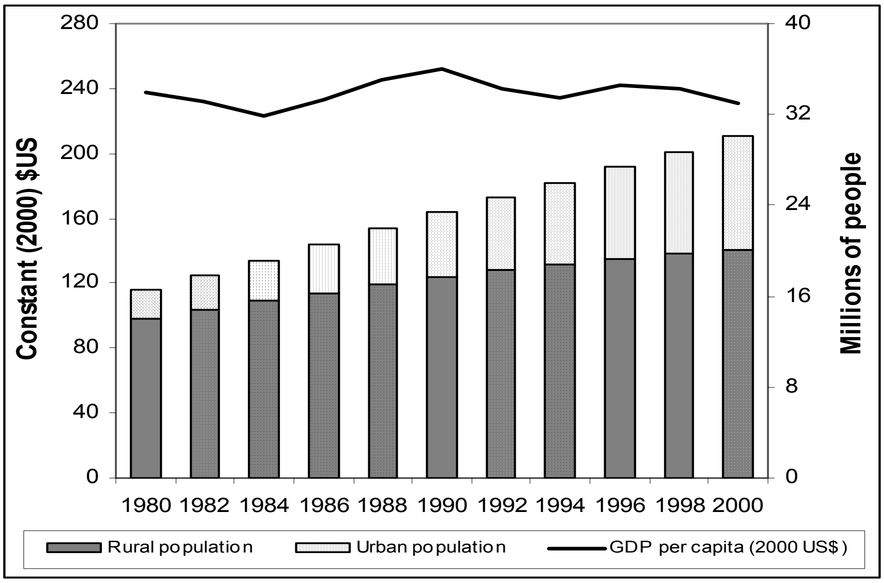
[b] Retail charcoal prices depend in the quantity purchased, which ranges from large sacks of 30-40 kg to small tins of 1-3 kg.

[c] This value represents the inflation adjusted average price at urban service stations. For peri-urban and rural consumers, who often buy kerosene in small quantities from retail shops, the price per liter is somewhat higher, while in remote areas the unit price may be as much as 300% higher than the price reported here.

Table 2 is based on the results of the 1980 Beijer Institute survey and the 2000 Kenyan Ministry of Energy (MoE) Survey.[3] It shows how the patterns of charcoal consumption has changed in the two decades between surveys. In addition, some key socioeconomic indicators are included as points of reference. In the twenty years between the two surveys, charcoal consumption increased by over 220% while the total population increased by only 81%. Charcoal is commonly considered an urban fuel, and it is possible that urban population growth can explain the increase in consumption. Kenya, like most countries in sub-Saharan Africa, has experienced very high rates of urban population growth. Figure 1 shows the country's population growth over the twenty years in question. It also shows per capita GDP in constant $US, indicating that little economic growth has occurred.

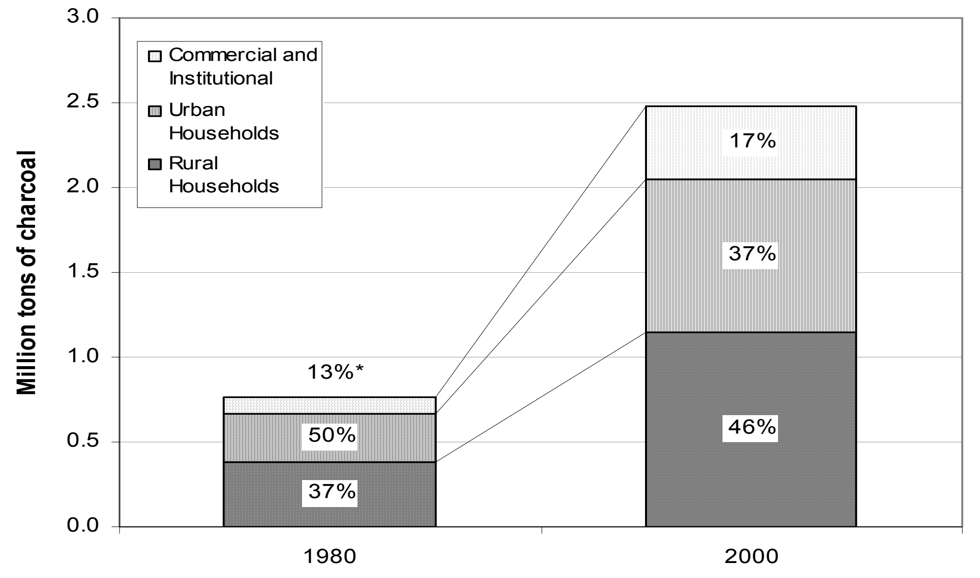
In 20 years, Kenya's urban population has increased 276%. At first glance, it would seem that the growth in urban population alone could explain the increase in charcoal consumption, however the results of the MoE survey tell a more interesting story. First, while the fraction of urban households using charcoal has remained the same (82% of households), the average consumption among urban charcoal users has actually decreased by 13%. This decrease is probably a reflection of two factors: the increasing use of alternate cooking fuels like LPG and electricity and the widespread dissemination of improved charcoal-saving stoves (see below). The survey also indicates that the fraction of rural households using charcoal has doubled since 1980. Moreover, the average level of charcoal consumption among rural households has increased by over 40%, so that there is no difference between the average quantity of charcoal consumed by urban households and rural households. As a result of this growth in rural charcoal consumption, the rural sector is now a larger consumer of charcoal than the urban sector, consuming 46% of charcoal produced in Kenya in 2000. Figure 2 shows the growth of charcoal consumption within the three main sectors of charcoal consumers: urban households, rural households, and commercial and industrial consumers.

Figure 1: Kenya's urban and rural population and per capita GDP (1980-2000)



[3] The results of survey work by Kituyi et al. (Kituyi, Marufu et al., 2001a; Kituyi, Marufu et al., 2001b) show patterns of charcoal consumption that are similar to the MoE results with some important differences. However this analysis focuses on the MoE results because they are presented in a form that makes them directly comparable to the results of the original Beijer Institute Survey.

Figure 2: Kenya's charcoal consumption in urban and rural households and the commercial sector (1980-2000)



* The numbers indicate the fraction of total consumption attributable to each sector

Thus, according to the latest survey from the MoE, between 1980 and 2000, annual charcoal consumption in Kenya increased from roughly 800,000 tons to nearly 2.5 million tons, *with over 50% of the increase attributable to increased consumption among rural households*. Roughly 30% of the increase is attributable to increased consumption in urban households, while the remaining increase is due to increased consumption among commercial, industrial and institutional users.

Disaggregating charcoal consumption in this way provides some important information about the nature of changing charcoal demand. However, in order to create more effective policies, additional information is needed regarding the cause of such changes. This is particularly important because of the socio-economic and environmental impacts associated with charcoal. Some of these issues have been used to justify Kenya's flawed policies, while others are ignored. A discussion of some of the more relevant issues follows.

SOCIO-ECONOMIC IMPACTS

Employment and revenue - Sources estimate that the charcoal industry in Kenya employs 40-50 thousand people and generates roughly US$ 300 million in annual revenues (Mugo, 1999; Kantai, 2002). The exchange of cash in this sector rivals the revenues generated by international tourism in Kenya, one of the highest priority industries in the country.[4] The illicit nature of charcoal has several socioeconomic impacts. First and perhaps most importantly, it makes it impossible to administer stumpage fees so that the cost of replacing the woodland resource is not internalized in the price of charcoal. Thus trees are removed with no regard to the environmental impact of their removal. This can lead to over-harvesting of trees and deforestation, which is discussed in more detail below. A second consequence is that the failure to legalize and regulate the industry leads to a loss of potential revenue that the

[4] According the World Bank (World Bank, 2003), Kenya's international tourism receipts for 1999 were US$ 304 million in 1999.

government could derive in the form of taxes and/or concessions for producers, transporters and sellers. With more logical policies in place, these revenues would help pay for the costs of regulation. In contrast to petroleum-based fuels and electricity, which the government taxes at a rate of 16-35%,[5] the government receives no revenue from charcoal consumption. Thirdly, the illicit nature of charcoal production leads to potentially exploitative working conditions for charcoal makers: the people who harvest and split trees, establish kilns, and burn the wood to make charcoal. Charcoal making tends to be an option of last resort for many people – particularly for charcoal made from arid and semi-arid woodlands, where 90% of Kenya's charcoal originates (Mugo, 1999). Charcoal making is considered a lowly occupation that few people with an alternate means of livelihood choose to pursue. The illegal status of charcoal production reinforces that sentiment, leaving producers no means to organize or create cooperative networks that would improve their working conditions and their bargaining power with transporters and wholesalers.

While no data exists on the exact level of employment within the charcoal industry, surveys estimate that between 40 and 50 thousand people rely on the charcoal trade for some part of their livelihood. The trade is split between producers, small and large transporters, wholesalers and retailers (Mugo, 1999). Research indicates that the largest share of revenue flows to producers, indicated in Table 3. However, this is misleading because producers outnumber other participants in the charcoal trade. Data is not available from Kenya to determine the number of participants at each point in the supply chain, however it is possible to draw lessons from research in Senegal (Ribot, 1998).

Table 3: Cost analyses from two studies of charcoal supplied to Nairobi

Cost break-down per bag	MoE study [a]		Mugo study [b]	
	KSh/bag	% of total price	KSh/bag	% of total price
Producer price	150	41%	100	25%
Transport costs	83	23%	129	32%
Wholesaler's cost (production + transport)	233	64%	229	57%
Wholesaler's selling price in Nairobi	300	82%	330	83%
Wholesaler's *margin*	67	18%	101	25%
Retailer's selling price (selling by the sack)	365	100%	400	100%
Retailer's *margin* (selling by the sack)	65	18%	70	18%

The MoE analysis assumes charcoal originated in Nyahururu, 180 km from Nairobi.

Mugo's analysis assumes the charcoal originates 200 km from Nairobi in an area that typically supplies charcoal to Nairobi.

5 The MoE survey reports that kerosene, as a "subsistence" commodity, has the most favorable tariff structure of petroleum-based products. It is taxed at 16%. In contrast, LPG is not VAT-exempt, and is taxed at a rate of 22%. Electricity has numerous taxes associated with it. These vary with the level of consumption, but hover between 30 and 35%.

In Senegal, roughly 35% of the revenue generated goes to charcoal makers, which is similar to the results of two studies shown here. Charcoal makers outnumber urban retailers by 4:1 and outnumber urban wholesalers by 39:1. Thus, the profits that charcoal makers derive is split among many people, making individual profits, on average, far smaller than profits earned by urban wholesalers. Small-scale retailers see a similar dilution of profits. While the proportions are unlikely to be exactly the same, this pattern is probably similar in Kenya.

Though the majority of Kenya's charcoal currently originates in state-owned ASAL regions, there have been successful efforts producing charcoal from private farms and plantations. One frequently cited example is the East African Tanning Extract Company (EATEC). This firm grew *Acacia Mearnsi* (Black Wattle) to extract tannin from its bark as an input in the leather curing process. With the exception of the bark, the entire tree is a by-product of tannin production. To supplement its income, the firm produced charcoal from the debarked trees. Though their feedstock was obtained at zero-cost, EATEC provides some lessons for the viability of private charcoal production. Using EATEC as a model, but accounting for wood feedstock purchased at market rates rather than obtained for free, the Kenyan MoE study found that private industry could produce charcoal for sale to wholesalers at the same price as charcoal produced on public lands indicated in Table 3 (100-150 KSh.30 kg sack). Furthermore, the charcoal is produced in large brick kilns so that worker safety is enhanced, efficiency is improved (30% by mass), and emissions could be controlled if desired. Each production run takes roughly two weeks and 36 person-days of labor, which indicates the job creation potential (Mugo, 1999; Ministry of Energy, 2002).

Charcoal and Public Health - Charcoal consumption is associated with both positive and negative health impacts. The emissions from cooking indoors with solid fuel: wood, charcoal, crop residues, dung and coal are a leading cause of death and illness worldwide.[6] The largest impact of solid fuel combustion arises from the emission of particulate matter (PM). High exposures to PM are associated with a number of ill health outcomes including acute respiratory infection (ARI), which is one of the leading causes of death in children under five worldwide. In addition to ARI, exposure to emissions from solid fuel combustion is associated with chronic obstructive pulmonary disease and some types of cancer[7] as well as increased incidence of asthma, tuberculosis, cataracts and elevated risk of carbon monoxide (CO) poisoning. The latter is particularly relevant for charcoal.

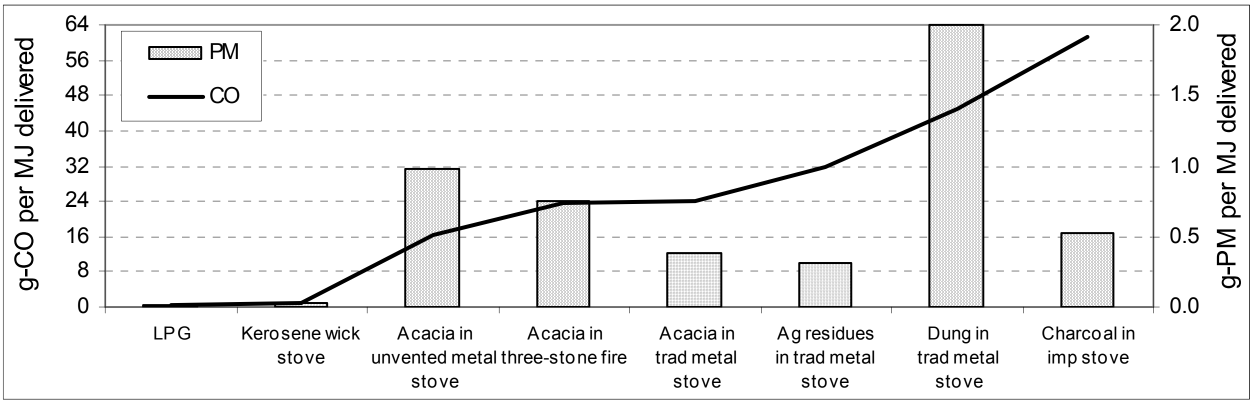
Pyrolysis removes most of the moisture and volatile compounds originally present in wood. Thus charcoal, on average, burns with fewer PM emissions than a comparable quantity of wood. However, it is still more polluting than most liquid or gaseous fuels. In addition, charcoal is 75-90% carbon. Carbon combustion involves an initial reaction where CO is formed. Thus CO is emitted at higher rates from charcoal combustion than from a comparable wood fire.

Figure 3 shows emission factors of CO and PM measured in a number of wood and charcoal stoves.

[6] The WHO's latest World Health Report (WHO, 2002) estimates that indoor pollution from solid fuel combustion is responsible for nearly 3% of the global burden of disease, with impacts concentrated in developing countries and falling disproportionately on women and children.

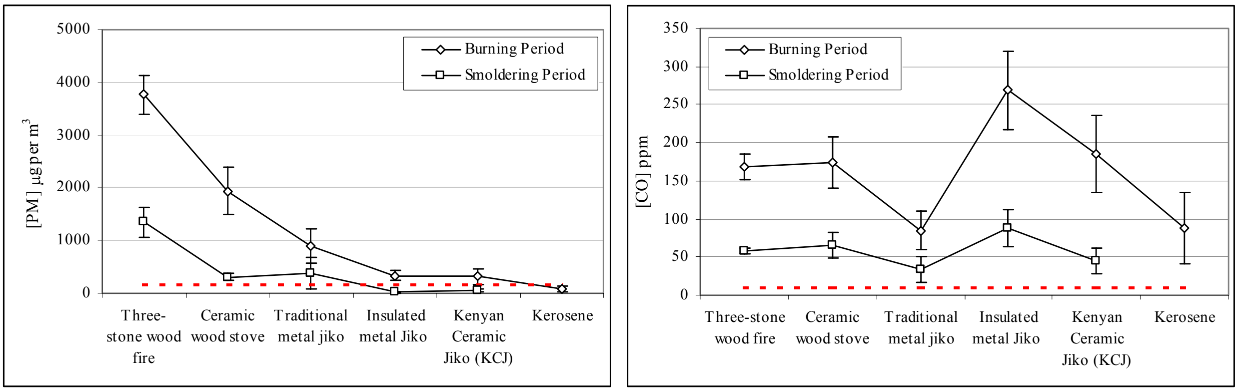
[7] Biomass combustion emissions contain carcinogenic compounds and exposure to them is a suspected cause of cancer, but the epidemiological evidence remains inconclusive (Bruce, Perez-Pedilla et al., 2000; Ezzati and Kammen, 2002a).

Figure 3: Emissions of PM and CO from common Indian stove/fuel combinations (Smith, Uma et al., 2000).



This graph shows emissions factors of stoves measured in simulated conditions. The entries are selected from a study of 28 stove-fuel combinations and are arranged in order of increasing CO emissions (dark line measured on left axis). PM is represented by the shaded bars and measured in the right axis. There is little correlation apparent between CO and PM emissions across stove-fuel combinations. The emission factors are defined in terms of energy delivered, which accounts for the energy content of the fuels and the efficiency of the stove. The graph was created by the author based on data from Smith, Uma, et al. (2000).

Figure 4: Concentrations of PM (left) and CO (right) measured in Kenyan households (Ezzati, Kammen et al., 2000).



These plots show average indoor concentrations of PM and CO from multiple measurements of 38 different households in rural Kenya. Each plot has two lines: one showing concentrations during burning periods (diamonds) and one showing concentrations during smoldering periods (squares), which are systematically lower. The error bars indicate standard errors. The PM data are arranged in descending order, with improved charcoal stoves resulting in considerably lower PM concentrations than woodstoves, but this pattern does not repeat for CO. The improved charcoal stoves result in CO concentrations that are as high, or higher, than the CO concentrations that result from wood stoves. Interestingly, kerosene is associated with the lowest PM concentrations, but the CO concentration arising from kerosene is comparable to most other stoves. Each plot also shows the USEPA's standard for concentration of each pollutant (dashed line). The standard set by the US EPA for PM is 150 µg/m^3 for a 24-hour period and CO is 9 ppm for an 8-hour period. Wood and charcoal stoves clearly exceed the PM standard under burning conditions (some also do so under smoldering conditions), while the CO standard is exceeded by all stoves under both conditions.

While emissions are important in assessing health impacts, indoor concentrations of pollution are a more direct way of predicting exposure to harmful pollutants. Indoor concentrations are a function of emissions from the stove as well as environmental factors and individual behavior that affects both the stove and the indoor environment. One study measured the concentrations of pollutant in dozens of rural Kenyan households using several different types of wood and charcoal stoves (Ezzati, Kammen et al., 2000). The authors found significant differences in the indoor concentrations PM and CO in households using open wood fires, closed wood stoves and different types of charcoal stoves. These differences are illustrated in Figure 4.

Environmental impacts

The public health and socio-economic aspects of the charcoal trade discussed above need to be balanced with the environmental impacts associated with its production and consumption. These impacts can be crudely split into impacts on forest cover and impacts arising from atmospheric pollution. The two are inter-related, but for simplicity, they will be discussed separately.

GHG emissions - All combustion of solid fuels results in the emission of carbon dioxide (CO_2), but in non-ideal conditions, many other compounds are also emitted. In fact, the same processes of incomplete combustion that lead to the emissions of health damaging pollutants like PM and CO also cause emissions of greenhouse gases. When solid fuels are burned in simple household stoves, the fuel can not mix sufficiently with air, and is not fully combusted. Hundreds of compounds are emitted including compounds that affect the radiative balance of the earth's atmosphere like methane (CH_4), which is 22 times more effective trapping heat than a molar equivalent amount of CO_2. Other compounds emitted from solid fuel combustion include CO, non-methane hydrocarbons (NMHCs), and nitrogenous compounds in trace amounts – all of which impact the atmospheric radiative balance more than an equivalent amount of CO_2 (IPCC, 1996).

Biomass fuels like wood or charcoal may be grown in a sustainable cycle such that harvested trees are replaced by an equivalent amount of biomass so that stocks are not depleted in the long-term. In that case, CO_2 released by combustion is effectively "removed" from the atmosphere by photosynthesis as stocks of biomass are replenished. However, the other greenhouse gases released by incomplete combustion are not removed from the atmosphere by photosynthesis. Thus, even if the CO_2 released by wood or charcoal combustion is fully removed from the atmosphere by newly grown biomass, processes of incomplete combustion inherent in small-scale household technologies ensure that the process is not greenhouse gas neutral (Smith, Khalil et al., 1993; Smith, Uma et al., 2000; Bailis, Ezzati et al., (2003)). Many of the gases released can contribute to climate change.[8] In addition, when biomass is not harvested sustainably, some of the CO_2 released must also be assessed in the impact on the climate.

8 Of the gases released in biomass combustion, only CH_4 and N_2O are currently mandated for control under the Kyoto Protocol. However, CO and NMHCs also have a warming effect (IPCC, 1990; IPCC, 1996). In comparison to CO_2, CH_4, and N_2O, they are shorter lived, their warming effects are less direct and are more dependent on local conditions. Thus their warming effect is less certain, but still a concern.

Table 4: Emission factors for charcoal stoves compared to wood and fossil fuels from current literature (g per kg dry fuel)

Pollutant	Charcoal: end-use (three different sources)			Charcoal: production (two different sources)		Other fuels: end-use LPG	Kero. (wick)	3-stone fire
CO2	2411	2740	2258	1802	1594	3085	2943	1536
CO	275	230	211	223	253	14.9	62	60
CH4	7.9	8.0	2.41	44.6	38.6	0.05	1.1	2.8
TNMOC	10.5	4.0	0.54	92.6	10.9	18.8	19.2	8.0
N2O	0.2	0.04	--	0.15	0.1	0.15	0.10	0.07
TSP	2.4	--	--	30.4	16.1	0.51	0.7	0.9
Source	a	b	c	d	c	a	a	a

Sources: [a](Smith, Uma et al., 2000), [b](Smith, Khalil et al., 1993), [c](Brocard, Lacaux et al., 1996), [d](Pennise, Smith et al., 2001)

In Kenya, charcoal is preferred over wood because it is burns with a slow and steady heat amenable for cooking some of the local staple foods, which require long simmering times. Charcoal is better suited to long slow cooking, because, as discussed above, the characteristics of charcoal combustion are quite different than wood. Smith et al (Smith, Uma et al., 2000) found that charcoal has a lower combustion efficiency than wood or fossil fuels.[9] As a result of its lower combustion efficiency, charcoal emits more CO than firewood, but it also tends to emit more CH_4.

Moreover, charcoal end-use only includes half of the global warming impact. Unlike unprocessed firewood, charcoal includes substantial "upstream" emissions. The pyrolysis process drives off many volatile compounds and in most cases, these pollutants are simply vented into the atmosphere. Including charcoal production in the analysis of greenhouse gas emissions nearly doubles the amount of CO, CO_2, and N_2O and increases the amount of CH_4 and NMHCs by factors of nearly 6 and 9 respectively, relative to charcoal end-use alone (Pennise, Smith et al., 2001).

Table 4 shows mass-based emissions factors reported in the literature for charcoal production and end-use. Emissions from simple wood fires, LPG and kerosene are included for comparison.

Table 5 lists the same emissions aggregated into a single measure of global warming impact using a range of aggregation methods. Firewood and commonly used fossil fuels are included for comparison. Figure 5 depicts the same results in terms of energy delivered to the pot, which accounts for energy content of the fuel and efficiency of the stove (see Smith, Khalil et al., 1993; Brocard, Lacaux et al., 1996; Smith, Uma et al., 2000 for the methods of calculation).

9 Smith et al. define a parameter called *nominal combustion efficiency* NCE which is a function of the emission ratios measured for each carbonaceous species: CO, CH_4, NMHCs, and PM. The average of three measurements for charcoal yields an NCE of 83% while wood in an open fire exceeds 90%. LPG and kerosene (wick stove) are each 98% efficient.

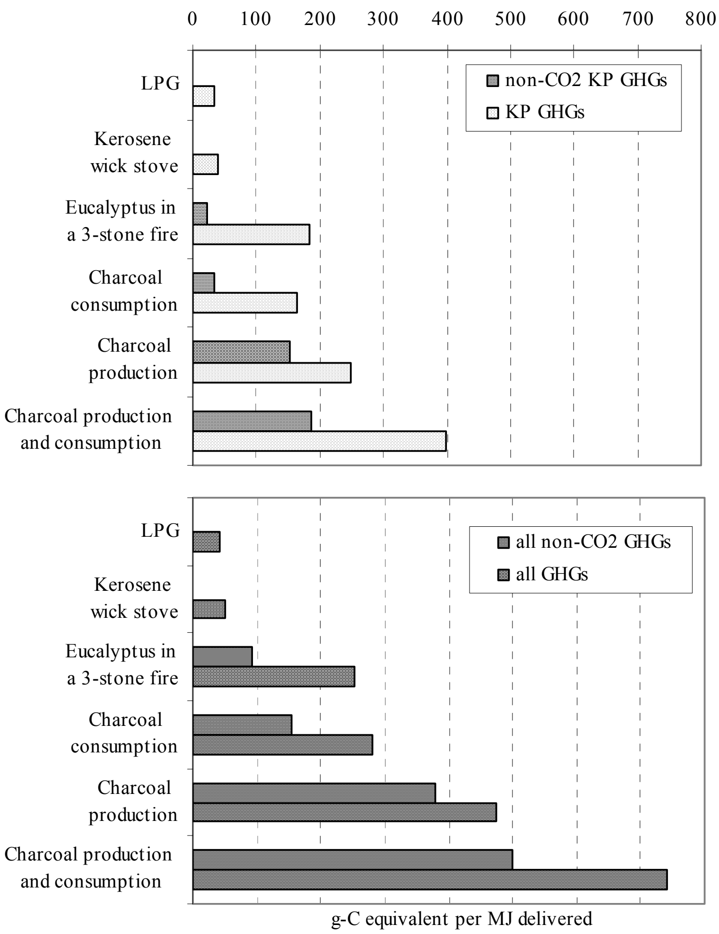
Table 5: Warming Impact by fuel for combinations of GHGs (g-C per kg fuel: 20-yr GWP)[a]

Global warming impact	Gases included in the calculation	*LPG*	Kerosene wick stove	Eucalyptus 3-stone fire	Charcoal consumption [c]	Charcoal production [d]	Production + consumption
Non-CO2 KP[b] GHGs	CH_4, N_2O	--	--	61	178	784	962
KP[a] greenhouse gases	CO_2, CH_4, N_2O	869	840	480	836	1275	2057
All non-CO2 GHGs	CH_4, CO, NMHCs, N_2O	--	--	241	793	1955	2573
All GHGs	CO_2, CH_4, CO, NMHCs, N_2O	1048	1113	660	1450	2446	3812

GWP or *global warming potential* is a measure of the warming impact of a gas relative to an equivalent amount of CO_2 (see IPCC, 1996).

KP = Kyoto Protocol [b] Charcoal consumption is from (Smith, Uma et al., 2000) [a] Data for production is from (Pennise, Smith et al., 2001)

Figure 5: Global warming impact of charcoal, wood, and common fossil fuels (g-C per MJ delivered 20-year GWP)



The upper plot in Figure 5 depicts the impact of the Kyoto Protocol gases only. Both the "renewable" (non-CO_2) and the non-renewable cases are represented. The lower plot depicts the net impact of all greenhouse gases emitted by the fuel, again accounting for CO_2 uptake in a "renewable" scenario.[10] The plots show that the global warming impacts of household fuels strongly depend on the methods of analysis. If all greenhouse gases are included as in the lower graph, biomass fuels are considerably more polluting than fossil fuels. If we consider only Kyoto Protocol gases, charcoal and wood used unsustainably have a larger impact than fossil fuels. However, if fuels are harvested sustainably so that CO_2 is absorbed by new tree growth, wood has a smaller impact, but charcoal still matches fossil fuels in terms of greenhouse gas emissions because of its high CH_4 emissions.

When charcoal production is included in the analysis, charcoal performs far worse. In every scenario, charcoal production emissions increase the net impact of charcoal by roughly a factor of two. The comparison with fossil fuels is not entirely fair, because they also involve emissions upstream, but these are not properly quantified in the Kenyan context. Nevertheless, it is instructive to see the effects of charcoal production relative to its end use.

Finally, it is useful to examine how the greenhouse gas emissions from charcoal compare to other sectors in the Kenyan economy. Table 6 shows the outcome of this estimate. Using national consumption data for wood and charcoal from the MoE survey and emission factors listed in Table 6, the net impact of wood and charcoal combustion is on the same order as industrial activities. This calculation uses only gases currently in the Kyoto Protocol and includes charcoal production as well as consumption. The net results show that woodfuels are a significant contributor to Kenya's total greenhouse gas emissions. Woodfuel emissions range from 3.3 to 12.6 Mton C depending on the degree to which fuels are harvested sustainably. In contrast, petroleum consumption, coal-burning, and cement manufacturing result in less than 2 Mton C emissions. Though the industrial emissions only include CO_2, it is likely that in the current Kenyan energy economy, aggregate woodfuel emissions are comparable to, if not well above, total emissions from industrial activities *even if wood is harvested on a sustainable basis*. Clearly, emissions reduction strategies and CDM activities must target both traditional and modern energy sectors

Table 6: Comparison of wood and charcoal to emissions from the petroleum sector and other industries in Kenya (2000)

	Consumption in metric tons (2000)	Emission factors (kg-C in 20 year CO_2 equivalent units per ton fuel)		Net Global Warming Impact (tons C in 20 year CO_2 equivalent units)	
		KP non-CO_2 gases	KP all gases	Renewable	Non-renewable
Firewood	15,730,000	61	480	966,000	7,556,000
Charcoal	2,476,000	962	2057	2,382,000	5,092,000
Total woodfuels				3,348,000	12,648,000
WRI data (2000)[a]					
Solid fuels					76,000
Liquid fuels					1,649,000
Cement Manufacturing					214,000
Total "modern" sector					1,940,000

[a] Industrial emissions are from the World Resources Institute's on-line database of environmental indicators (WRI, 2002). The most recent greenhouse gas data available is for 1996. 1996 emissions were scaled with inflation adjusted GDP growth (~5%) to estimate emissions in 2000.

[10] Table 5 explains the gases that are included in each scenario. Obviously, LPG and kerosene can not have non-CO_2 scenarios.

Deforestation - Charcoal is often blamed for the loss of forest cover in Kenya and other countries where charcoal is heavily used. While most rural firewood consumers do not cut living trees for their energy supplies, preferring to gather fallen branches and dead wood, charcoal makers harvest live trees, sometimes selectively and sometimes indiscriminately. However, deforestation, like many contemporary socio-environmental issues, exists in a complex and interdependent relationship with social, cultural, economic and political forces that tie local actors to global market forces and distant seats of power and influence. It is tempting, among policy analysts and politicians, to try to reduce deforestation to a single cause in order to arrive at an efficient solution to the "problem". In Kenya, it is true that a lot of charcoal reaching the market was harvested from deforested land, but the charcoal is often a secondary cause of land clearance. Land that is cleared for cultivation or development must first be cleared of tree cover. Charcoal making represents an attractive source of secondary income from newly cleared land, though in many cases it is not the primary factor influencing clearance. Much of Kenya's deforested land would have been cleared in the absence of charcoal production. In addition, land that is cleared specifically for charcoal production can revert to secondary forest under the right management regime. Similarly, agroforestry techniques can be employed to ensure that cultivated land maintains a high degree of tree cover with useful tree species.

Currently in Kenya, nearly all of the primary upland forest has been cleared, privatized or placed under protection by the state so that charcoal making has been pushed to the marginal ASAL regions (Mugo, 1999; Kantai, 2002). Ecological research has shown that these regions are resilient and that tree cover returns in a reasonable time period under a range of management regimes (Chidumayo, 1993; Hosier, 1993). However, just as land can be managed in a way that is favorable for the reestablishment of tree cover, it may also be managed in a way that prevents trees from returning, which leads to permanent deforestation. Thus, in the case of charcoal production, the permanent loss of tree cover depends not only on the actions of initial charcoal makers; it also depends on a range of other actors and structural factors. For example, pastoralists may graze their animals too soon or too often after trees are harvested, which can prevent new trees from establishing from shoots or seed. The likelihood of permanent tree loss also depends on cultivators, who may occupy the land after it is cleared, and the farming techniques they employ.[11] Subsequent charcoal makers also have a role – returning to harvest from the same area too frequently may deplete both soil nutrients and the seed bank, reducing the likelihood of trees returning in the long-term.

Ultimately the real impact of charcoal trade on forest cover becomes a question of policy. In Kenya, the current policy, which has banned charcoal production from public lands since 1986 with the aim of reducing forest loss, is a clear failure. Policies can and should be redesigned to address both demand side management and supply-side impacts. Demand can be tempered by dissemination of improved stoves. Kenya has one of the most successful stove programs in sub-Saharan Africa, with roughly 1.5 million stoves disseminated. While this is an impressive number, over half of the households reportedly using charcoal still do not use improved stoves. With fuel savings of roughly 30% observed (Kituyi, Marufu et al., 2001b), the potential for demand reduction on a national scale remains very large. As charcoal becomes increasingly popular among rural consumers, the need for new stove design and dissemination efforts to meet changing patterns of demand remains.

[11] Fire, an important tool in dryland agriculture, plays a similar role as grazing livestock. Burning too early or too often after harvesting trees can kill new shoots and seedlings. On the other hand, fire can help some species of trees to reestablish by suppressing ill-adapted competitors.

As this paper discusses, there are numerous positive and negative impacts associated with Kenya's growing demand for charcoal. Increased consumption may result in reduced incidence of ARI if consumers substitute charcoal for wood, but it will also result in higher levels of CO exposure and increased greenhouse gas emissions. Charcoal has the potential to create jobs in the rural economy, but the current policy framework reinforces charcoal making as an illicit occupation, discourages entry into the trade and prevents producers from making investments in efficiency. Finally, increasing rates of charcoal consumption do represent a threat to Kenya's forests, but this is more the result of poorly designed policies than of the inherent destructiveness of charcoal production. Charcoal production can be done in a sustainable way, but only if the trade is legalized (Matiru and Mutimba, 2002). These issues require policies that address them directly, rather than attempt to wish them away, as the current policy does.

REFERENCES

Bailis, R., M. Ezzati, et al. ((2003)). Greenhouse Gas Implications of Household Energy Technology in Kenya. *Environmental Science and Technology,* Forthcoming .

Brocard, D., C. Lacaux, et al. (1996). Emissions from the combustion of biofuels in Western Africa. In *Biomass Burning and Global Change*. J. S. Levine. **1:** 350-360.MIT Press, Cambridge, MA

Bruce, N., et al. (2000). Indoor Air Pollution in Developing Countries: A Major Environmental and Public Health Challenge. *Bulletin of the World Health Organization* **78** (9): 1078-1092.

Chidumayo, E. N. (1993). Zambian Charcoal Production: *Miombo* Woodland Recovery. *Energy Policy* **21** (5): 586-597.

Ezzati, M. and D. Kammen. (2002a). The Health Impacts of Exposure to Indoor Air Pollution from Solid Fuels in Developing Countries: Knowledge, Gaps, and Data Needs. *Environmental Health Perspectives* **110** (11): 1057-1068.

Ezzati, M., D. Kammen, et al. (2000). Comparison of Emissions and Residential Exposure from Traditional and Improved Cookstoves in Kenya. *Environmental Science and Technology* **34** (4).

FAO. 1987. Simple Technologies for Charcoal Making. FAO Forestry Paper No. 41, Rome, Food and Agriculture Organization of the UN.

FAO-WETT. 2002. Wood energy information in Africa: Review of TCDC Wood Energy country reports and comparison with the regional WETT study. Rome, Food and Agriculture Organization of the UN**:** 61.

Gov't of Brazil. 1991. Censo Demographico: Familias e Domicilios. Rio de Janiero, Instituto Brasiliero do Geografica e Estadistica (IBGE).

Hosier, R. (1985). *Energy in Rural Kenya: Household Demand and Rural Transformation*. The Beijer Institute and The Scandanavian Institute of African Studies, Stockholm

Hosier, R. H. (1993). Charcoal Production and Environmental Degradation: environmental history, selective harvesting, and post-harvest management. *Energy Policy* **21** (5): 491-509.

IPCC. (1990). *Climate Change: The IPCC Assessment*. Cambridge University Press, Cambridge

IPCC. (1996). *Climate Change 1995: Scientific-Technical Analyses of Impacts, Adaptations, and Mitigation of Climate Change*. Cambridge University Press, Cambridge, UK and New York, NY, USA

Kantai, P. 2002. Hot and Dirty: Inside Kenya's 23 Billion Shilling Charcoal Industry. *EcoForum*. Nairobi. **25:** 16-22.

Kituyi, E., et al. (2001a). Biofuel Availability and Domestic Fuel Use Patterns in Kenya. *Biomass and Bioenergy* **20** : 71-82.

Kituyi, E., L. Marufu, et al. (2001b). Biofuel Consumption Rates and Patterns in Kenya. *Biomass and Bioenergy* **20** : 83-99.

Matiru, V. and S. Mutimba. 2002. Legalise It. *EcoForum*. Nairobi. **25:** 34-35.

Ministry of Energy. 2002. Study on Kenya's Energy Demand, Supply and Policy Strategy for Households, Small Scale Industries and Service Establishments: Final Report. Nairobi, KAMFOR Company Limited**:** 158.

Mugo, F. W. 1999. Charcoal Trade in Kenya. Nairobi, Kenya, RELMA/SIDA**:** 35.

O'Keefe, P., P. Raskin, et al., (eds.) (1984). *Energy and Development in Kenya: Opportunities and Constraints*. The Beijer Institute and The Scandinavian Institute of African Studies, Stockholm

Pennise, D., K. R. Smith, et al. (2001). Emissions of Greenhouse Gases and Other Airborne Pollutants from Charcoal-Making in Kenya and Brazil. *Journal of Geophysical Research-Atmosphere* **106** : 24143-24155.

Ribot, J. C. (1998). Theorizing Access: Forest Profits Along Senegal's Charcoal Commodity Chain. *Development and Change* **29** : 307-341.

Smith, K., R. Uma, et al. 2000. Greenhouse Gases From Small-Scale Combustion Devices In Developing Countries Phase IIa: Household Stoves In India. Research Triangle Park, NC, US Environmental Protection Agency**:** 98.

Smith, K. R., M. A. K. Khalil, et al. (1993). Greenhouse Gases From Biomass and Fossil Fuel Stoves in Developing Countries: A Manila Pilot Study. *Chemosphere* **26** (1-4): 479-505.

WHO. 2002. World Health Report: Reducing Risks, Promoting Healthy Life. Geneva, World Health Organization.

World Bank. 2003. Development Indicators Data-Base. http://devdata.worldbank.org/dataonline/

WRI. 2002. Earth-Trends: The Environmental Information Portal. http://earthtrends.wri.org, Accessed 15 January, 2002

LAMNET Project Coordination

WIP
Sylvensteinstr. 2
81369 Munich
Germany
Coordinator: **Dr. Rainer Janssen**
Phone: +49 89 720 12 743
Fax: +49 89 720 12 791
E-mail: rainer.janssen@wip-munich.de
Web: www.wip-munich.de

LAMNET Coordination Partner

ETA – Energia Trasporti Agricoltura
Piazza Savonarola, 10
50132 Florence
Italy
Contact: **Ms. Angela Grassi**
Phone: +39 055 500 2174
Fax: +39 055 573 425
E-mail: angela.grassi@etaflorence.it
Web: www.etaflorence.it

LAMNET Coordination Partner

EUBIA – European Biomass Industry Association
Rond Point Schuman, 6
1040 Brussels
Belgium
Contact: **Dr. Giuliano Grassi**
Phone: +32 2 28 28 420
Fax: +32 2 28 28 424
E-mail: eubia@eubia.org
Web: www.eubia.org

LAMNET Coordination Support Point South America

CENBIO – Centro National de Referência em Biomassa
Avenida Prof. Luciano Gualberto 1289
05508-900 São Paulo
Brazil
Contact: **Prof. Dr. José Roberto Moreira**
Phone: +55 115 531 1844
Fax: +55 115 535 3077
E-mail: Bun2@tsp.com.br
Web: www.cenbio.org.br

LAMNET Coordination Support Point Central America

Universidad Nacional Autónoma de México
Instituto de Ecología
AP 27-3 Xangari
58089 Morelia, Michoacán, México
Contact: **Dr. Omar Masera**
Phone: +52 55 5623 2709
Fax: +52 55 5623 2719
E-mail: omasera@oikos.unam.mx
Web: www.oikos.unam.mx

Steering Committee

Contact: **Dr. Peter Helm**
E-mail: peter.helm@wip-munich.de

This Thematic Network is funded by the European Commission, DG Research, (Project No. ICA4-CT-2001-10106).