Abstract

In an ever increasing global world it is becoming more important for scientists and engineers to research global and regional causes and effects of climate change and devise sustainable appropriate solutions. Day-to-day activities and the choices we make can have drastic regional and global impacts; by assessing these impacts we can make informed and positive choices for a more sustainable future. Researching how products and systems affect human health, global warming, ecosystems, and resources will assist decision makers and individuals achieve this end. This paper looks specifically at the “cradle to grave” impacts that fuel usage in developing countries have on local health and global climate change. Based on our results we recommend appropriate and cost effective solutions for improved cooking practices in sub-Saharan Africa.
Introduction

The task of cooking food is a common activity in our day-to-day lives that almost everyone takes part in. Cooking with solid fuels is the oldest environmental health hazard known to man, however, only recently have scientists begun quantifying its affects on Acute Respiratory Illness (ARI) and other human health problems. Today more than three billion people, almost half the world’s population, cook in their homes using traditional fires and stoves that use solid fuels such as wood, dung and crop waste. In Tanzania greater than 95% of the population uses solid cooking fuels as their primary source of fuel. People spend much of their time indoors breathing in lethal fumes which, according to the World Health Organization, claim the lives of one and a half million people per year (WHO, 2002). Women and children account for the majority of these deaths due to their increased exposure in the home. Further research into the effects and quantities of black carbon, particulates, and harmful gasses produced by solid fuel burning is vital for global sustainability planning. Utilizing our current understanding of these issues and Life Cycle Assessment (LCA) software, SimaPro 7.1, we will assess the global and regional implications of four household cooking fuels on health and climate change.

As we enter the 21st Century there is many global problems that must be addressed. Environmental degradation, climate change, population growth, water quality, and disease are just a few of the problems that the world’s scientists and engineers are tasked to deal with. Nine years ago world leaders established goals for achieving environmental sustainability and global development to improve the standard of living for humanity and secure a viable future for the generations to come. One goal set forth by the United Nations (UN) that greatly effects all eight Millennium Development Goals (MDG’s), is halving the amount of people that use solid fuels by 2015 (Table 1). In order to reach the MDG’s by 2015 interdisciplinary solutions are needed. Global issues are complex adaptive problems that require solution framework encompassing various fields of study and expertise from scientists, engineers, social scientists, and policy makers alike. This project will combine information about the contributions of harnessing the fuel source, transporting the fuel, and the negative risks associated with combustion for four fuel sources. Cost, effectiveness, labor, and social constraints of using various fuel types will also be investigated. If people are to become more resilient to global changes, scientists must have a better understanding of the global impacts from regional variability.

Fuel emissions also effect climate change by contributing particulates, soot, and green house gases into the atmosphere. Reducing fuel emissions would have an impact similar to improving the efficiency of automobiles and could be an additional mitigation wedge. By expanding our regional knowledge about health risks and negative impacts to the environment, the scientific community’s and policy maker’s abilities to make accurate climate impact predictions and choices regarding cooking stove implementation and intervention will be enhanced.
Scope and Data

Preliminary surveys showed five primary fuels used in sub-Saharan Africa. We analyzed each fuel to see which is the most applicable and available for most inhabitants. The assessment included five different fuel types:

Firewood: Firewood is the most common type of energy used in sub-Saharan Africa, (Figure 1) with 86% of the population in Tanzania relying on it as their primary fuel source. The average annual per capita consumption was estimated to be approximately 1204.5 kg with the use of the traditional cooking stove, 3-stone method (Smith et al., 2007). However, with the use of an improved cooking stove the energy consumption was reduced between 15% - 80%, for this study we estimated a 50% fuel reduction (Bailis et al., 2007). Firewood is obtained mainly from agro forestry or on-farm sources (84%), from trust lands (8%) and from gazette forests (8%). Approximately 76% of households obtain all of their firewood free of charge, 17% of households regularly purchase it, while 7% supplement their free collection by purchasing some firewood (Theuri, 2005). The efficiency of firewood is 16 MJ/kg (Leach, 1988). Firewood is not only used for cooking, it is also important for its lighting and heating capabilities.

Charcoal: Charcoal is primarily an urban fuel, because of the difficulties related to the transportation distances and ease of use. We found that only about 6% of the population in Tanzania uses charcoal for cooking. Per capita consumption was estimated to be at 1000 kg/year (Wijayatunga and Attalage, 2002). Cost per 36-kg bags of charcoal are approximately 5,000 Tsh (3.80 USD) equaling an annual cost of $105.55. This is expensive for most Tanzanians but is sometimes the only affordable alternative cooking fuel if wood and crop residues are not available. The average energy efficiency of charcoal is 30 MJ/kg (Leach, 1988).

Kerosene: Kerosene is often regarded as a “poor man’s” fuel and is used by approximately 92% of all households (rural – 94% and urban – 89%), but mainly for lighting (Theuri, 2005). Only about 5% of people use Kerosene for cooking because of high costs due to mark-up retail prices. The annual per capita consumption at the household level is estimated to be 800 liters or 902.8 kg (Wijayatunga and Attalage, 2002). The energy output from kerosene is 42.7 MJ/kg (Leach, 1988).

Liquefied Petroleum Gas (LPG): LPG is not widely used, with only 5% of households (mainly in urban areas) using it due to various constraints. Average per capita consumption of LPG is 111 kg (Wijayatunga and Attalage, 2002). LPG is used along with firewood in rural areas while in urban areas it is used as a supplement for electricity. LPG efficiency is 45 MJ/kg. LPG-based appliances are expensive and regulators are incompatible between different major dealers, making it difficult to interchangeably buy LPG from a variety of companies (Theuri, 2005). The composition of LPG drawn from the Earth is roughly 90% methane (sold as “Natural Gas” by utility companies), 5% propane and 5% butane, ethane and others. Our estimated cost, from field observations in Tanzania, of converting to LPG as the primary cooking fuel would require a significant initial cost of $110 for the stove and gas tank. The tanks of 12.5 kg of gas are $25, making the annual fuel cost, $222.

Electricity: Electricity is the most modern and convenient fuel and ranks highest on the energy efficiency ladder. However, electricity is expensive and only 1% of all households in sub-Saharan Africa use electricity for cooking. Electricity is limited due to its high cost and lack of infrastructure in many areas, so for this study it was not included in our LCA.
Methods

Life Cycle Assessment (LCA)

LCA is a standardized technique for measuring and comparing the environmental consequences of providing, using and disposing of a product or a service. Impact assessment is a technical, quantitative process to assess the effects of environmental burdens identified in the inventory analysis. Impact assessment consists of three steps; classification, characterization and valuation. LCA assessment was performed using SimaPro 7.1 with input estimates from World Energy Council, World Health Organization, and other peer reviewed literature. After defining the goal of the study an inventory of inflows and outflows from the life cycle system is constructed. The inventory input will eventually determine the life cycle impact of the product or system, thus giving details about the environmental consequences or benefits of using certain products.

Functional Unit

The functional unit is a means to put all products being analyzed in comparable units. For the purposes of this LCA the functional unit of kg of fuel per capita per year was chosen to compare the four fuel types (Table 2). Physical unit conversion allows for easy computation between kg of fuel used to energy output (MJ). The functional unit is also used in determining the emission contribution per kg of fuel burned.

System Boundaries

Prior to executing the LCA, clearly defined system boundaries must be identified. For this study we were interested in both the global and regional environmental effects as well as the immediate health impacts. In order to assess these impacts we needed to include the inputs from sequestering, refining, and combustion of the fuels. There is very little waste produced by burning all of these fuels so the waste disposal was ignored for this analysis. Additionally, the transportation costs, glass bottles for kerosene, bags for charcoal, and gas tanks for LPG were also ignored because of their insignificant contribution after averaging the impact of these inputs across the overall system. All available emissions data from combustion of each fuel was entered into SimaPro 7.1 and was estimated using the functional unit interpreted from published sources - Black Carbon, CO2, Methane, Particulates, NO2, SO2, CO (Jungbluth et al., 1997). Analysis was done using the IPCC GWP 100a and the Eco-Indicator 99 (I) methods to calculate impacts to the environment/global climate change and human health, respectively.

Indicators

Eco-Indicator 99 recognizes that the “environment” includes biological, physical, and chemical conditions influenced by man and is thus divided into three main categories; human health, ecosystem quality, and impacts to resources. The three indicators are aligned with the definition of sustainability; that our actions today should not inhibit or negatively affect future generations. The human health indicator is the most applicable to this study, expressed in DALY: Disability Adjusted Life Years. The
The impact of burning solid fuels can have global implications, therefore a scientific comparison must be done to measure the global warming potential (GWP) of each fuel. Since there are a number of different emissions from each fuel, their impacts must be converted to a unit which can be used to compare the overall impact. IPCC GWP 100a indicator is a 100 year method to convert green house gas (GHG) emissions into a comparable unit, kg CO₂ equivalence. The contribution percentage allotted to GWP for each phase in the life cycle is illustrated in (Table 3). For each fuel type the GWP contribution is dominated by the combustion of the fuel, while the fuels collection and production has a much lower significance or a positive contribution to GHG emissions.

Results and Discussion

The Eco-Indicator 99 Individualist (I) method was used to evaluate the immediate health effects of combustion of each fuel type with a focus on direct human exposure (i.e. CO is important for acute exposure). Figure 2 shows the non-weighted Eco-Indicator 99 results. In regards to human health charcoal is the most hazardous while LP gas has the lowest impact. For ecosystem quality charcoal is again the worst offender with wood having the lowest impact because of it is assumed that wood is a renewable resource and is harvested at a sustainable rate. In the resources category kerosene has the most impact while wood is again the lowest. Kerosene was high in this assessment category because of its negative resource influence from refining and harvesting the fuel, Kerosene is not a renewable resource. This is also why LPG did not score as low as wood in this category.

Figure 3 shows the weighted Eco-Indicator 99 results. It clearly shows how the Individualist method gives greater importance to the human health category. In fact, in relationship to human health the ecosystem quality and resources category effects could be considered negligible. The human health indicator is a product of emissions from each fuel type indoors. It ranks LPG as the best for human
There is an inherent difficulty in finding accurate and/or abundant data on the processes that were analyzed in this life cycle assessment. Therefore, some assumptions and estimations were necessary, which may have an effect on the outcome of the study. Some of the assumptions made and anticipated future research to improve these assumptions is discussed in this section.

The tropospheric aerosol burden has a direct effect on GWP through the backscattering and absorption of incoming solar radiation. Carbonaceous aerosols represent a significant portion of the tropospheric
burden and are strongly light absorbing. According to conservative estimates, one ton of black carbon causes about 600 times the warming of one ton of CO₂ over a period of 100 years. Therefore, black carbon is estimated to be the second largest contributor to radiative forcing, second only to CO₂. Globally, household combustion accounts for as much as half the world’s black carbon production as well as a significant amount of total carbon monoxide and volatile organic compound emissions (Smith, 2009). It is believed that continually reducing present day emissions of black carbon over the next fifty years to remove 25Gt C from the atmosphere would be equivalent to doubling the efficiency of two billion cars (Grieshop et al, 2009). Moreover, the estimated life time of carbonaceous particles is of the order of days to several weeks, so reducing black carbon should result in immediate global response. Studying the particulate and aerosol emissions form biomass burning will provide detailed scientific information about the extent of local health hazards and global implications. The results will potentially motivate government and development organizations to implement sustainable solutions that reduce emissions and improve cooking practices. Implementing improved combustion technologies that increase efficiency and reduce particle emissions by several orders of magnitude will improve global climate change, poverty, gender equality, and public health. Therefore, the understanding, improvement, and implementation of sustainable technology addressed at lowering black carbon emissions produced by solid fuel burning are vital for global sustainability. However, the effects of solid fuel burning and black carbon on the Global Warming Potential (GWP) are not yet fully understood and the most recent findings are not included in SimaPro 7.1’s estimation of black carbon impact on GWP. Additionally, the effects of solid fuel use usually does not take into account the health problems associated with burns and kerosene ingestion or the time spent searching for and gathering fuel. Therefore, further research is needed to define the extent and impact of these factors on human health and climate forcing.

All biomass products were assumed to produce the same output of energy (16 MJ/kg) and emissions. In actuality there is a great deal of variation in both. Wood combusts at different rates depending on moisture content; when wood is allowed to cure (decreasing moisture content) it burns much more efficiently. In addition, different wood species have different combustion efficiencies. In sub-Saharan Africa it is common for people to burn crop residue, fallen branches, or whatever else is combustible and easily transportable by hand. The only way to accurately predict combustion efficiency and accurate emissions would be to conduct a large scale field study.

The emissions data for this LCA was estimated based on several different publications. This procedure is not ideal and likely led to some variability in the results. Data for all the fuel types was only available for certain emitted compounds; therefore, not all emitted compounds could be included in the LCA. However, the major contributors to GWP and human health were included. Controlled emissions testing would greatly increase the accuracy of the data.

The functional units were estimated based on the combustion efficiency of the fuel type (MJ/kg). This procedure is not ideal, but currently there is a lack of accurate understanding regarding the actual daily fuel usage of a typical family in Sub-Saharan African. For example, it is difficult to estimate how much LPG fuel a family would use since none of them currently use it. There are many factors that would affect fuel usage practices that are not taken into consideration when calculating the fuel usage based
on combustion efficiency. Families may be more conservative with fuel if there is a cost associated with the fuel. This method also does not take into account how the fuel can be controlled. For example, with wood or charcoal it is nearly impossible to use the exact amount of fuel one needs for a desired task. Think about a grill where there is always a fire still going after a BBQ when wood or charcoal is used, but a LP gas or kerosene grill can be extinguished immediately after cooking is completed. This post burn for wood and charcoal is referred to as a smoldering fire which emits large amounts of products of incomplete combustion because of the lower burning temperature. These variables are difficult to quantify using a comparison calculation. So, to improve the accuracy of the functional unit a large scale survey of rural families’ cooking practices is needed.

SimaPro 7.1 quantifies health impacts in DALY’s using Ecoindicator 99, based on information up to 1999. There has been a great deal of research since 1999 about the effects of particulates and black carbon on respiratory health, specifically in terms of indoor exposure, that is not properly quantified into the DALY’s calculation method used in Ecoindicator 99. Therefore, Ecoindicator 99 may be underestimating DALY’s. Similar issues exist with the GWP indicators. There has been a great deal of recent research related to black carbon’s impact on radiative forcing. Black carbon is now known to have a very high impact on global warming, second only to that of CO₂. In addition, it is thought to be accelerating the melting of glaciers because after its deposition it can greatly increase the surface temperature leading to melting and heat absorption. Aerosols can also influence climate in major ways through their role of cloud condensation and as ice nuclei (IPCC, 2007). Increase in aerosols causes an increase in the droplet number concentration. This has two distinct impacts. The first way is through an increase in droplet concentration resulting in an increase in cloud reflection properties, leading to climate cooling. Second, the higher concentration decreases the droplet radius thus lowering the precipitation efficiency. This results in longer cloud lifetime and height, having a longer impact on surface cooling. However, BC in clouds absorb heat, which on one hand blocks solar radiation from reaching the surface (masked cooling) but traps heat in the clouds causing cloud burn-off.

**Future Research**

The work presented in this paper can be used as a framework for future analysis. More research is needed in quantifying health, social and ecological impacts, more accurately measured fuel consumption, and finally the extent and impact of black carbon and particulates on GWP.

The examination of the effects of solid cooking fuels at the household level on emissions and public health are often overlooked according to the World Health Organization. Indoor air pollution is a major environmental and public health hazard for many of the world’s poorest, most vulnerable people. However, current evidence is based on a limited number of studies, few of which have measured smoke exposure directly (WHO, 2002). Further research is needed to quantify the health impacts of indoor air pollution from cooking.

Solid fuels, predominantly wood, are the primary materials used for cooking in Tanzanian communities, and when coupled with current housing design lead to dangerous levels of indoor air pollution. Houses are not properly ventilated nor do they include energy efficient stoves. This results in a high degree of
both respiratory ailments and de-forestation. This future project will focus on understanding and defining the negative effects of indoor air pollution through the following activities:

- Laboratory emissions testing of particulate matter and carbon monoxide for indigenous and improved cooking methods and scenarios
- Laboratory efficiency measurements between indigenous and improved cook stoves
- In-situ data logging measurements in rural village households to detect particulate matter and other gas emissions
- Interview surveys will be performed inquiring about stove type, fuel usage, cooking time, fuel cost or time collecting, as well as household health conditions
- Satellite and ground based PM observations of fossil fuel and biomass combustion in sub-Saharan Africa
- Black carbon C14 dating and concentration measurements on Kilimanjaro snow pack
- Finally, building on our findings, reanalyze the life cycle effects of different types of cooking fuels and devices

In-situ indoor air pollution measurements are vital for the understanding of global impacts from burning solid fuels. Globally household combustion accounts for as much as half the world’s black carbon production as well as a significant amount of total carbon monoxide and volatile organic chemical emissions (Smith et al., 2009). Research will be done using an optical ionization measurement technique for characterization of micrometer and submicrometer aerosols in household environments (Litton et al., 2004). To gain a better understanding of the real world productions of aerosols and black carbon from household solid fuel burning, particulate measurements will be performed at numerous households using improved and local stove designs with various fuel types at different periods of the year. Additionally, in a laboratory setting a small smoke box equipped with ventilation hood, and a constant output atomizer will be used to compare aerosol output from local fuels. The data obtained will provide insight into quantifying indoor and outdoor air pollutants, and their effects on global climate change and respiratory diseases. Furthermore, information will be obtained in order to determine the most sustainable fuel type in combination with stove design for future research and design.

Climate models indicate the significant impact aerosols have on the earth radiation budget through the scattering and absorption of incoming light. However, scientists have a limited understanding of the regional impacts and extent of aerosol transport, which creates uncertainties in climate system models. The CALIPSO satellite uses an active LIDAR sensor to provide vertical profiles of aerosols and their properties (Yu et al., 2006). By combing the simultaneous acquisition of aerosol data using real-time indoor optical ionization and photo-acoustic measurements with CALIPSO observations, a greater understanding of variations in aerosol contribution to global climate change will be achieved. Moreover, MISR utilizes nine cameras to observe reflected and scattered sunlight in four wavelength bands, designed to measure aerosol particle size and shape, both over land and ocean (Yu et al, 2006). However, no single sensor can solely characterize a complex aerosol system which is why we plan to utilize the benefits of multiple systems. Ground based measurement, CALIPSO, and MISR will assist in defining the aerosol profile, the particle size and texture, direct effect of aerosol optical depth (AOD), and single scattering albedo (SSA). This field campaign will provide an improved characterization of global aerosols, clouds, and particulates from combustion and biomass burning, hence quantification of
radiative forcing and regional health risks. Additionally, the data will serve as a regional baseline to measure the effects of sustainable changes such as increased fuel efficiency, social practices, and improved stove technologies.

The knowledge about cooking stove efficiency and acceptance obtained by this research will serve to more accurately define the hazards from cooking fuel combustion, thus better informing policy makers and health workers on the effects and extent of indoor air pollution in rural Tanzanian villages. The project will take a holistic approach by measuring cooking fuel emissions in the laboratory and real world conditions along with studying the social impacts of traditional and improved cooking methods. This information will be used by academics and governments in the re-designing and implementation of appropriate stoves, houses, and ventilation systems. Additionally, the project will provide a better understanding of what improved cooking methods are most likely to be accepted and implemented by local villagers and in turn, on a broader scale, provide some insight into what introduced solutions in the developing world are accepted and why. The results obtained from this research would contribute to the technical and behavioral influences on environmental risks associated with burning solid fuels.

**Conclusion**

The purpose of the study was to provide a comparison of the environmental footprints for four different fuels: charcoal, kerosene, LPG, and wood. The study quantified the environmental effects resulting from the collection, production, and use of each product system. The study provided an indication as to which system places less burden on the environment by assessing the GHG emissions using the IPCC 2007 100a and the human health impacts using EcoIndicator 99 through the LCA software SimaPro 7.1.

The results are as follows:

- Negative health impacts are the greatest from charcoal briquettes and kerosene
- Best fuel related to health improvement is LPG. However, with the implication of efficient improved cook stoves wood is shown to be even more beneficial
- Serious benefit could be gained through the dissemination of improved cooking stoves
- Assumptions and lack of data may have affected output, showing need for future research

It is important to note that the fuel with the highest cost benefit relationship is wood. This is due to wood currently being a free commodity to most Tanzanians’ while not being the highest contributor to DALY’s lost. LPG has the least impact; however, it is so expensive that it prohibits wide spread adoption by most Tanzanians. In fact for a Tanzanian family to cook with charcoal, kerosene, or LPG the cost is greater than 10% of the average annual income (Table 4). When wood is a free commodity and health is difficult to link to indoor air pollution it can be difficult to get people to accept the change. The cost prohibitive nature of fuel types other than wood may make any project that promotes those fuel types unsustainable. In many rural regions fuels other than wood are not readily available. The data used for the cost analysis in table 4 uses average annual Tanzanian income. The income of people in rural
communities is likely to be significantly lower than that number (442 dollars per year according to U.S. state department).
References


Smith, K., Balakrishnan, K. Mitigating climate, meeting MDG’s, and moderating chronic disease: the health co-benefits landscape. Commonwealth Health Minister’s Update 2009, p59-65.


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<th>Millennium Development Goals</th>
<th>Contribution of improved household energy practices</th>
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</thead>
</table>
| Goal 1: Eradicate extreme poverty and hunger | • Saving time spent being ill or having to care for sick children will cut health care expenses and increase earning capacities.  
• Where fuels are purchased, increasing fuel efficiency and thus cutting down on the quantity of fuel needed will ease constraints on already tight household budgets.  
• Improved household energy technologies and practices will open up opportunities for income generation.  
• Access to electricity will provide a source of light for economic activities in the evening and a source of energy for operating, for example, a sewing-machine or refrigerator. |
| Goal 2: Achieve universal primary education | • With less time lost in collecting fuel and due to ill health, children will have more time available for school attendance and homework.  
• Better lighting will allow children to study outside of daylight hours and without putting their eyesight at risk. |
| Goal 3: Promote gender equality and empower women | • Allowing the drudgery of fuel collection and reducing cooking time will free women's time for productive endeavors, education and child care.  
• Reducing the time and distance that women and girls need to travel to collect fuel will reduce the risk of assault and injury, particularly in conflict situations.  
• Involving women in household energy decisions will promote gender equality and raise women's prestige. |
| Goal 4: Reduce child mortality | • Reducing indoor air pollution will prevent child morbidity and mortality from pneumonia.  
• Protecting the developing embryo from indoor air pollution can help avert stillbirth, perinatal mortality and low birth weight.  
• Getting rid of open fires and kerosene wick lamps in the home can prevent infants and toddlers being burned and scalded. |
| Goal 5: Improve maternal health | • Curbing indoor air pollution will alleviate chronic respiratory problems among women.  
• A less polluted home can improve the health of new mothers who spend time close to the fire after having given birth.  
• A more accessible source of fuel can reduce women's labor burdens and associated health risks, such as prolapse due to carrying heavy loads. |
| Goal 6: Combat HIV/AIDS, malaria and other diseases | • Lowering levels of indoor air pollution levels can help prevent 1.6 million deaths from tuberculosis annually. |
| Goal 7: Ensure environmental sustainability | • Where biomass is scarce, easing the reliance on wood for fuel through more efficient cooking practices will lessen pressures on forests.  
• Moving up the energy ladder and using improved stoves can increase energy efficiency and decrease greenhouse gas emissions. |
| Goal 8: Develop a global partnership for development | • Recognition in development agendas and by partnerships of the fundamental role that household energy plays in economic and social development will help achieve the Millennium Development Goals by 2015. |

**Table 1:** United Nations Millennium Development Goals (MDG) related to household energy practices (WHO 2006).
### Table 2: Functional unit equivalence for each fuel type in kg/person/year.

<table>
<thead>
<tr>
<th>Fuel Type</th>
<th>Energy Output</th>
<th>Functional Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charcoal</td>
<td>30 MJ/Kg</td>
<td>1000 kg/person/yr</td>
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<tr>
<td>Kerosene</td>
<td>42.7 MJ/Kg</td>
<td>902.8 kg/person/yr</td>
</tr>
<tr>
<td>LPG</td>
<td>45 MJ/Kg</td>
<td>111 kg/person/yr</td>
</tr>
<tr>
<td>Wood</td>
<td>16 MJ/Kg</td>
<td>1204.5 kg/person/yr</td>
</tr>
</tbody>
</table>

### Table 3: Contribution to Global Warming Potential (GWP) from each life cycle phase. *Production should loosely equal the inverse of combustion, however due to incomplete combustion there is a slightly positive carbon sink.*

<table>
<thead>
<tr>
<th>Fuel Type</th>
<th>Production Contribution %</th>
<th>Combustion Contribution %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charcoal</td>
<td>4.7</td>
<td>95.3</td>
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<tr>
<td>Kerosene</td>
<td>16.5</td>
<td>83.5</td>
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<td>LPG</td>
<td>8.6</td>
<td>91.4</td>
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<tr>
<td>Wood</td>
<td>Positive contribution*</td>
<td>100</td>
</tr>
<tr>
<td>Wood-Improved</td>
<td>Positive contribution*</td>
<td>100</td>
</tr>
<tr>
<td>Fuel Type</td>
<td>Cost (TZS/MJ)</td>
<td>Cost (person/yr)</td>
</tr>
<tr>
<td>-----------</td>
<td>--------------</td>
<td>------------------</td>
</tr>
<tr>
<td>Charcoal</td>
<td>1.75</td>
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<tr>
<td>Kerosene</td>
<td>6</td>
<td>231,297</td>
</tr>
<tr>
<td>LPG</td>
<td>11</td>
<td>54,945</td>
</tr>
<tr>
<td>Wood</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 4: Average cost of fuel usages in Dar Es Salam scaled up using fuel usage estimates from the functional unit and averaged using the % annual income of Tanzania.

**Figures**

Figure 1: Distribution of fuel usage in Northern urban and rural Tanzania. Household surveys 2009
Figure 2: EcolIndicator 99 (I) damage assessment, not weighted.
Figure 3: EcolIndicator 99 (l) weighted assessment, notice much heavier weighting related to human health impacts. Charcoal is the largest contributor to human health followed by Kerosene, wood, and LPG.

![Graph showing EcolIndicator 99 weighted assessment]

Figure 4: IPCC GWP 100a assessment of kg CO₂ equivalence for each fuel type. Notice that overall biomass sequesters CO₂, resulting in a slightly positive carbon sink.

![Graph showing IPCC GWP 100a assessment]

Figure 5: EcolIndicator 99 Single score assessment. Notice the overall impact from wood/biomass burning is even less than natural gas with the implementation of improved stoves.
Figure 6: Single score impact using Ecoindicator 99 illustrating the reduction in impact from improved cooking stoves vs. traditional 3-stone method.
Figure 7: Radiative Forcing (W m$^{-2}$) and its effects on Global Warming Potential (GWP). Note that the third most important factor contributing to radiative forcing is black carbon, which are dark soot particles deriving exclusively from incomplete combustion of fossil fuels and biomass, from (Smith, 2009).