Indoor Air Pollution: Health Effects and Policy Opportunities in Rwanda

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History of Rwanda

Pre-colonial History

The pre-colonial history of the origins and ways of life of the three main ethnic groups of Rwanda: the Tutsi, the Hutu and the Twa, is largely tainted by the speculation of European colonialists and their European-educated Rwandan counterparts. These origins portray the Twa as the first ethnic group to settle in Rwanda, and characterize the Twa as a hunter-gatherer group that predominantly lived in forests (Twagilimana 2007, xli-xlii). Later, between the fifth and eleventh centuries, the Hutu, a group of farmers, were believed to have arrived in Rwanda, a group more advanced than the Twa due to their political and clan organization (xli-xlii). The very last group to arrive in Rwanda, the Tutsi, was believed to have come from the Horn of Africa in the fourteenth century (Department of State). The Tutsi were seen to be the most highly developed of all of the groups due to their extensive cattle holdings, as cattle were seen as the primary measure of wealth in Rwanda. The Tutsi conquered both the Hutu and the Twa, and by the sixteenth century, Tutsi king, Ruganzu II Ndori, unified the many disparate Rwandan kingdoms, forming a feudal monarchy (Twagilimana 2007, xlii).

Under Tutsi rule, Hutu were subject to a vassalage system, known as ubuhake, wherein Hutu pledged their service, as well as the services of their descendents, to a Tutsi lord (Department of State). The Hutu, in turn, received protection, a loan or gift of cattle and land for cattle grazing and planting (Department of State). Thus, ubuhake created a class of Hutu serfs with Tutsi lords around the system of cattle-based wealth (Department of State). However, the separation between Hutu and Tutsi may not have been as definite as is often portrayed, and, in some ways, could be classified as an economic distinction,

rather than an ethnic divide (Twagilimana 2007, xlii). Hutu were often defined as such because they engaged in farming, while Tutsi were seen to own and raise cattle (xlii). Thus, Hutu who gained many cattle may have later been considered a Tutsi and Tutsi who lost cattle might, in turn, be considered Hutu (xlii).

By the nineteenth century, Rwanda had evolved into a nation-state with a king, an army and a tripartite political structure of a military chief, a cattle chief and a land chief, which ensured that there were checks and balances made on the king's power (xliii). While this system of political organization helped to protect many Rwandans against a monarch with absolute power, most land and political positions continued to be given exclusively to Tutsi (xlii-xliii).

Colonial History

The Berlin Conference, in which the European colonial powers divvied up control of the African continent, resulted in Rwanda and its neighbor to the south, Burundi, becoming part of the German East African protectorate (xliv). Under the Germans, many missionaries arrived in the country (Department of State). The Germans created a system of indirect rule through the Rwandan king, supporting the king's efforts to put down Hutu insurrections (xliv).

In 1916, during World War I, Belgian troops defeated the small number of Germans stationed in Rwanda and Burundi, taking control of the territory (Twagilimana 2007, xliv). After the war ended, the League of Nations officially mandated the territories of Rwanda and Burundi, called Ruanda-Urundi, to Belgium (Department of State). The Belgians continued the German tradition of indirect rule; however, they reduced the power of the Rwandan king considerably (Twagilimana 2007, xliv). The

Belgians, at the beginning of their rule, propagated the political and economic preeminence of the Tutsi, allowing ubuhake to continue for many years (xlv). They also disbanded the tripartite power structure of the military, land and cattle chiefs, of which a Hutu was traditionally Chief of Land, instead replacing the chiefs with a single overarching position, which was given to a Tutsi (xliv-xlv). In 1956, of the forty six chiefs and six hundred and three sub-chiefs in Rwanda, not a single one was Hutu (xliv). Most positions in schools were also given to Tutsi, making Tutsi a more educated group than the Twa and the Hutu (xliv).

Both German and Belgian colonists had been surprised by the highly organized nation-state system that they had found in Rwanda, assuming that all Africans lived in a system of unenlightened anarchy. They, therefore, believed that Rwanda had to be influenced by Europeans, and they felt this influence came in the form of the Tutsi, an ethnicity more closely related to Europeans than "Africans." The Europeans then classified the Tutsi, Hutu and Twa on perceived physical characteristics and mental abilities, including that Tutsi were lighter skinned and had thinner noses (or were more European in appearance) than the darker, shorter Hutu and Twa (xliii-xliv). These arbitrary distinctions overlooked the few cultural differences between the three Rwandan ethnic groups, as all three speak the same language (Kinyarwanda), share the same traditional religions (though most have now converted to Christianity) and have historically intermarried (xli). As noted earlier, it also overlooked the importance of class in the division of groups, rather than differences in physical or cultural characteristics (xlii).

After World War II, Ruanda-Urundi became a UN Trust Territory, still under the administration of Belgium (Department of State). The UN encouraged reforms that would provide more Rwandans with positions in government, and Belgium responded in 1952 with a decade-long plan to give more political power to the Hutu majority (Twagilimana xlv). This culminated in the dismantling of the ubuhake system in 1954 and the division of land and cattle among both the Hutu and the Tutsi (xlv). These reforms sparked resentment and anger among the Tutsi upper classes (xlv).

As independence movements were spreading throughout Africa, Hutu and Tutsi elites began to wrestle for control of government positions, and, ultimately, to shape the future of post-colonial Rwanda (xlv). Assisted by the Belgian military, the Hutu population overthrew the Tutsi monarchy in 1959, and, in 1961, elections were held in which the Party of the Hutu Emancipation Movement (MDR-PARMEHUTU) was victorious (Department of State). Full independence was given to Rwanda in 1962 (Department of State). The overthrow of the Tutsi monarchy and the consequent victory of MDR-PARMEHUTU in the election resulted in a violent backlash against the Tutsi, including burning Tutsi homes, taking Tutsi land and even murdering Tutsi (Department of State; Twagilimana 2007, xlvi). This violence led over 150,000 Tutsi to flee to surrounding countries (Department of State).

Independence and The Kayibanda Years

Grégoire Kayibanda became the first president of Rwanda, creating a one-party political system (Department of State). He enacted reforms aimed at correcting the balance of power between Hutu and Tutsi, however, his quota system used in schools and for political posts only served to exclude Tutsi and promote Hutu primacy (Twagilimana

2007, xlvi; Department of State). Kayibanda was unable to solve the problem of Tutsi refugees, and the associated invasions of Rwanda by Tutsi attempting to reinstate a Tutsi-controlled government (xlvi). Beginning in 1972, and continuing into the next year, ethnic unrest, including Hutu mobs chasing Tutsis out of schools and administrative posts, spelled the end of the Kayibanda administration (xlvii). He was overthrown in a bloodless coup by the Rwandan military, under the control of Major General Juvenal Habyarimana (Department of State; xlvii).

The Habyarimana Years

Although Habyarimana abolished political parties and activities in 1973, he founded a new political party, the National Revolutionary Movement for Development (MRND), in 1975, thus creating a one party state (xlvii; Department of State). Habyarimana's regime heavily favored the northern part of the country, as both Habyarimana and his military officers were northerners, leading to northerners being disproportionately selected for choice educational and political posts during his regime (xlvii). While Habyarimana did not explicitly declare an anti-Tutsi agenda, his policies precluded Tutsi participation in the military and positions of power (xlvii). In 1978, Rwandans voted for a new constitution, which enshrined the preeminence of the MRND party and cemented Habyarimana's role as president (Department of State).

The issue of Tutsi refugees continued to go unaddressed under Habyarimana (xlvii). In response, the refugees created the Rwandan National Union party in 1979, which became the Rwandan Patriotic Front (RPF) in 1987 (xlvii). In 1990, the RPF invaded Rwanda from neighboring Uganda, frustrated by their inability to return to Rwanda (Department of State). In response to the resulting civil war, in 1991,

Habyarimana's regime authorized a new constitution which allowed for multiparty democracy and the creation of political parties (xlviii). In 1993, the Habyarimana regime and the RPF ended the civil war with a peace agreement that was supervised by the United Nations (xlviii). However, Habyarimana stalled the implementation of the peace plan due to pressure from Hutu hardliners who did not want to sacrifice political control of Rwanda (xlviii).

The Rwandan Genocide

While violence and uncertainty had gripped the nation since 1990, the signing of the 1993 peace agreement only served to heighten interethnic tension (xlvii). On April 6, 1994, Habyarimana's plane, which was also carrying the president of Burundi, was shot down while landing in Kigali, killing all of the passengers (Department of State). In response, the Presidential Guard, the Interahamwe (MRND militia), and the Impuzamugambi (the militia of the CDR, a Hutu extremist party), began to kill Tutsis and Hutu moderates (xlvii). Beginning in Kigali, the killing quickly radiated throughout the country, with citizens being tasked with killing their Tutsi neighbors by government officials and the militias (xlviii).

Members of the RPF in Rwanda were also fiercely attacked, prompting the RPF to reinvade Rwanda, causing a resurgence of the civil war. The RPF met with success against the Rwandan military and took Kigali on July 4, 1994, ending the genocide. The genocide, which only lasted from April to July of 1994, left approximately 800,000 Tutsi and Hutu moderates dead (Department of State).

Post-Genocide Rwanda

After the RPF gained power in Rwanda, it created a government of national unity, including members of many political parties (xlix). Pasteur Bizimungu, a Hutu, was made president, and Faustin Twagiramungu, an MDR member, was made prime minister, though he later resigned over revenge killings of Hutu that took place in some parts of post-genocide Rwanda (xlix). A major challenge faced by the new government was the two million Hutu refugees, who had fled Rwanda during the civil war for countries such as Zaire (now the Democratic Republic of the Congo) (xlix). Many of these refugees were prevented from returning to Rwanda by the defeated Rwandan military and elements of the Habyarimana regime, who hoped to invade Rwanda and reassert their political and military control (xlix). In 1996, the Rwandan military attacked the refugee camps in Zaire, and were able to bring many of the refugees home to Rwanda (xlix). However, some of the refugees disappeared and may have died in their attempt to move to other areas of Zaire, or even surrounding countries (xlix). Also in 1996, a movement towards repatriation of Tutsi refugees began with 600,000 people returning in just a two week span (Department of State). Another 500,000 people followed in a second wave of repatriation (Department of State).

Post-Genocide Justice

Since 1994, over 100,000 Rwandans have been jailed for crimes committed during the genocide (l). The traditional court system was not sufficient to handle this high volume of cases, leading to the institution of gacaca courts in 2001 (Department of State; l). Gacaca courts are traditional Rwandan courts used to settle minor disputes within the community by using a respected person or group of people, such as elders, to listen to the quarrel, and provide judgment (l). To date, the gacaca courts have dealt with

1.5 million cases, a number that almost certainly could not have been handled by traditional courts alone (Binyon 2010). However, despite the gacaca courts' ability to try a high volume of cases, there have been many issues with the courts, as well, often because gacaca courts were formed to deal with minor disputes, and now can sentence defendants to decades in prison for murder (l). Many defendants are not given sufficient time to prepare their defense, and judges can act not only in the capacity of a judge, but also as accusers, leading many to question the impartiality of their judgments (li). Similarly, many people feel that the courts promote an ideology of "guilty until proven innocent," making innocent defendants vulnerable to conviction (li). There is some evidence showing that people have been wrongly accused of crimes in the gacaca courts due to past grudges or even in an attempt to receive land or goods from the accused as reparations (li).

Contemporary Rwanda

People

The current population of Rwanda is approximately 11 million people, who are living in an area that is 26,338 square kilometers, slightly smaller than the state of Maryland (CIA). Its population density is 365 people per square kilometer, the highest rate on the African continent (Thaxton 2009, 2-3). Population growth in Rwanda has been rapid, starting from a population of 2.6 million in 1960 and growing over the next forty years to a population of 8.2 million in 2002 (2). Just six years later, in 2008, the population was estimated to have grown by over one million individuals (2). If the population growth of Rwanda continues at its current pace (a growth rate of almost 3%),

by 2025, Rwanda will be a country of 14.6 million people (2; CIA). Currently, the total fertility rate is an average of 5.12 children born to every Rwandan woman (CIA).

Approximately 84% of Rwandans are identified as Hutu, 15% as Tutsi and 1% as Twa (CIA). The majority of the population is Christian, with the largest denomination of Christianity being Catholicism (56.5% of the population), followed by Protestantism (26% of the population) and Adventism (11.1% of the population) (CIA). About 4.6% of the population is Muslim (CIA). Only about 18% of the population is classified as urban, as many families continue to live in traditional rural hillside compounds (CIA; Department of State).

The three official languages of Rwanda are the widely spoken Kinyarwanda, a Bantu vernacular, French and English (CIA). Rwanda has an overall literacy rate of 70%, despite the fact that only 5% of the Rwandan population has attended secondary school (Department of State). However, a renewed governmental focus on education, which has made primary school free and compulsory, has increased primary school enrollment rates to 97% (UNDP).

Health

The average life expectancy for the total Rwandan population at birth is 56.77 years, a global ranking of 192 out of 224 countries (CIA). There are a number of reasons for poor health outcomes in Rwanda. HIV/AIDS remains a large problem in the country. While HIV prevalence has fallen dramatically from a 13% prevalence rate in 2000 to 3% in 2006, Rwanda's HIV prevalence continues to be the twenty fifth highest in the world (UNDP; CIA). Approximately 7,800 Rwandans per year die of the disease (CIA).

HIV/AIDS is also associated with a twin epidemic of tuberculosis, as 60% of people living with HIV/AIDS are diagnosed with TB (Republic of Rwanda).

Malaria is the largest cause of morbidity throughout Rwanda, and fifty percent of all visits to health centers in the country are necessitated by malarial infection. The incidence rates of malaria have skyrocketed in Rwanda, from a scant 3.5% rate in 1982 to 48% in 2003. Increased population density, rainfall and temperature changes and the resistance of malaria to existing treatment options are all believed to contribute to the increasing infection rates. Malaria is an especially devastating disease condition for young children, with children under five experiencing more than half of all hospital visits linked to malaria, as well as more than half of all malaria-related deaths. Malaria is also a health risk for pregnant mothers (Thaxton 2009, 4).

However, malaria is not the only health issue faced by children or pregnant women in Rwanda. The infant mortality rate is 67.18 for every 1,000 live births, and maternal mortality rates number at approximately 750 deaths for every 100,000 live births (CIA; Rusa et al. 2009, 191). Only 52% of births are assisted by a skilled birth attendant, a number lower than the global average (Republic of Rwanda). Having a skilled birth attendant present during childbirth is key to preventing and treating conditions that can lead to disease or death in the fetus and the mother.

Older children in Rwanda also suffer poor health outcomes, as the mortality rate for children under five years of age is 103 in every 1,000 children (CIA; Republic of Rwanda). A contributing factor to this high rate is that forty five percent of all children under five are chronically malnourished. Malnourishment can be the result of a disease,

such as a parasite, or be a cause of disease, as malnourishment weakens the immune system, making children more vulnerable to infection (Rusa et al. 2009, 191).

Economy

Rwanda's economy virtually collapsed during the genocide, though major governmental and global efforts to restore Rwanda's economy to pre-1994 levels have largely been successful (CIA). Rwanda's GDP is approximately 3.4 billion dollars with a per capita income rate of 370 dollars (Department of State). However, major gains still need to be made, as 60% of the Rwandan population lives below the poverty level of 250 Rwandan francs per day, the equivalent of forty three American cents (CIA). There has also been a decline in the real GDP growth rate in Rwanda as the global economic recession has curbed tourism and export demand (CIA).

Rwanda's economy is heavily dependent on agriculture, with the agricultural sector accounting for approximately 40% of GDP (CIA). Eighty five percent of the population also engages in agriculture of some kind, often at the subsistence level (CIA). Rwanda's main agricultural products are coffee, tea and pyrethrum, an insecticide made from chrysanthemums (Department of State). Despite Rwanda's focus on agriculture and its fertile land, it often must import foodstuffs in order to meet the demand of its growing population (CIA).

Besides, exporting agricultural products, Rwanda also exports minerals, such as coltan, cassiterite, tin and iron ore (CIA). Minerals have even recently overtaken both coffee and tea as Rwanda's primary export (Department of State). Countries that receive Rwanda's exports include China, Belgium and Germany, and Rwanda often imports from Kenya, Uganda and China (Department of State). Rwanda has, in recent years, worked to

become a more powerful player in regional trade, and has joined the East African Community in an attempt to spur economic growth (CIA).

Government

Paul Kagame has been president of Rwanda since 2000. Born in Rwanda, he left with his family for Uganda at the age of four amid growing anti-Tutsi violence. He spent years fighting in Uganda under Yoweri Museveni, and later was instrumental in the formation of the RPF. After the RPF captured power, Kagame accepted the position of Vice President, but was regarded by many as the preeminent powerbroker in Rwanda (Simpson 2000).

Under Kagame's leadership, Rwanda has made great strides in repairing the damage done by the genocide. Millions of dollars of aid money is channeled into Rwanda yearly due to its reputation for low levels of corruption and its detailed spending plans. Education has become one of the state's major causes, and the government has also focused on building up infrastructure and increasing Rwandans' access to technology. Reforms to create a more equitable society for women have resulted in Rwanda being the first country in the world where female legislators outnumber their male counterparts (Economist 2010).

However, the run-up to the presidential election in August 2010 has led to some international uncertainty about Kagame's leadership. Claims of suppressing opposition parties and the press have been lodged against Kagame's government, despite the fact that he is almost guaranteed reelection. Opposition parties are forbidden to "use words or facts that defame other politicians," or face criminal charges and jail sentences (Economist 2010). A new opposition group, the Democratic Green Party, may not even

be able to register a candidate for the election. One of the Green Party's reported members, a former intelligence officer, has fled to South Africa after being wanted by the police, ostensibly due to criticisms he has lodged against the government (Economist 2010).

Indoor Air Pollution Background

While clean air is just as important to good health as clean water, the issue of indoor air pollution has received disproportionately little attention outside of public health policy circles (Bruce, Perez-Padilla and Albalak 2002, 5). When the issue has been focused upon, indoor air quality studies have largely been conducted in schools and offices of developed countries (Smith 2002, 198). However, the highest levels of exposure to indoor air pollution are actually found in rural and urban areas of developing countries, due to the widespread practice of burning unprocessed solid fuels (Bruce, Perez-Padilla and Albalak 2002, 5).

Approximately half of the world's population, or 3 billion people, use solid fuels for cooking and heating their homes (Smith 2002, 281). Unprocessed solid fuels include coal, as well as a group of fuels known as biomass fuels, or fuels derived from plant and animal products (Bruce, Perez-Padilla and Albalak, 2000, 1078). Dung, wood and agricultural residues are the most common biomass fuels in use (1079). About 2.4 billion people use biomass fuels, with the remainder relying on coal use, which is especially prominent in China (Bruce et al. 2006, 793). In Europe less than twenty percent of all people use solid fuels, whereas in sub-Saharan Africa and South Asia, more than eighty percent of people use solid fuels for cooking and heating (793). Use of solid fuels is, therefore, connected to poverty, as people in developing nations often cannot

afford to purchase or do not have access to alternative fuel sources (793). Historically, as people's economic status improves, they are able move up the energy ladder, changing to more efficient, expensive and cleaner burning fuels, for example, trading wood for electricity (793). However, during the 1990s, while some areas of the world were able to decrease their dependence on solid fuels, in Sub-Saharan Africa high population growth and low economic growth led to an increase in dependence on biomass fuels (793). It is estimated that in Sub-Saharan Africa and South Asia, reliance on solid fuels will continue to increase. Globally, biomass fuel use will increase from 2.4 billion people to 2.6 billion people using biomass fuel by 2030 (794-5).

Indoor Air Pollutants

Solid fuels are used for cooking and heating the home and are burned on rudimentary open fireplaces, which can consist of as little as a ditch in the ground, or poorly maintained stoves made of metal or earth. Because combustion tends to be incomplete in these stoves, and biomass fuels and coal smolder for hours at a time, indoor pollutant emissions are high (Bruce, Perez-Padilla and Albalak 2000, 1078-9). Many homes lack proper ventilation for their fires, including flues, hoods or chimneys, leading to pollutants remaining in a household's living space (Smith 2002, 198).

A range of pollutants are associated with the burning of solid fuels. Particles are one of the primary pollutants derived from burning solid fuels, as they can pierce deep into the lungs. Particles with diameters smaller than 10 microns, PM_{10}, are considered especially harmful due to their small size, allowing them greater access into the deep recesses of the lungs. The United States Environmental Protection Agency (EPA) has set guidelines for 24-hour average concentrations of PM_{10} at 150 mg/m^3. However, in homes

burning solid fuels, the rates of PM_{10} are typically between 300 and 3,000 mg/m^3, and can reach as high as 30,000 mg/m^3 during periods of burning (Bruce, Perez-Padilla and Albalak 2000, 1079).

Carbon monoxide, another major pollutant caused by burning solid fuels, similarly reaches levels that are much higher than EPA standards. EPA guidelines for an 8-hour period is 9 parts per million (ppm) of carbon monoxide, but 24-hour carbon monoxide levels in homes burning solid fuels are typically between 2 and 50 ppm (1079). During the burning of solid fuels, carbon monoxide rates have even reportedly been as high as 500 ppm (1079).

Despite the data that is known about high solid fuel pollutant levels in homes, many studies have been unable to extrapolate their results to larger populations. This is hindered by the variety of variables that can contribute to higher and lower pollutant levels in a home, such as the presence or absence of ventilation systems, type of stove and type of fuel used (Smith 2002, 200-1). For example, wood is considered to be a cleaner burning biomass fuel than dung or agricultural residues, yet even people who prefer to use wood, often do not do so throughout the year due to cost and availability restrictions (Bruce, Perez-Padilla and Albalak 2002, 5; Barnes and Mathee 2002a, 20). Similarly, other variables such as weather and season can affect people's ventilation practices and fuel choices (Barnes and Mathee 2002a, 8-9). For example, an observational study of villages in South Africa found that during the summer months, people tend to cook outdoors, reducing pollutant levels in their homes (8-9). However, during the winter and cold spells throughout the year, the fire is used for cooking and heating the home, which increases indoor burning times (8-9). Also during periods of

cold weather, windows and doors are likely to be shut to prevent heat from escaping, a practice that increases pollutant levels in the home (26).

The season can also affect the amount of time that people spend in their homes near a fire, which determines their level of exposure, or time that people spend breathing in polluted air. Throughout the world, people spend the majority of their time indoors, especially in their homes, leading to indoor air pollution causing greater pollutant exposures than outdoor air pollution (Smith and Mehta 2003, 280). On average, people in the developing world are exposed to high levels of indoor pollution for between three and seven hours daily (WHOf). In cold areas, during the winter and at high altitudes, the exposure levels could be much higher, as people remain indoors to escape the cold weather outside (Barnes and Mathee 2002a, 8).

However, even within these regions, exposure levels are not uniform. Throughout the world, women are disproportionately more likely to suffer from high exposure rates, due to their traditional role in cooking and tending the fire. Women's young children, who are being cared for by their mothers, and thus accompany them throughout their daily tasks inside the house, are equally likely to be exposed to indoor pollutants. The high exposure rates of women and children make them the most vulnerable groups for diseases associated with solid fuel pollutants (Bruce, Perez-Padilla and Albalak 2000, 1080).

Disease Burden of Indoor Air Pollution

A wide range of diseases have been linked to indoor air pollution. As noted earlier, small particulate matter and carbon monoxide are two damaging pollutants caused by burning solid fuels. Particulate matter can cause wheezing, respiratory infections and

trigger asthma attacks (Bruce, Perez-Padilla and Albalak 2002, 11). Emerging evidence also links particulate exposure with cardiovascular disease (Bruce et al. 2006, 795). High rates of carbon monoxide exposure are linked to poor health outcomes for pregnant women and their children, including low birth weights and an increase in perinatal deaths. Other pollutants caused by burning solid fuels are also linked with health risks. Benzopyrene is one carcinogen that is prevalent in homes that burn coal. It is linked to cancers in the digestive and respiratory systems. Nitrogen dioxide and sulfur dioxide, other pollutants associated with solid fuels, can exacerbate asthma symptoms and respiratory infections. The smoke from solid fuels has even been linked to cataracts, caused by the lenses of the eye absorbing pollutants from the air (Bruce, Perez-Padilla and Albalak 2002, 11).

Though indoor air pollution has been linked to a number of health conditions, the most prominent and disturbing health risk for young children is the link between indoor air pollution and acute lower respiratory infections, or ALRI. ALRI is a group of diseases, including pneumonia, bronchiolitis and bronchitis, which can be caused by both viruses and bacteria (Smith 2002, 199; WHOa). It is the greatest cause of death for children under the age of five, contributing to two million deaths annually, and it is responsible for one twelfth of the global burden of disease (Bruce, Perez-Padilla and Albalak 2000, 1081; Smith 2002, 199). Children who live in polluted households have been found to be two to three times more likely to develop an ALRI than children in unexposed households (Smith 2002, 199). In one study, seventy percent of infants under thirteen months of age who were infected with an ALRI had received daily exposure to

pollutants from a wood burning fire, a significantly higher amount of exposure than children who were uninfected (Barnes and Mathee 2002a, 5).

However, children are not the only population at risk of serious diseases caused by indoor air pollution exposure. Women also experience negative health outcomes from exposure, specifically lung diseases. COPD, or chronic obstructive pulmonary disease, is a general term for a number of illnesses characterized by a permanent and progressive obstruction of airflow to the lungs (WHOd). Two well-known COPD diseases are emphysema and chronic bronchitis (WHOd). While in high income nations, COPD is most commonly caused by tobacco smoke, the high prevalence of COPD in developing nations is largely due to indoor air pollution (WHOc). Women who cook over solid fuel fires or stoves over a period of years are two to four times more likely to suffer from COPD than women who do not use solid fuels (Smith 2002, 199). Currently, an estimated eighty million people are living with COPD, and the disease was responsible for three million deaths in 2005, five percent of all global deaths (WHOb). However, most available information on COPD is from high-income nations, despite ninety percent of deaths from COPD occurring in developing nations (WHOb). While in 2002 COPD was the fifth leading cause of death globally, it is estimated that by 2030 it will have increased to be the third leading cause of death worldwide (WHOb).

Similar to COPD, lung cancer in the developed world can be explained by smoking, however, in developing nations, high rates of lung cancer, especially among female non-smokers, has been linked with exposure to carcinogens produced by burning coal. While, currently, there is no definitive link between burning biomass fuels, such as wood, and lung cancer, it is known that carcinogens are one output of biomass fires. If

carcinogen exposure from wood smoke is analogous to particulate exposure, it is estimated that cooking with biomass stoves is equivalent to smoking several cigarettes per day. The high rates of COPD among women who use solid fuels is also a major link with lung cancer, as previous lung disease is a risk factor for lung cancer. It is unclear whether exposure to the pollutants that cause COPD can culminate in lung cancer or if injured and inflamed lungs, caused by COPD, can make tissue more prone to cancer development (Bruce, Perez-Padilla and Albalak 2002, 19).

There is also data which supports a link between indoor air pollution and tuberculosis (Bruce, Perez-Padilla and Albalak 2000, 1082-4). A study in Mexico City found that people who were exposed to pollutants from wood fires in their homes were 2.4 times more likely to develop tuberculosis than those that were not exposed (Smith 2002, 199). Studies conducted on animals support these findings, as respiratory immune function has been shown to be reduced by chronic exposure to pollutants, making the lungs more vulnerable to tuberculosis infection (199).

Worldwide, it is estimated that solid fuels account for 1.6 million excess deaths and 2.7 percent of disability-adjusted life years (DALYs) lost annually. When only the statistics of developing countries are analyzed, rather than global rates of disease, the percentage of DALYs lost to indoor air pollution is even higher, with indoor air pollution accounting for 3.7 percent of DALYs lost in developing countries. These rates make indoor air pollution exposure the third greatest environmental cause of disease globally after lack of adequate water and sanitation services and poor hygiene practices. The global DALYs burden occurs mainly in Sub-Saharan Africa and South Asia, with thirty

two percent of the burden occurring in Africa and thirty seven percent of the burden in Asia (Bruce et al. 2006, 797).

Globally, more female deaths are caused by indoor air pollution than male deaths, but the sexes experience the DALYs burden equally. The parity in DALYs lost is associated with a higher death rate for male children under five from ALRI than female children. However, when looking at specific data surrounding COPD, women experience three times the death rate from COPD of men. They also have twice the rate of DALYs lost from COPD when compared with men. Again, when looking specifically at developing nations rather than global statistics, exposure to indoor air pollution is an even greater source of negative health outcomes. For example, in Sub-Saharan Africa, thirty percent of deaths caused by ALRI can be attributed to indoor air pollution, as can half of all COPD deaths in women (797).

Interventions to Address Indoor Air Pollution

There are a wide variety of different interventions which can be used to address people's high exposure to pollutants in developing countries. One of the most effective in reducing indoor air pollution levels is using alternatives to solid fuels. These fuels could include solar power, electricity, biogas and liquid petroleum gas. Improving stoves through using new or well-maintained stoves can also reduce pollutant output from solid fuels by facilitating better combustion, and, frequently, shorter cooking times. The installation and utilization of ventilation systems, such as windows, chimneys, hoods and flues is another major way to reduce pollutant levels in homes. Lastly, behavior modification through people spending less time near stoves, drying wood before it is used

and breaking fuel into smaller pieces can also result in smaller, but significant, decreases in pollutant exposure (WHOe).

There is a dearth of studies that have been conducted to find out how effective and feasible each of these different interventions is (Smith 2002, 201). One study that was conducted focused on the cost-effectiveness of providing access to cleaner fuels in comparison to providing access to cleaner burning stoves, which included ventilation systems such as chimneys (Mehta and Shahpar 2004, 53). It compared three interventions: providing the entire population with cleaner fuel alternatives, providing the entire population with improved stoves and providing half of the population with clean fuels and half with improved stoves (53). The study relied heavily on estimations of the cost and the effect of each intervention, because while changing fuels and access to improved stoves are known to reduce pollutant output, the amount of the reduction, especially for stove use, is not known, and largely depends on the type of stove and fuel used (54). When comparing two types of cleaner fuel alternatives, kerosene and liquefied petroleum gas, the study found that kerosene is the more cost-effective option for implementing a public health program (58). However, kerosene use is also associated with poisoning, burns and carcinogen output (58).

Overall, the study concluded that it would be more feasible to promote improved stoves, as changing to alternative fuels is a difficult process, and many of the substitute fuels carry their own health risks (58). Alternative fuels are also inaccessible for many people due to living in a remote, rural area or due to their higher costs (58). For a widespread program to address the cost and accessibility of alternative fuels, large investments in a country's energy infrastructure could be necessary (58). Therefore,

improved stoves would be cheaper to purchase and more feasible to create as they can be made from local materials, making improving stove and ventilation systems the more cost-effective intervention (58).

A study conducted in South Africa also shows data that would seem to be unsupportive of programs promoting alternative fuel use. The study measured solid fuel use among households that had recently gained access to electricity. While these households did use electricity, they also continued to use solid fuels because of the high cost of electricity and requisite electrical appliances (Bruce, Perez-Padilla and Albalak 2000, 1087). Other findings have shown that households that receive access to electricity tend to use it to light their homes, while still using biomass fuels for cooking and heating (Bruce et al. 2006, 795). Therefore, although global access to electricity is expected to increase by 2030, without substantial increases in the socioeconomic status of electricity users, this is not an adequate intervention to reduce indoor pollution levels (795).

Other studies have concurred, and found that improved stoves are the most cost-effective intervention for Sub-Saharan Africa and South Asia, the two regions with the highest rates of disease from indoor air pollution. While improved stoves cannot reduce pollution levels as effectively as alternative fuels, they have been shown to produce some major gains in indoor air pollution levels. In East Africa, improved stoves for burning wood have reduced kitchen pollution by as much as fifty percent. Similarly, in Nepal, there has been as much as a two thirds reduction in PM levels with improved stoves. The highest gains from improved stoves have been made in Latin America, as plancha-type stoves, made of cement blocks with a metal flue, have reduced PM_{10} levels by as much as ninety percent. While Sub-Saharan Africa has had little success with the implementation

of improved stoves to date, recent studies in Kenya have shown that stoves with hoods and flues have reduced 24-hour PM levels by up to seventy five percent. While improved stoves have been shown to yield major reductions in pollutant levels, it is important to note that a concurrent reduction in pollutant exposure does not always occur. For example, the Kenyan stoves that produced a seventy five percent reduction in PM levels, only yielded a thirty five percent reduction in pollutant exposure for the average woman (Bruce et al. 2006, 803).

It is also important to note that while improving or maintaining stoves are a cheaper alternative to switching to substitute fuel sources, it is still not financially feasible for every family. A study conducted in rural South Africa found that the cost of maintaining wood-burning stoves was too high for most families to afford. Families in the study who were able to fix or maintain their stoves used low-cost methods such as patching chimneys with dung. These methods do not reduce pollutant emissions as much as more expensive methods such as buying a new stove, or having a stove professionally refurbished. Therefore, stoves that had been fixed were still emitting high levels of pollutants, despite the intervention. Homeowners, however, were unaware of the persisting pollutant levels, and felt that the maintained stoves were safer, producing fewer pollutants. Mothers and their children, therefore, actually spent a greater amount of time near the fixed stoves in comparison to the unmaintained stoves, leading to the possibility that fixed stoves could lead to greater pollutant exposure. Therefore, programs to introduce new or improved stoves should contain an educational component to address people's misperceptions of indoor pollution (Barnes and Mathee 2002b, 20-1).

The same study also tested the feasibility of different behavior changes to reduce pollutant exposure. It found that reducing the duration of burning was not a feasible solution to indoor air pollution, because of the need to heat homes and the constraints that a shorter burning duration placed on women, including trying to do all of their household chores in a shorter period of time. The study found that a more feasible option is for mothers to try to keep children away from the fire, especially through an adult watching the child in an area that is far from the stove. Another behavior change that was shown to be feasible was increasing ventilation practices, such as opening windows and doors in the house, especially during periods of high pollutant emissions such as when fuel is added to a fire (Barnes and Mathee 2002b, 21).

Another feasible way to reduce pollutant emissions is to change the type of solid fuels that families use. Because of the difficulty in changing from biomass fuels to fuels such as kerosene and liquid petroleum gas (LPG), some countries, especially in Sub-Saharan Africa, have begun using charcoal as a temporary, transitional fuel source. While charcoal is a biomass fuel, it is also a processed fuel, which is cleaner burning than wood and other unprocessed biomass fuels. Concentrations of PM_{10} in households using charcoal is, on average, ninety percent lower than in households that continue to burn wood. Households gradually transitioning from wood to charcoal could postpone one million deaths globally, while a more rapid transition could delay 2.8 million deaths by 2030. However, switching from biomass fuels to LPG and kerosene could yield even greater health benefits. A gradual transition to LPG and kerosene could reduce mortality rates by 1.3 million deaths and a rapid transition would prevent 3.7 million deaths by 2030. Therefore, those that have access to LPG and kerosene, especially those in urban

areas could be encouraged to adopt those fuels, while people living in rural areas, especially the most impoverished individuals, could switch to charcoal as a healthier alternative to wood. Charcoal is seen, however, to be a temporary fuel option until people are able to climb the fuel ladder and afford even cleaner burning, more efficient alternatives, such as kerosene and LPG, eventually culminating in the use of electricity for all of the household's energy needs (Torres-Duque et al. 2008).

Indoor Air Pollution in Rwanda

Sub-Saharan Africa is one of the regions of the world that is most affected by indoor air pollution, with more than eighty percent of its people using biomass fuel. Dependence on biomass fuel in Sub-Saharan Africa is only expected to increase in the future. As noted earlier, thirty two percent of all DALYs lost due to indoor air pollution occur in Sub-Saharan Africa (Bruce et al. 2006, 793-7). In total, lower respiratory infections were estimated to be the third leading cause of death in Sub-Saharan Africa in 2000 and COPD was the thirteenth leading cause of death, causing 1.1% of all deaths in the region (Rao, Lopez and Hemed 2006, 53).

Within Sub-Saharan Africa, Rwanda is one of the countries that is most impacted by indoor air pollution. In Rwanda, more than ninety five percent of the population use solid fuels, one of the highest rates in the world (WHO 2007). Of these solid fuels, firewood provides over 92% of all energy for Rwandan households, with charcoal and agricultural residues being the other two biomass fuels in use in the country (Sustainable Energy Africa 5). Even Rwandan industry is highly dependent on biomass fuels with an estimated 40% of industry and commerce's energy needs being provided by firewood (5).

In 2002, 8,100 deaths were attributable to indoor air pollution in Rwanda, with over ninety percent of those deaths occurring in children under the age of five due to ALRI infection. The remaining deaths were caused by COPD in adults. It is also estimated that for that same year, 262,300 Rwandan DALYs were lost due to indoor air pollution exposure. In total, indoor air pollution caused by solid fuel use accounted for 5.8% of the Rwandan national burden of disease in 2002 (WHO 2007).

Current Indoor Air Pollution Policy in Rwanda

The Rwandan government's 2005 official document on Health Sector Policy does not contain a single reference to indoor air pollution. "Environmental pollution" is vaguely listed as one of the causes of non-communicable diseases in Rwanda, but this is only after a laundry list of other causes, including diabetes, cancer and alcohol abuse (Government of Rwanda). Similarly, acute lower respiratory infections in children under five are only briefly referenced in the context of a long list of childhood illnesses faced by Rwandans. COPD went completely unmentioned in the document. HIV/AIDS, malaria and tuberculosis are the main priorities discussed in the policy paper, as well as information on reproductive health. While these diseases are, of course, important and should compose a large section of Rwanda's national health policy, the complete lack of any reference to the problem of indoor air pollution, and the diseases associated with it, show that Rwandan health policymakers lack consciousness about how widespread and devastating the issue of indoor air pollution is (Government of Rwanda).

In a separate 2008 government document, entitled "Environmental Health Policy," the Rwandan Ministry of Health does acknowledge indoor air pollution as a primary cause of acute respiratory infections (Rwandan Ministry of Health 1). However,

the report included general statistical information about indoor air pollution in developing countries, rather than specific information about Rwanda (11). The document also discussed the issue of indoor air pollution jointly with the topic of outdoor air pollution (11). While indoor and outdoor air pollution are related, they have different causes. Indoor air pollution often results from the pollution of households, whereas outdoor air pollution results from cars, industry and mostly large-scale polluters. Just as indoor and outdoor air pollution have differing causes, they also have differing solutions. Therefore, to seriously address either issue, it is not useful for the two to be lumped together into a single problem to be addressed.

The document claims that limited institutional and resource capacity has resulted in the inability of the government to measure or mitigate air pollution. Similarly, little public awareness of air pollution and a lack of political and institutional will to enforce legal measures that control pollution have resulted in little being done to address the issue (11). While the document is forthright about the limitations of the Rwandan government, it does not suggest specific policies or strategies that the government could undertake to improve these limitations (11). Also, the issue of indoor air pollution receives only a brief mention in the multi-page document, and is not considered one of the "major contributing factors to environmental health diseases in Rwanda" (7). Therefore, both the Environmental Health Policy document and the National Health Sector document, do not prioritize indoor air pollution, and do not contain policy solutions to deal with this unaddressed need.

While indoor air pollution has received little attention in Rwandan health policy circles, it has received greater priority among international NGOs and development

professionals who are focused on the issues of energy and environmental protection in Rwanda. Because over ninety two percent of Rwanda's energy needs are met by firewood, the country faces a major deforestation problem. Similarly, thirteen percent of soil degradation in Africa is linked to the overexploitation of forest resources for energy production (Borchers and Annecke 6).

There has also been a push among some organizations in the international development community for a multi-sectoral approach to development in Rwanda, which would target the interrelated issues of poverty, energy and the environment. The poor are most dependent on biomass fuels, because they do not have the resources to purchase more efficient fuel sources (Sustainable Energy Africa 5). Therefore, when biomass resources become depleted, such as in the case of deforestation, the poor must begin to pay for a fuel source that they once accessed for free (5). Similarly, the poor spend approximately fifteen to twenty eight percent of their income on fuel, whereas the wealthy pay only between three and seven percent of their income for energy (6). By addressing the interrelated nature of poverty, energy and the environment, some international development professionals hope to encourage a movement away from the use of biomass fuels in Rwanda, through the encouragement of economic growth (Borchers and Annecke). Economic growth would then lead to the Rwandan population's ability to pay for more efficient fuels, which are better for the environment and for their health (Borchers and Annecke).

Developing New Policies

While there is an inarguable connection between poverty, environmental degradation and energy use, a multi-sectoral approach that would address all three issues

jointly is not the most efficient way of ameliorating the problem of indoor air pollution in Rwanda. While economic growth and an increase in Rwandans' incomes would allow people to purchase more efficient fuels, an improvement in a country's economic prospects is often a long-term endeavor requiring years, if not decades, to produce gains for the poor. In the mean time, people will continue to use biomass fuels, be exposed to indoor air pollution and suffer the related health effects. Similarly, while the environment and fuel choices are intimately related, a policy approach that focuses on both environment and energy would be a broad undertaking. There are many problems associated with environmental degradation in Rwanda, not only deforestation, including overgrazing and the poaching of endangered wildlife (University of Gothenberg 2). Even the issue of deforestation is not entirely linked to energy use, as the main causes of deforestation are actually clearing land for agricultural use and unsustainable land use (Sustainable Energy Africa 7). Therefore, wide-ranging policies would be needed to address the problems of poverty, the environment and energy, and, often, these policy measures would not result in tangible returns for years to come. Focusing on all three major, complex issues is not the best way for Rwanda to adequately address the specific issue of indoor air pollution in a timely fashion. Instead, Rwanda would be better served by having precise policies in place to encourage people to reduce their exposure to indoor air pollution in the short and medium-term until economic growth and environmental protection laws are able to curb biomass fuel use entirely.

While, as discussed earlier, there are many ways that exposure to indoor air pollution can be reduced, including through changing fuels, using improved stoves, changing burning behaviors or modifying ventilation practices, most studies have found

that in sub-Saharan Africa, changing to improved stoves is the most cost-effective way to address indoor air pollution (Bruce et al. 2006, 805). However, there are two very important barriers to families using improved stoves in Rwanda. The first is the financial barrier of not having the disposable income necessary to afford a new stove, and the second is the lack of awareness and knowledge about indoor air pollution and the diseases it brings about.

An instructive program that could possibly deal with both of these barriers is being carried out in Kenya. In Kenya, during the 1990's, a number of improved stoves were given out to households free of charge by NGOs focused on reducing indoor air pollution (Kenya 40). However, this program was not large enough to benefit a significant amount of Kenyan households (40). Past experiences have generally shown the provision of free stoves on a large scale is not efficient, and better gains in air pollution reduction can be achieved through creating demand for the stoves (Bruce et al. 2006, 800). To this end, Kenya has created a new program, which is aimed specifically at institutions, such as schools and hospitals, which utilize biomass fuels (Kenya 42). It has worked to promote the use of improved stoves by the institutions through creating awareness about the issue of indoor air pollution, and removing governmental barriers to the purchase of stoves (40). The Kenyan government has set a specific goal of 3,500 improved stoves being purchased over a four year period (42).

A similar project could be undertaken by the Rwandan government, but with a greater focus not only on the institutional and commercial level, but also at the household level. To address the knowledge barrier and create demand for improved stoves, the Rwandan government must strive to educate its citizens about the causes and

consequences of indoor air pollution. The Rwandan government has already made great strides in promoting education, increasing its primary school enrollment rate to 97%, and can utilize the school system to teach children about energy use, environmental degradation and indoor air pollution (UNDP; Bruce et al. 2006, 800). Similarly, media campaigns should be created to educate the general public about indoor air pollution exposure and the importance of using improved stoves (800). Entertainment-education programs, which integrate health information into a soap opera-style television or radio program, could be an effective means to teach people about indoor air pollution.

Besides simply encouraging use of the stoves, the education campaigns in schools and in the media are also a key way not just to educate Rwandans on the issue of air pollution, but also to ensure that they understand how stoves are to be maintained to insure optimal performance. Similarly, the educational component of the campaign must include the information that stoves are not a panacea, they simply reduce pollutant output, but they cannot completely eliminate it. To coincide with the push for the purchase of improved stoves, therefore, women and their children should be advised to spend as much time away from the stove as possible to further eliminate exposure rates. Education campaigns should encourage older women in the village to take on the responsibility of watching young children while young mothers are cooking or need to be near the fire for other chores, thus, again, reducing exposure rates of young children. Entertainment-education campaigns could provide models for these types of behaviors.

For a program to coincide with the education campaigns, the Rwandan government could use the Kenyan model to encourage the use of improved stoves. Just as the Kenyan program strived to reduce governmental barriers to the purchase of new

stoves, the Rwandan government could reduce or eliminate any taxes that might be applied to new stoves (Bruce et al. 2006, 800). Similarly, subsidies could be applied to the stoves, even if they are only limited to an initial period in order to increase demand at the beginning of the stove utilization program (800). Again, media should be utilized to advertise the improved stoves, as well as subsidies and tax exemptions for the stoves (800). The Rwandan government would be well-advised to follow the lead of the Kenyan government and set a specific goal for the number of stoves to be purchased over the course of a certain time span. The Rwandan government should then work to track the purchases of stoves, in order to determine what groups of people purchased the new stoves, and what groups should be focused on to encourage their uptake of improved stoves in the future.

While the Rwandan program should incorporate many of the policies of the Kenyan government's stove program, it should also avoid the mistakes that lead to the failure of India's program. India carried out its own National Stove Program between 1983 and 2000. However, the Indian program gave out over thirty three million stoves free of charge, rather than encouraging demand for the stoves. Despite the large amount of stoves delivered, less than seven percent of all stoves used in India are improved stoves. Because of lack of demand for the stoves, poor utilization and maintenance of the stoves often resulted, as households were not motivated to use or preserve a device which they had no personal investment in. Another problem faced by the Indian program was that the stoves given out by the government were of poor quality, and resulted in a life span of less than two years (Bruce et al. 2006, 809).

The Rwandan program would avoid the problem of people not using or maintaining the stoves, by helping to create a market for the stoves through financial incentives and education campaigns. Therefore, anyone who purchased an improved stove would both desire to use an improved stove, and have personally invested in the stove through a financial payment. In order to facilitate purchasing of the stoves among Rwandans who lack monetary resources, besides giving consumers tax incentives to purchase stoves, the Rwandan government could also give manufacturers subsidies or tax exemptions in order to encourage them to create stoves in a range of prices and sizes, in order to benefit as many people as possible. As noted earlier, stoves can often be made from local materials at a small cost, and these local manufacturers should be encouraged by the Rwandan government (Mehta and Shahpar 2004, 53). Another way to lessen the financial difficulty of purchasing an improved stove is to support microcredit schemes through the government, NGOs or women's groups, for families who would like to purchase a stove, but cannot pay for the stove in one lump-sum payment (802). There are, therefore, many ways to reduce the financial burden of purchasing improved stoves, while ensuring that consumers have a vested interest in using and maintaining their stoves.

Conclusion

While indoor air pollution accounts for millions of deaths and DALYs lost annually, it has received little attention outside of international health policy circles, and has often been overlooked in favor of other environmental health problems, such as lack of access to clean water and sewage systems. Indoor air pollution affects the most vulnerable individuals in society: the poor, who cannot afford efficient fuel sources,

women, who are forced to breathe in pollutants in order to cook and care for their families, and young children, who accompany their mothers and receive the same exposure to pollutants. In Rwanda, especially, the problem of indoor air pollution and its related health conditions is large, yet, has received little attention from policymakers. By prioritizing a policy program to control, and eventually eliminate, indoor air pollution, the Rwandan government could help to ameliorate a health problem that is devastating, but preventable.

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