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OPPORTUNITIES FOR UTILIZING WASTE BIOMASS FOR ENERGY IN UGANDA

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Opportunities for Utilizing Waste Biomass for Energy in Uganda

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Ekstrakt

This thesis assesses agricultural residues from the main cash and food crops in Uganda, as well as municipal solid waste (MSW) in Kampala. The available biomass waste resources are mapped by material flow analysis, the energy content is examined and possible ways of utilization is discussed. The crops selected for studies are banana, cassava, potatoes, maize, rice, groundnuts, coffee and sugar cane.

The current waste collection rate in Kampala is 39 %, anf the non-collected waste is representing problems like open burning of waste. The emissions of particles, NO and CO from open burning of MSW in Kampala are assessed applying risk analysis. The results show that the resulting concentration of PM_{10} is 40 $\mu g/m^3$, which is leading to a life time cancer risk at 0.56 % for the population of Kampala. The emissions of CO and NO are not found to be representing any danger.

The most promising residues for utilization when the practical barriers are considered are electricity production from bagasse and MSW and charcoal production from bagasse. Bagasse is available at three specific sites, so it is no need for transport, and the technical experience and knowledge is already present at the sugar factories. There are more barriers to utilizing MSW as energy. The most important is to improve the collection rate of MSW from the current at 39 %. This can be done by changing the system from being based on punishment to be based on reward. Electricity production from combustion of MSW is the option which is recommended, with a practical potential at 98 GWh in 2004, a theoretical potential at 250 GWh (100 % collection rate). The potential of electricity from bagasse is 150 GWh.

	Stikkord på norsk	Indexing Terms English
Gruppe 1	Biomasseavfall	Biomass residues
Gruppe 2	Uganda	Uganda
Egenvalgte stikkord	Avfall (MSW)	Municipal Solid Waste (MSW)
	Materialstrømsanalyse	Material Flow Analysis

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MASTEROPPGAVE

for

Stud.techn. Lars Petter Bingh

Våren 2004

Muligheter for energiutnyttelse av biomasse avfall i Uganda

Opportunities for Utilising Waste Biomass for Energy in Uganda

Background

Uganda has an area of 236 040 km^2 and a population of 24 million people, the latter growing at about 2-3% per year. According to the official energy statistics, biomass contributes to over 90% of the total end-use energy, while electricity contributes to just over 1%. More than 70% of the energy use is firewood used in the residential/commercial sector, most of it for cooking. Central and Southern Uganda are rich in biomass and remarkable for its biodiversity; the North is arid and semi-arid. The forest cover has been shrinking fast, and soon only national parks and protected areas will contain forest. The main reason for deforestation is the expansion of agriculture, both fields and pastures. With a shrinking amount of biomass available, a biomass energy strategy needs to focus on the utilization of waste biomass, an increase in the efficiency and effectiveness of the energy conversion, and potentially growing and utilizing dedicated energy crops.

The Department of Energy and Process Engineering has developed cooperation with the Engineering Faculty of Makarere University in Kampala. This cooperation concerns energy and environment in general, but it focuses on energy policy, biomass and waste. As part of this cooperation, five students from the energy and environment program conduct research in Uganda in 2003.

Aim

The aim of this thesis is to provide an improved understanding of the potential for the utilization of waste biomass for commercial energy production and to describe its costs and benefits and obstacles. The work should focus on biomass waste from industry and larger municipalities.

The analysis should include following elements:

1. A characterization of the available biomass waste.
2. Description of the technologies used for commercial biomass utilization in Uganda today.
3. Description of the technologies that may be used in the future, based on the technologies that are currently used in other places. This may include gasification of bagasse, utilization of risk husks, and waste incineration.

4. Analysis of the advantages and disadvantages of using biogenic waste for energy production.
5. Recommendations, and discussion, on which biomass technologies that are best suited for Uganda, taking into account their specific situation and needs.

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Summary

The energy system in Uganda is largely based on biomass and especially wood. The high demand for wood results in fast reductions of the available wood stocks. This thesis is focusing on biomass waste as a supplement to the existing energy carriers.

This thesis includes agricultural residues from the main cash and food crops in Uganda, as well as municipal solid waste (MSW) in Kampala. The available biomass waste resources are mapped, the energy content is examined and possible ways of utilization is discussed by using material flow analysis, MFA. The MFA flow schemes are provided for all the crops selected for studies, which are banana, cassava, potatoes, maize, rice, groundnuts, coffee and sugar cane.

The current waste collection rate in Kampala is 39 %, which means that there are large amounts of waste ending at other places than the existing landfill. The non-collected waste represents problems like bad odour, epidemics, flies, aesthetical degradation and pollution from open burning. The emissions of particles, NO and CO from open burning of MSW in Kampala are assessed by applying risk analysis. The results show that the resulting concentration of PM_{10} is 40 $\mu g/m^3$, which is leading to a life time cancer risk at 0.56 % for the population of Kampala. The emissions of CO and NO do not represent any danger. Exposure to indoor smoke from combustion of solid fuels for cooking also represents a health risk, and there is a potential of lowering these risks by changing the energy system.

The results shows that the theoretically available crop residues represent an energy content of 4.5 TWh and constitute to 4.6 % of the firewood and charcoal currently consumed. The practical available amount (2.6 TWh) represents 2.7 % of the total consumption of charcoal and firewood in 2001 (the data includes rice husks, coffee husks, g-nut husks, bagasse and maize cobs). If the potential from MSW is included as well, the theoretical potential increases to 6.8 TWh.

An evaluation of the performance of the different fuels applied to cover the need of energy for cooking shows that electricity production from groundnut husks has the highest output of energy per unit input of mass. However, charcoal production from bagasse can serve the highest number of households, because of the larger volumes available of this resource. But, there are also practical, economical and technical barriers to overcome to utilize the biomass resources. The most promising residues for utilization when these barriers are considered are electricity production from bagasse and MSW and charcoal production from bagasse. Bagasse is available at three specific sites, so no transport is needed, and the technical experience and knowledge is already present at the sugar factories. There are more barriers to utilizing MSW as energy. The most important is to improve the collection rate of MSW from the current at 39 %. This can be done by changing the system from being based on punishment to be based on reward. Electricity production from combustion of MSW is the option which is recommended, with a practical potential at 98 GWh in 2004, and theoretical potential at 250 GWh (by 100 % collection rate).

Sammendrag

Energisystemet i Uganda er hovedsakelig basert på biomasse, og da særlig tre. Den høye etterspørselen etter tre som brensel har ført til en rask nedgang i skogsreservene. Denne studien fokuserer på biomasseavfall som et alternativ til de eksisterende energibærerne.

Denne studien omfatter landbruksavfall fra de viktigste landbruksproduktene så vel som kommunalt avfall i hovedstaden Kampala. Målet med studien er å kartlegge de tilgjengelige biomasseressursene, å beregne energiinnholdet i dem og foreslå alternativer for energiutnyttelse. Kartleggingen av ressurstilgangen er gjort ved å bruke material-strømsanalyse (MFA). Det er utarbeidet flyskjemaer for masseflyten til de utvalgte avlingsgruppene banan, cassava, potet, mais, ris, peanøtter, kaffe og sukkerrør.

Innsamlingsgraden av kommunalt avfall i Kampala i dag er på 39 %, hvorpå store mengder avfall aldri havner på deponi. Dette avfallet representerer en rekke problemer som dårlig lukt, fare for epidemier, fluer, estetisk forringelse og forurensning fra utendørs forbrenning av avfall. Utslippene av partikler, NO og CO som følge av forbrenningen er analysert ved å bruke risiko analyse. Resultatene viser at konsentrasjonen av PM_{10} som følge av forbrenningen blir 40 µg/m^3, noe som medfører en kreftrisiko over menneskets levetid på 0,56 % for befolkningen i Kampala. Uslippene av NO og CO ble ikke funnet å representere noen risiko. Disse negative påvirkningene, så vel som eksponering for røyk fra matlaging basert på faste brensel representerer en negativ side ved dagens energisystem som andre løsninger studert her kanskje kan bøte på.

Resultatene viser at det teoretisk tilgjengelige biomasseavfallet representerer en energimengde på 4,5 TWh og utgjør 4,6 % av dagens forbruk av trekull og trebrensel, mens den praktisk tilgjengelige mengden er på 2,6 TWh eller 2,7 % av trekull og trebrenselforbruket i 2001. Hvis potensialet fra MSW også inkluderes, beløper det teoretiske potensialet seg til 7 %.

Analysen av prestasjonen til de ulike energibærerne om de benyttes som energi til matlaging viser at elektrisitetsproduksjon fra peanøttskall har det største energiutbyttet per enhet masseinput. Likevel er det trekullproduksjon fra bagasse som kan dekke energibehovet til det største antall husholdninger fordi volumet av bagasse tilgjengelig er mye større. Men, det er også praktiske, økonomiske og tekniske barrierer som avgjør om det er realistisk å utnytte ressursene. Slike hinder gjør at det er elektrisitetsproduksjon eller trekullproduksjon fra bagasse samt elektrisitetsproduksjon fra MSW som representerer det mest realistiske potensialet. Bagasse er tilgjengelig på tre steder, så det er ikke behov for transport av brensel til en eventuell utnyttelse. Sukkerfabrikkene har også kompetanse på hvordan man skal utnytte energien i bagasse til elektrisitetsproduksjon allerede. Det er en lengre vei å gå for å utnytte MSW som brensel. Et viktig steg er å øke innsamlingsgraden fra dagens 39 %, noe som også vil bedre på situasjonen med hensyn på negative påvirkningen som følge av bl.a. utendørs avfallsforbrenning. Dette kan gjøre ved å gå fra å bruke pisk til gulrot i innsamlingssystemet. Elektrisitetsproduksjonen kan teoretisk sett gi 250 GWh ved 100 % innsamlingsgrad, og 98 GWh ved dagens innsamlingsgrad (2004-tall).

Preface

This thesis is written at the Norwegian University of Science and Technology (NTNU), Department of Energy and Process Engineering. The project is a part of a collaboration programme between the universities of NTNU and Makerere University in Kampala, Uganda. This is the second year of the project, which was started in 2003.

I would like to thank Edgar Hertwich and Øyvind Skreiberg for useful guidance as my advisors during the work with this thesis. I am also grateful for the guidance from Izael da Silva and Francis Nturanabo during the field work in Uganda, as well as Mackay Okure for being the responsible for the contact between the two universities. I would also like to thank Britt-Mari Langåsen for helpful support and company especially in the period of the field work in Uganda.

Trondheim, 29.06.2004

Lars Petter Bingh

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Acronyms

ARI	Acute Respiratory Illness
BOD	Biological Oxygen Demand
DDT	dichlorodiphenyltrichloroethane
EHV	Effective Heating Value
G-nut	Groundnut
GWP	Global Warming Potential
HHV	Higher Heating Value
IPP	Independent Power Producers
KCC	Kampala City Council
LPG	Liquefied Petroleum Gas
MFA	Material Flow Analysis
MSW	Municipal Solid Waste
KCC	Kampala City Council
RPR	Residue to Product Ratio
UEDCL	Uganda Electricity Distribution Company Limited
Ush	Uganda Shillings
VOC	Volatile Organic Compounds

1 Background

The population of Uganda was 25.4 million people in 2003, and 12 % of this is urban population. The growth rate has been at 3.4 % on average in the period between 1991 and 2002. The GDP was 9 792 429 million Ush in 2002, which is 5 132 million US Dollars according to the exchange rate of 17.05.2004 (Exchange rate, 2004). The GDP growth rate was 5.3 % the same year (Uganda Bureau of Statistics, 2003).

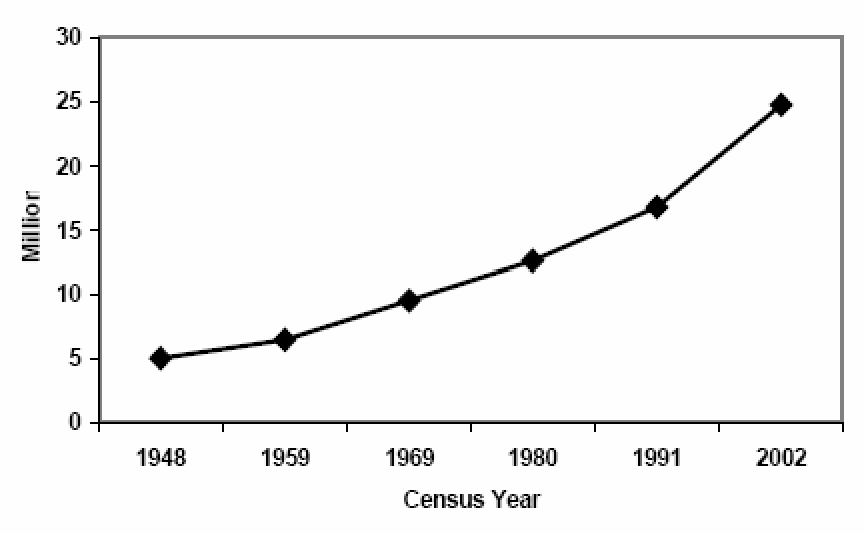


Figure 1: The population trend in Uganda (Uganda Bureau of Statistics, 2003).

1.1 The energy situation of Uganda

The energy system in Uganda is largely based on biomass, and 93 % of the total energy consumption origins from biomass. The biomass consumption in 1995 was consisting of 80.5% from wood, 14.5 % charcoal and 4 % crop residues. The per capita energy consumption of woody biomass was 4 kg in 2001 (Pedersen et al., 2003).

Energy for use in households contributes to an important share of the biomass products consumed in Uganda. In urban households, 78 % of the energy comes from biomass, while the share of biomass in rural households is 99 % (Pedersen et al., 2003).

Quite a big share of the Ugandan energy system is not monetary, a fact that contributes to elevate the uncertainties affected by the actual levels of energy consumption. Out of the production of wood 31 % of the total production is monetary (Uganda Bureau of Statistics, 2003). The non-monetary share of the energy system is often based on collection of firewood for cooking in households, a work which mainly is carried out by women (Reddy et al., 1997). This fact implies that the energy system also is highly decentralized and unorganized, in other word that very many people are somehow working in the energy sector, many of whom don’t receive any salery for this work apart from covering basics needs for living. This means that the character of most of the energy system in Uganda is consisting of small fuel cycles by geographical standards, meaning that the distance from source to utilization is very short. This is in contrast to the world market energy carriers, which only constitutes to a smaller share of the Ugandan energy market, like oil products. They are transported over great distances and stored for long time periods (Reddy et al., 1997).

The imports of petroleum products to Uganda were at 175 million US$ in 2002 (Comtrade, 2002), which is 16.3 % of the total imports to the country that year. The import of oil is an important aspect affecting the economy of the state of Uganda (refer chapter 1.2.2). The oil is imported through two ports: Mombasa in Kenya where 70 % of the supply is delivered, and Dar es Salaam in Tanzania which accounts for 30 % of the import (Pedersen et al., 2003).

There are not generated enough electricity in Uganda to fill the demand in the country at the time being. The total amount of electricity generated in 2002 was 1.7 TWh. At the same time the exports of electricity in 2002 was at the value of 15.6 million US$. The reason is that the shortage of electricity is due to the fact that the installed effect in the system is too low to fill the demand in the high load period between 6 pm and 11 pm. Ergo, the limitations of the system is the lack of installed effect rather than the total amount of electricity produced. The result is that the electricity distribution company UEDCL has to cut off several parts of the capital, Kampala, in the high load period between 6 pm and 11 pm (New Vision, 2004). The electrification level in Uganda is approximately at only 5 % (Karekezi, 2002), which means that there is a great need for further grid extensions. However, the shortage situation means that further extension of the electrical grid has to be followed by extensions of the generating capacity.

Uganda experiences a shortage of wood for energy. The unsustainable character of the exploitation of the forest resources has led to a decline in the forest resources. Studies by the Forest Department (2002) conclude that the available stock of wood will be depleted by the year of 2025. Henriksen (2003) claims that the forest resources will be lost even earlier; by presenting five different scenarios of utilization in which the conclusion involves that the stock will be lost in the period between 2011 to 2014. The most optimistic scenario shows that the standing stock of wood will be lost in 2014. This scenario involves 2.6 % increase of the firewood and charcoal consumption a year, and no use of improved stoves or efficiency improvements in the charcoal production. The most pessimistic scenario leads to finishing the stock available in 2011, by assuming an increase in the firewood consumption at 4.02 %. In this number wood for other use also is included, and the efficiencies of the stoves and charcoal kilns are still the same. By introducing improved cooking stoves at the rate of 5 % a year from 2003 and a higher growth rate of charcoal consumption, the standing stock of wood will be lasting one more year to 2012.

1.2 The energy situation’s influence on other societal aspects

There are several reasons for improving the energy situation of Uganda. A more efficient use of energy will improve the environmental situation, and will also be economically advantageous in many cases. Besides, the energy situation also influence on issues like development and poverty. This section will provide some general, theoretical aspects on the link between the energy situation and these issues.

1.2.1 Development

Development can be elimination of poverty, as well as improved access to education, reduce infant and maternal mortality rates and population growth (Wilkins, 2002). Poverty refers to an individual's, or family's, inability to achieve minimal standards in fulfilling basic human needs such as food, clothing, shelter, health, education, and sanitation services (Reddy et al., 1997). However, poverty is often defined based on a single parameter such as monetary income. In an energy context, poverty can be defined as “the absence of sufficient choice in assessing adequate, affordable, reliable, high-quality, safe and environmentally benign energy services to support human and economic development” (WEA, 2000, p. 44). To fight poverty, basic needs such as defeating hunger needs to be first priority. Next, energy is an important aspect according to poverty. There is a connection between the energy carrier used in a household and the income of the household. Low-income households tend to use traditional fuels like biomass and often low quality biomass fuels which are freely available, while households of higher income have a higher share of commercially available fuels as LPG and electricity (Reddy et al., 1997). The quality of the biomass fuels used by the poorest, and the way it is used, can be connected to a set of negative impacts that counteract development. One problem is that biomass for cooking is a main source for indoor air pollution, a problem which causes health effects and contributes to reduced quality of life. These negative impacts of the energy source may make the population less suited to benefit from economic growth (Reddy et al., 1997). The opportunities for education will also be reduced if there is no electricity available, because electricity is necessary to access knowledge via radio and television, lighting in schools and to prevent an unsatisfactory indoor climate in the schools. Electrification also contributes to better healthcare services through lighting, sterilization and vaccine refrigeration. These facilities also help attracting better qualified staff, both in health services and education (Wilkins, 2002).

1.2.2 National Economy

The foreign exchange required for fossil fuel imports, usually oil, has been a heavy burden on the balance of trade of many countries. Many countries are highly dependent on oil, which makes them highly sensitive to fluctuations in the oil prices. A rise in the oil price leads to an increase, often a high one, in the total costs of imports. If the export earnings are not increasing in the same way, the trade balance will be disturbed. The consequence of such a situation is either to fill the gap by borrowing, or by running down foreign exchange reserves. More than 30 countries have energy imports exceeding 10 % of the value of all imports, a fact that leads to debt problems in many of these countries (Reddy et al., 1997), and Uganda is one of these countries (refer chapter 1.1). Zimbabwe is an example of a country where this negative trade balances from electricity imports led to severe consequences for the national economy. The county was relaying on electricity imports from neighboring countries representing around 40 % of the total amount of electricity consumed. The consequence was the need to allocate hard currency to the energy sector, to finance the energy import. That resulted in currency shortage of other sectors which also needed import inputs. Hence, the development of these sectors was restrained (Mbohwa and Fukuda, 2002).

1.2.3 Environment

The use of energy, or more correct transformation of energy into other forms of energy, can cause impacts on the environment and on human health if the utilization is not in proper control. The impacts caused by energy consumption depend on the energy carrier used, the technology used and the area of release. Pollution emitted in sparsely populated areas will cause less damage to human health than the same amount emitted in a densely populated area. The emissions may also have impacts on ecosystems, and the damage levels depend on the emitted concentration as well as the ability of the environment to absorb and handle the pollutants.

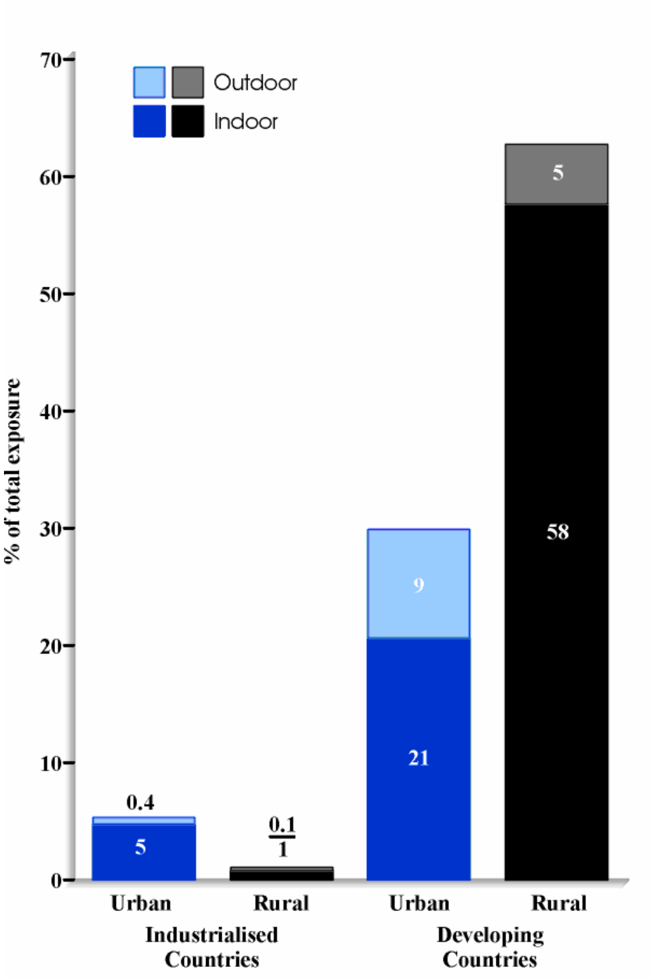


Figure 2: The difference in human exposure to particulate emissions in developing and developed countries

An environmental problem which is special for developing countries is the pollution of the indoor climate in households due to the use of low quality biomass energy combined with simple technological solutions (refer chapter 1.3.2). Figure 2 shows the distribution of exposure to particulate emissions in industrialized and developing countries. The big differences among these groups are mainly according to exposure in the households in the developing countries. The cooking in developing countries is done either directly on the ground in a hole, or in quite simple metal or clay stoves by applying low quality solid fuels. In many cases there is no chimney to remove the pollutants. The simple equipment is also contributing to a relatively high share of incomplete combustion products which may imply health effects (Reddy et al., 1997). Households in developing countries mostly apply high quality energy carriers as electricity or gas, and the differences in exposure because of this can be seen in Figure 2.

1.3 Energy quality

1.3.1 The concept of Energy Quality

The concept of energy quality is a consequence of the thermodynamical laws.

- The first law of thermodynamics: Energy cannot disappear; it is only transformed into other energy forms.
- The second law of thermodynamics: Heat cannot be directly transformed to mechanical work. Transition is possible only if some of the heat is given to a lower level of temperature.

Mechanical energy can be totally utilized by performing mechanical work, so is also electricity. Hence, they are valued as highest energy quality. Energy quality can be defined as:

$$\text{Energy quality} = \frac{\text{maximal share of mechanical work}}{\text{quantity of energy}}$$

Out of this expression follows that the highest energy quality is 1 or 100%. Energy quality is, however, a theoretical quantity, and the maximal share of mechanical work will only be available through reversible processes (Bredesen, 1999).

1.3.2 Quality of bioenergy and conversion technologies used in Uganda

The term energy quality is a theoretical term, and the technology used in the energy transfer processes is determining to what extent the quality stored in the energy carrier is utilized fully. According to Larsen et al. (2003), the use of bioenergy can be divided into five fundamental forms, and these are:

- “Traditional domestic” use in developing countries. This category includes traditional methods and fuels like firewood, charcoal or agricultural residues for cooking, lighting and space heating. The energy conversion efficiency is generally between 5 and 15 %.

- "Traditional Industrial" methods for processing of tobacco, tea, bricks and tiles etc. The biomass supply is often regarded as free, like fire wood from forests. There is a lack of incentive to make more efficient use of the energy source. The efficiency of the energy conversion is then often 15 % or less.
- "Modern industrial", where industries are applying more technologically advanced equipment for energy conversion. The conversion efficiency in this group range from 30 % to 55 %.
- Newer "chemical conversion" technologies like fuel cells
- "Biological conversion" techniques, like anaerobic digestion for biogas production.

The energy system of Uganda can in general be situated in the two first groups, and the challenge is to move the system to the three other categories, where the efficiencies are higher. When the efficiencies are improved, the negative impacts from the energy consumption will also be minimized.

The technology used for cooking varies among the different households. The four most common technologies are presented in Figure 3. The three stone stove is the simplest of the cooking stoves. It is made up of three equally sized stones, and the fire is situated among these stones. The traditional metal sigiri is fired by charcoal. It is made by metal scrap, and is quite easy to make. The improved stoves are made in many different varieties, but they are in general characterized by better efficiency than the other stoves (Pedersen et al., 2003). Figure 3 shows that 97 % of the cooking stoves used in Uganda belongs in the "traditional domestic" group.

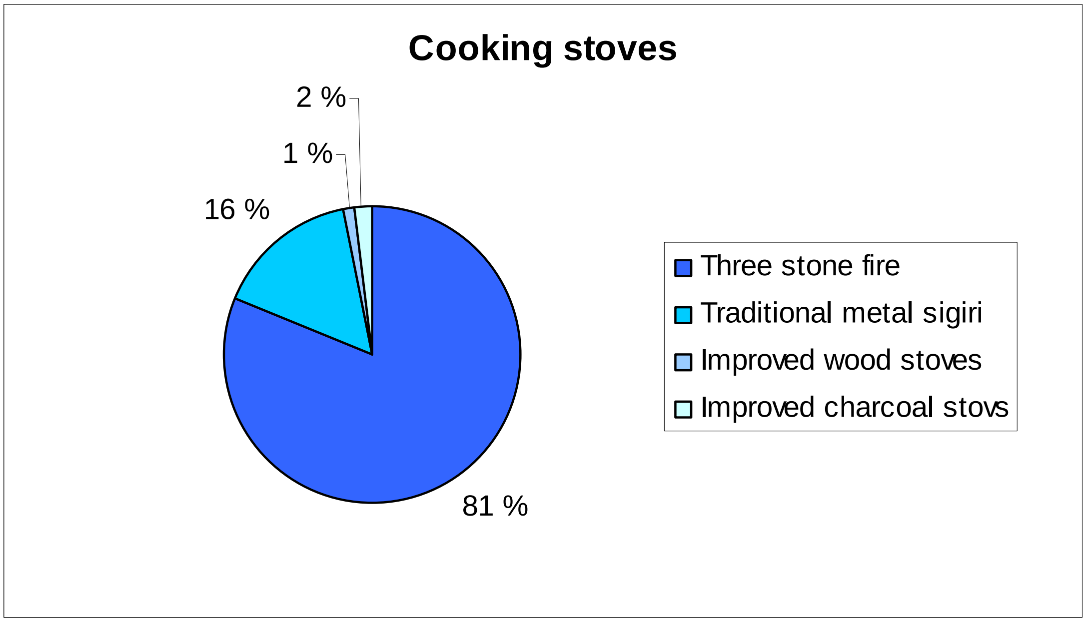


Figure 3: The percentage share of the four most common categories of cooking stoves.

1.4 The aim of the thesis

This thesis will focus on energy from biomass. The biomass resources can be divided into five main categories (Hall et al., 1982): wood, crop residues, animal manure, household wastes and food processing wastes. Firewood represent a large share of the biomass consumed in Uganda (refer chapter 1.1), which make this group the most widely used in the country. The theoretical limitation of wood as a resource is the amount of forests and woodlands present. Although the forested areas of Uganda are declining, there are still wood resources left, which are making this energy source easily available (Henriksen, 2003). However, the rapid utilization of the forests is making this resource more scarce (refer chapter 1.1), a fact that is accelerating the need to replace some of the wood by other energy sources. The main reason of the declining forests is not necessarily the utilization of wood for energy, as a study by Reau (2002) shows. The main reason of the deforestation of the western forests at Madagascar is due to expansion of cultivated areas. Therefore, the solution is not to replace wood as an energy source alone, but this might be a part of the solution. Anyway, the already high share of wood as fuel in Uganda is an important motivation factor to develop other alternatives for energy utilization and increase the flexibility of the energy system.

The crop residues are theoretically limited by the amount of residues produced every year. The practical limitation is competition from other energy sources and seasonality of supply (Hall et al., 1982). However, for most of the crop residues discussed in this thesis the supply is present 12 months a year because of the tropical climate of Uganda (Pedersen et al., 2003). The real limitation in the case of Uganda is competition from other energy carriers, a fact that may explain the low share of crop residues in the biomass use of Uganda (refer chapter 1.1). The low share of the crop residues in the energy mix in Uganda at present and the high amounts of unexploited crop residues make this group very interesting for further studies, and combined with the fact that the studies already available on biomass energy in Uganda all concentrate mainly on firewood and charcoal (Norplan 2002; Forest Department 2002; Henriksen 2003), confirm the need to focus on this issue. The hypothesis is that the crop residues represent an important potential for energy utilization in Uganda.

The animal manure will not be included as an object for analysis in this thesis. The potential of this group is not as realistic as for the crop residues. The wastes might be more difficult to utilize than the manure, but as the character of the MSW is more inline with the crop residues, this will be a more interesting scope in this thesis.

The household waste and food processing waste will be discussed as one group in this thesis. The theoretical amount available is the waste generated, while the most important limitation is the ability to collect it (Hall et al., 1982). The treatment is not satisfactory at the time being, so the utilization of the waste as an energy source may represent an environmental improvement. The aim of the study of the waste treatment in this thesis will be to compare the cost (not necessarily measured in money, but in terms of negative impacts) of the system as it is today, by the advantages associated by improving the system. The aim is to strengthen the incentive to develop a sustainable waste treatment system. The savings by the improved system will also be quantified in some way. This part will be restricted to Kampala city, due to the available data sources and the extent of this work. The hypothesis is that the costs of improving the waste management system in fact will be lower than the societal costs of the system as it is right now.

The two main aspects on the nexus energy and development commented in chapter 1.2.1 are the problems of no electrification of the households and the use of low quality biomass fuels. Since the focus of this thesis will be improved utilization of biomass residues, the electrification in terms of grid extension will not be included in the discussion. However, generation of electricity by the utilization of biomass resources is an actual scope.

There are too many possible technologies for utilization of the energy in the resources that will be mapped in this thesis to cover all the alternatives in detail. The focus will therefore be set on electricity production by combustion and charcoal or briquette making. The reason is that these energy carriers already are well established in the Ugandan market, and doesn't need construction of new distribution systems, as pipelines for LPG. Biogas is an example of a very interesting way of utilization, but because of higher barriers for use, this alternative is only mentioned in general.

The aspects discussed in this chapter, as well as the theoretical links between energy and poverty, development and economy described in chapter 1.2, can be summarized in a set of motivations to improve the energy system of Uganda. In this thesis the focus will be on biomass residues from waste and agriculture.

2 Methods

2.1 Fieldwork

Six weeks of the work with this thesis was carried out as fieldwork in Uganda. The fieldwork work was necessary due to problems to access correct information from Norway. The use of telephone, e-mail and web publishing is not as widespread as in the developed world. The need to access information by being there in person is much more present than in Norway for instance. The second main reason of the fieldwork was to get new information by interviewing people and to understand the situation by observations and documentation. Then, another aspect was to study the sectors that are object of study in this thesis. The field work was implemented using the following methods:

- Qualitative interviews with ordinary people
- Qualitative interviews with professionals
- Visits to factories and other installations
- Documentation of the situation by observations and photography

- Get access to written information and studies available from professionals

The weeks in front of the fieldwork period were used to preparation the fieldwork. Some time was spent mapping areas of interest as well as reading the latest published literature covering actual subjects. The interview schemes were made prior to the fieldwork period to be sure to cover the issues necessary to answer the questions of the thesis properly. However, it is hard to plan everything in detail in front of the research, so many adjustments to the plans made prior to the stay was made during the field work period.

The cultural differences are one of the most important aspects to have in mind in front of and during a fieldwork session in a country of another culture. Some of these aspects were a part of the preparation period in front of the fieldwork, while other aspects weren't known in advance. The time aspect is differing between the culture in Norway and Uganda. While Norwegians expect a precisely and accurate understanding of the time aspect, a Ugandan person has a period of one hour tolerance. This difference is not only important when meeting people or in organized meetings, but also when you are expecting an e-mail or a letter. The understanding of the term efficiency is also wider than the one used in Norway, a fact that often results in e-mails received later than one would have expected in Norway.

Another difference is due to development. Uganda is a developing nation, so many things that we take for granted in Norway is not yet there in Uganda. Many factors in society influence the work of collecting information. The organizing of the society in terms of traffic flow etc. is influencing the time spent to get from A to B and the standard of the internet connections are influencing the ability to access research publications from other parts of the world. The standard of the internet connections is probably one of the reasons that it is less common to publish reports on the internet. The alternative is to store them in hard copy format in an office or a library. However, all communication systems are improving fast, and the functioning of the system was better than I expected in advance of the stay. One example is the telecom systems. Most people have their own mobile phone, making it easy to contact people.

2.2 Theory and methods applied in the thesis

2.2.1 Material flow analysis

The material flow analysis (MFA) is based on the law of conservation of mass (Lavoisier, 1789), which says that what goes in must go out:

$$\text{Mass in} = \text{Mass out}$$

Based on this statement, the aim of a material flow analysis is to map the flows of a specific material from the time it enters the technosphere to the time it leaves it again for the natural environment. In that way the system boundary of material flow analysis is the interface between the human economy and the natural environment (Matthews et al., 2000). The left side of a flow chart system is where the inputs to the technosphere are coming. Inputs and outputs regarded as irrelevant both economically and environmentally are represented on the upper side of the flow chart. The outputs to the environment or to the technosphere of another economy (exports) are mapped on the right side of the diagram. Material that is retained in the economy for more than one year is defined as net additions to stocks (NAS), depending on the time limit set on the material flow analysis (Matthews et al., 2000).

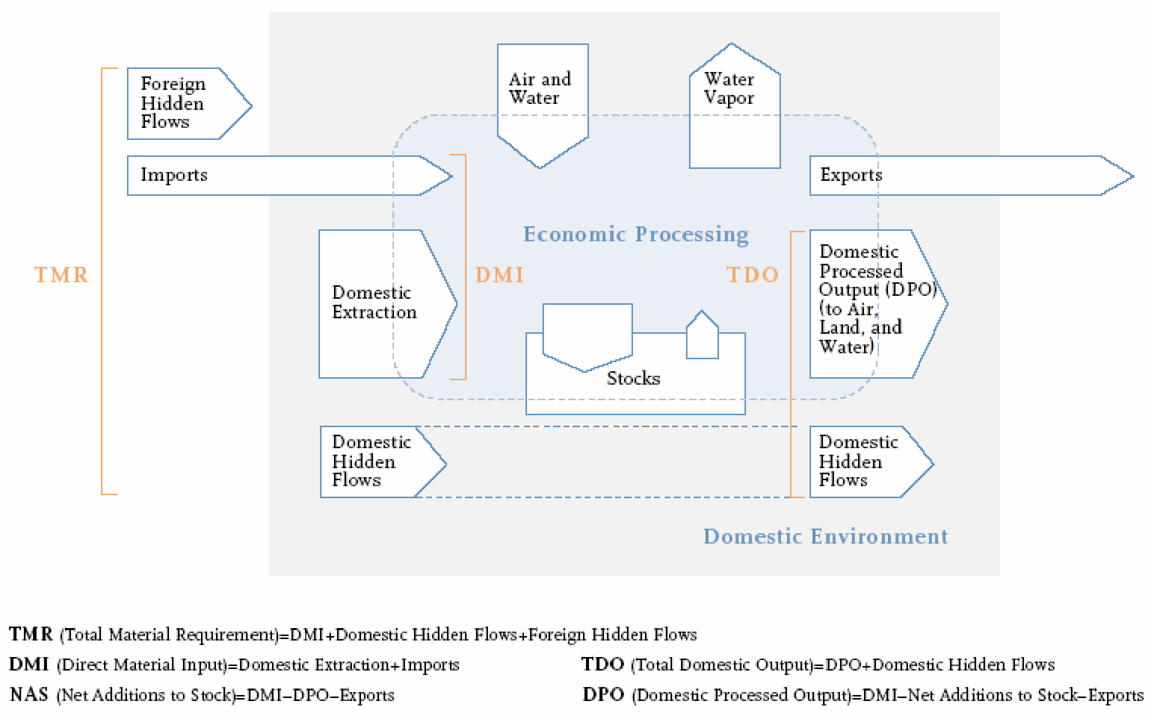


Figure 4: General example of a material flow analysis scheme (Matthews et al., 2000).

Bringezu (2003) defines two different types of motivation for implementing a MFA. Type 1 is developed due to the objective of studying specific problems related to substances or materials. For instance, the flow of carbon can be studied because the carbon flows are related to the problem of global warming. In this thesis the use of MFA is motivated in the objective of mapping the flows of biomass in Uganda to improve the use of these resources as well as improve the understanding of the environmental pressures associated with these streams, which make it a type one motivation. The type 2 version is based on the requirement of mapping the industrial metabolism of a certain area or region to get an idea of the degree of sustainability in that region and how to improve the situation.

The traditional economic indicators used on national economies are based on financial flows. However, such methods provide insufficient information regarding environmental concerns. The environmental costs are not sufficiently reflected in the prices of goods and services in the economies. Hence, financial flows are not always suitable to address environmental concerns. That is why there is a need for tools that measure physical parameters of national economies, and material flow analysis is a tool like that (Matthews et al., 2000).

2.2.2 Risk assessment

Risk can be defined as: “the probability that an outcome will occur times the consequence, or level of impact, should that outcome occur” (Hassenzahl et al., 1999). Risk assessment is about quantifying the risk. This can be done by technical and analytic methods as provided by Hassenzahl et al. (1999).

2.2.3 Fuelsim

Fuelsim is a computer program for making mass, volume and energy balances for combustion applications (Fuelsim, 2002). It is used to estimate the electricity generation potential for some agricultural residues and MSW in this thesis. Such calculations are possible provided that the element composition or the heating value of the fuel is known, as well as moisture content and feeding rate. The theory behind the program is described by Skreiberg (2002).

2.2.4 The dynamics of fuel change in households

The energy ladder has often been used to understand the dynamics of the change of household energy carrier as the income of the household increases. The model claims that as the household’s socioeconomic status increase, the inefficient, cheap and polluting energy carriers are replaced by improved ones. According to Masera et al. (2000) the lower energy carriers are dung, fuel wood and charcoal. The next steps are represented by improved wood and charcoal stoves, followed by kerosene, LPG and electric stoves. The preferences for shifting fuel are that they are easier to use, they are cleaner, better to store and the women have more time at work. This process has often been described as a linear process, where the users of the different energy carriers are situated at different stages of development. However, this understanding is adjusted by the “multiple” fuel model. This model is based on the findings that many households in developing countries tend to use two or more energy carriers at time. For instance, the household may use electricity for light and electrical equipment, while charcoal is used for cooking. There can be both technical and socioeconomic reasons as well as cultural preferences why charcoal still is used for cooking in a household like that. As in the case of Mexico, firewood is often preferred as the energy source for making tortillas even if the household already has a LPG stove. The reason is that the LPG stove is not so well suited for this purpose as the traditional methods. Similarly, for the preparation of the traditional dish matooke in Uganda the traditional fuels like charcoal or fire wood is preferred.

3 Description of the current situation

3.1 The waste management of Kampala

3.1.1 Waste composition

The most updated information on waste composition in Kampala is dating back to 1990 (Engebretsen, 2003). However, the estimates made in 1990 are still valid (Gubya, 2004). The total amount of waste generated in Kampala has increased, but each of the different waste compartments has increased at the same rate, leading to no change in the waste composition (Gubya, 2004). The far largest quantity of waste generated in Kampala is consisting of vegetable matter. The other fractions are all contributing to less than 10 % of the total amount of waste generated, as presented in Table 1.

Table 1: Composition of the waste generated in Kampala. According to Gubya (2004), most of the paper, plastic and metal are removed for recycling either before the waste is deposed, or at the landfill. If 50 % removal of these compartments is assumed, the waste composition after recycling will be as presented in the column named "after recycling" (refer chapter 3.1.4).

Component	Percentage composition [wt. %]	By weight [tons]	After recycling [tons]	Percentage composition after recycling [wt. %]
Vegetable matter	73,8	317340	317340	77,7
Tree cuttings	8	34400	34400	8,4
Street debris	5,5	23650	23650	5,8
Paper	5,4	23220	11610	2,8
Metal	3,1	13330	6665	1,6
Saw dust	1,7	7310	7310	1,8
Plastic	1,6	6880	3440	0,8
Glass	0,9	3870	3870	0,9
Sum	100	430000	408285	100

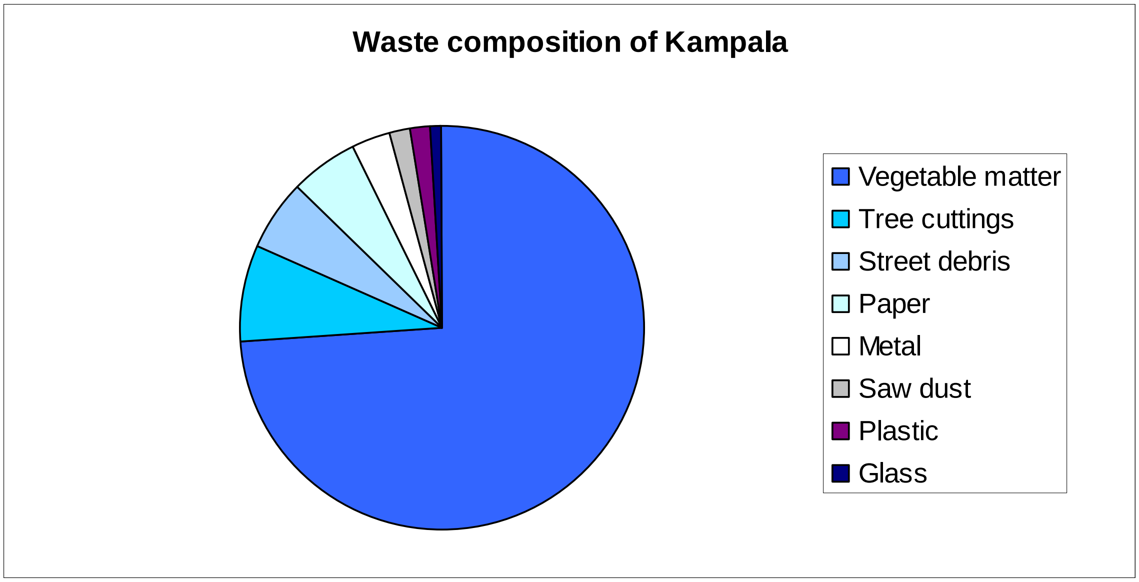


Figure 5: The waste composition in Kampala illustrated by a pie chart.

The waste composition presented in Table 1 and Figure 5 was estimated by using a sample from the total amount of waste generated in Kampala. The research team got 2-3 skips as a sample. These skips were sampled from high income areas, low income areas and markets, which in sum are supposed to serve as an average of the waste generated in Kampala in general. KCC reserved the skips for that purpose, and guarded them to make sure that the skips were sent untouched for research. The research team separated the different waste compartments and weighed the fractions. On this basis the samples were compared and an average waste composition of waste generated in Kampala was calculated (Gubya, 2004).

The amount of waste generated is approximately 1 kg per capita per day (KCC, 2002). Given the population of Kampala in 2002, which was 1.2 million inhabitants, the waste generated that year in Kampala was 430 000 tons, which is approximately the same as the amount of waste presented in the report by KCC (2002).

3.1.2 Organization

Kampala City Council (KCC) is responsible for the solid waste management of Kampala, due to the Local Governments Act, 1997. KCC is the District/Urban local Government in the city of Kampala. The KCC consists of an elected Council headed by a chairperson as well as team of professionals headed by the Chief Executive.

KCC is divided into five sub-counties, called divisions in Kampala. The divisions are all administrative units and they are responsible for solid waste collection and transportation of the solid waste in their own division. Solid waste disposal is the responsibility of the KCC headquarters.

The solid waste is collected either by KCC itself or by private actors. The private actors accounted for around 10 % of the waste delivered to the landfill in 2002 (KCC, 2002). The private collectors can only collect waste from areas where people can afford to pay for the waste they generate. KCC prefer to delegate the responsibility of collecting the solid waste to as many private actors as possible. The reason is that KCC is not allowed to charge money for their work directly from each household. KCC gets its money from the taxes paid by the residents of Kampala. However, the private actors are allowed to charge their customers for the work they do. The private actors provide a door to door service of waste collection twice a week at 20 000 to 30 000 Ush a month (KCC, 2002). Because of the advantages of letting private actors take care of the waste collection, the KCC plan to extend the rate of using private contractors to collect the waste. Such an extension will imply specific costs for waste collection also for residents of medium and low income areas. Residents living in low income areas like Bwaise, Katwe, Kalerwe and Kinawataka will pay 100 Ush a day or 2 500 Ush a month according to a proposal made by Lubowa, the city secretary for health, hygiene and environmental improvement. People living in the medium income areas like Najjanankumbi, Kitintale, Kabowa and Rubaga will be charged 200 Ush a day or 5 000 Ush a month (Ntabadde, 2004).

The KCC itself is responsible for collecting the remaining waste. For that purpose KCC has 20 trucks available to collect the waste from their 500 skips. These skips range from a capacity of 5 m^3 to a maximum of 15 m^3. The waste is transported to the landfill site of KCC, Mpererwe landfill.

3.1.3 Mpererwe landfill

Figure 6: This picture shows the leachate treatment plant at Mpererwe landfill.

In 1996 the landfill site of KCC at Mpererwe was opened. Until 1996 the waste was dumped at various locations in town which was not designed as deposits for waste. The landfill is a containment landfill which means that the ground at the landfill site was protected by a water proof cover before the waste was dumped at the site. A containment landfill is necessary if the characteristics of the soil, waste and amounts of waste are such that the soil cannot itself clean the leachate before it reaches the groundwater. The leachate is the liquid appearing at the landfill consisting of moisture from the waste mixed with rainwater. The landfill also has a leachate treatment facility to reduce the leachate oxygen demand (KCC, 2002). This facility was ready for operation in 2001. The process is described in Figure 7.

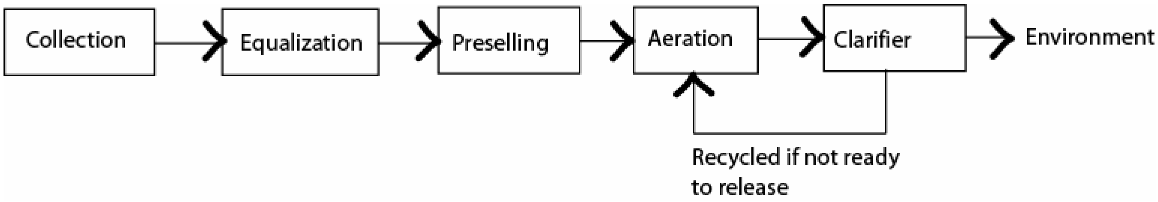


Figure 7: Flow scheme of the leachate treatment facility at Mpererwe landfill. The aeration is a biological process where microorganisms are depleting the compounds in the liquid. In the aeration tank there have to be sufficient amounts of oxygen for the bacteria to live. The bacteria break down the BOD to carbon dioxide and water. The composition of the liquid at the point where it enters the environment is measured once a month, to make sure that the composition of the leachate is such that the leachate can be released into the environment.

3.1.4 Recycling

The percentage of recycling in Kampala today is at about 11 % according to Gubya (2004). However, the degree of removing of recyclable items from the landfill is not known exactly. If 11 % recycling is reality, this means that all paper, plastics and metal are removed from the landfill and the skips. It will hardly be possible to remove 100 % of the recyclable items from the landfill, a view which is supported by Mudanye (2004), so in the calculations in this thesis 5 % recycling rate is assumed.

No recycling is initiated by KCC, but the recycling is done by people who can see the chance to earn some money on it. Some people have seen the possibilities to make a business out of utilizing the resources that other people regard as waste. However, these recycling businesses are mainly unorganized, making it impossible to give an exact picture of the situation.

Figure 8: Woman who cleans bottles for reuse or recycling.

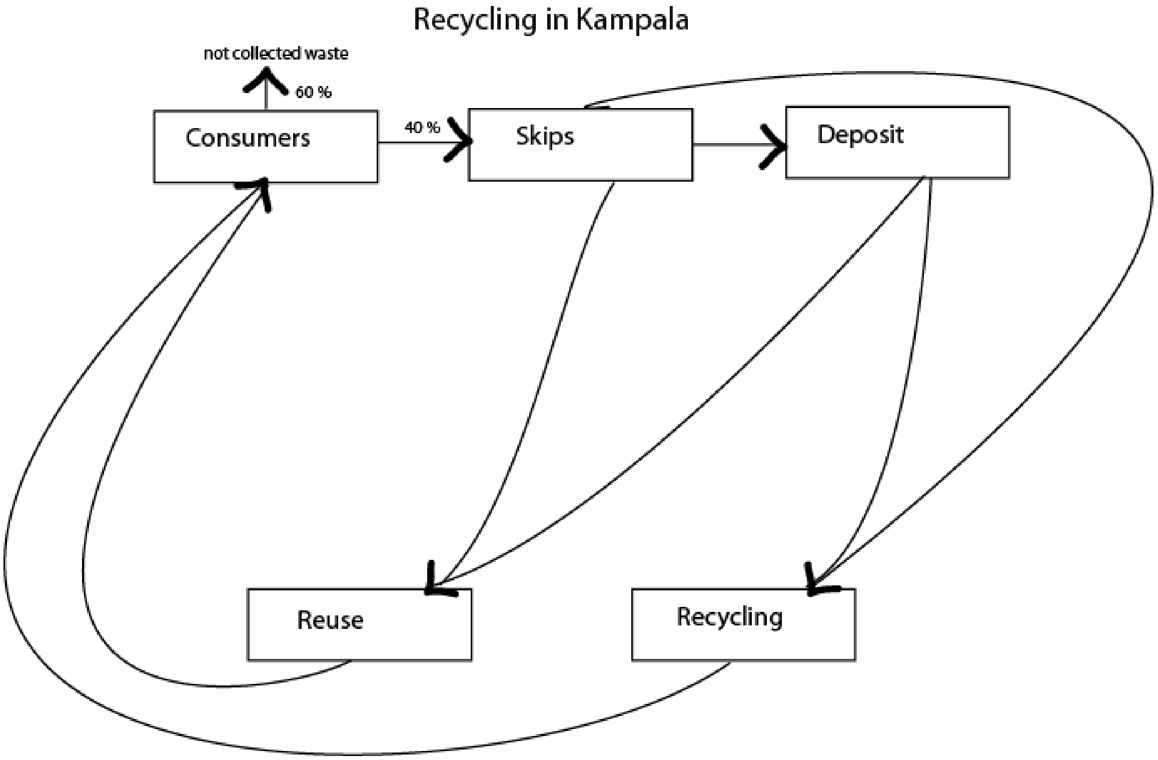


Figure 9: Flow scheme of the recycling in Kampala. The flows out of the boxes named "skips" and "Deposit" is in total representing approximately 10 % of the waste entering the box marked "skips".

Quite many people in Kampala make a living out of this. At Mpererwe there are about 25 people picking waste from the landfill (KCC, 2002). They take away about 1 ton of waste a day consisting of paper, cardboards, plastic and metals. Then there are people working with recycling of banana peelings, plastics, rubber, metals and paper around town. Only in Katwe there are 10 people working on metal recycling (Katarilepes, 2004). The rubber recycling company employs 10 people (Musolke, 2004), while the plastic recyclers employ 5 people (Kalungi and Mayanya, 2004). However, all of these have similar "competitors" elsewhere in Kampala, so the total number of workers is much larger. And there are also many street kids, boda boda drivers etc. who collect the waste and deliver it to these companies where the waste is treated further (Kalungi and Mayanya, 2004). So, usually there are two levels of workers which need to earn money from the waste before it reaches an established factory to process it to reusable items.

3.1.5 Description of the situation

Currently only 40 % of the waste generated in Kampala is collected (KCC, 2002). This praxis results in waste lying around in the streets of Kampala. The environmental awareness of the population of Uganda is not very high in general (Nicholas, 2003), which is one reason why there is waste lying around in the streets everywhere. Another reason is that the equipment used for waste collection is too few and in bad condition. The skips are filled up too quickly and they are in bad condition. The skips are not filling the requirements of the need they are meant to cover anymore when there are holes in the walls of the waste container, but it seems like skips in such condition still are in use. The consequence is that some of the waste thrown away in the skip is falling out again and remains lying on the ground. The same is happening when the skips are overfull. A significant part of the waste is remaining on the sites where the containers are situated. Some waste is also falling of the trucks when they are transporting the skips to the land-fill. The skips are only covered by a big masked net while transported, so some of the waste situated on the top easily falls off during transport.

Figure 10: The picture to the left is showing a skip, filled up by waste, while the one to the right is showing a street where the waste is flowing.

3.2 Status of existing technologies for biomass utilization

This chapter will focus on technologies in use today to utilize energy from biomass residues. The industries where such technologies are implemented are the bricks and tiles making industry, the cement industry and the sugar industry.

3.2.1 The bricks and tiles making industry

This industry is represented by both the traditional way of brick making, as well as the modern, industrial way of manufacturing. The traditional production methods are still the most important, and most people choose to build their houses from the traditional made bricks, because those are cheaper than the industrial ones (Mayinza, 2004). Because the traditional made bricks are from the informal sector, there are no statistics on the volumes produced in this way. The only way to estimate the size of this sector compared to the formal one is to make a qualified guess. Mayinza (2004) believes that around 70 % of the bricks made in Uganda are made the traditional way. However, there are statistics available of the production volumes from the industrial sector, and these data are presented in Table 2. There are only three factories contributing to those data, and they are Uganda Clays, Butema brick factory, and Butende (Mayinza, 2004). There are also other, smaller bricks and tiles works in Uganda, but they are not included in the statistics.

Table 2: The production volumes of tiles and bricks in Uganda the last years from the industrial sector (Uganda Bureau of Statistics, 2003)

Bricks and tiles, industrially produced		
Year	**Volume**	**Unit**
1998	32054	tons
1999	32504	tons
2000	20744	tons
2001	29570	tons
2002	34639	tons

The Hoffmann kiln

Uganda Clays Ltd. at Entebbe road currently has one Hoffmann kiln (Figure 11), and at the time of writing they are constructing a new Hoffmann kiln to phase out the old fire wood and furnace oil fired stoves (Kayando, 2004).

The Hoffmann kiln, also called ring kiln, which is dexcriptive for the basis principle of the shape of the kiln. The Hoffmann kiln is constructed in a ring. The main purpose of this design is to make it possible to recover the heat from the flue gases in the combustion process. This design makes it possible to use the hot flue gas to preheat and dry the bricks before they enter the hottest parts of the kiln. In the post combustion phase, the heat from the finished bricks are preheating and drying the newly entered bricks (Nturanabo2, 2001). The kiln is divided into different chambers, and the combustion process is taking place in one of these chambers at time. There are channels connecting the chambers, where hot air and flue gases are transporting heat through the kiln. The kiln is fired by coffee husks. The husks are fed automatically into the kiln from wholes in the ceiling of the kiln. The rate of fuel entering the combustion chambers is regulated by measurements of the temperature inside the kiln.

Figure 11: The entrance to one of the chambers in the Hoffmann kiln at Uganda Clays can be seen to the left. The right picture is showing the wholes in the ceiling of the kiln used to feed coffee husks into the kiln.

When the feeders of coffee husks are moved to the next chamber, the temperature in that chamber is approximately 700 ºC. Then, when the fuel starts pouring in, the temperature rises from 700 ºC towards 900 ºC which is reached after 1.5 or 2 hours. When the feeding of coffee husks is stopped, it takes around 1.5 to 2 hours before the temperature drops to 700 ºC. When the combustion zone are moved further away, the temperature will decrease further from 700 ºC and reach lower levels until around 100 ºC when the bricks are ready to be removed from the kiln (Kayando, 2004). The kiln is emptied and filled up again opposite the combustion zone, because this area is the temperature is at its lowest. In this way, the combustion zone is moving constantly around in the kiln, and the combustion has lasted continuously since the kiln was opened.

The dimensions of the kiln are quite large. Four of the chambers in the kiln are fired a day. The capacity of these four chambers are 2400 Maxpan blocks, 16 000 Mangolone tiles (roofing tiles) and 6000 Half bricks. The fuel consumption for this quantity is two 7 tons lorries filled with coffee husks. The exact capacity of these lorries are not measured, but estimated to 3-4 tons of coffee husks.

Traditional kiln

The traditional kilns can be built nearly everywhere, because the construction of the kilns is quite simple. These kilns are not permanent, and the construction material is mainly the bricks themselves. After the bricks are given their shape by forming them either by a wooden frame or by hand, they are piled into a pyramid-like construction Figure 12. At the basis of the construction two tunnels are made where the firewood can be put in (these kilns are always fired by firewood). When the combustion takes place the hot flue gases are rising through the pyramid of bricks. In that way, the temperature in the bricks raises enough for the chemical reactions in the bricks to happen.

Figure 12: The shape of a traditional brick kiln

3.2.2 Sugar industry

There are three sugar factories in Uganda, and they all make use of more or less the same technology. The interesting aspect for this thesis is the energy technology. Though, an important aspect is also how the bagasse is produced. Therefore, a description of the process in general will be provided.

The raw sugar canes are transported from the fields to the factory and then they enter the factory on a conveyor belt. The first processing step is the kicker, where the canes are cut down into smaller pieces by a series of rotating, cutting knives. The canes are chopped further in the Fibrizer, where the canes are shred and the sugar containing cells are exposed. In the milling station rollers crush the cane and extract the juice. Maceration or imbition water is added to the crushed crane prior to the final crushing. That is to assist in extracting the cane juice. At this point the sugar content juice is already separated from the bagasse. The bagasse is the fiber from the canes, and the bagasse is transported to the boilers for combustion. The excess bagasse is transported out of the factory. The extracted juice is pumped into a receiving tank. From this tank, the juice is pumped further to the primary juice heater, where the juice is heated to around 70 ºC. The next step is a reaction tank where a lime solution is added. The lime solution prevents sucrose inversion because the pH is increasing from around 5.2 to 7. In the secondary heater the temperature increases further to 100-105 ºC, before the juice is pumped to the clarifier, where the solids are allowed to settle out. The mud from the clarifier is transported to a filter, where the rest of the juice is extracted. The filtrate is transported back to the rest of the juice on the way to the evaporators, where the water content of the juice is gradually reduced until it becomes syrup. Sulphur dioxide is bubbled through the syrup. After the crystallization, the sugar is separated from the molasses in the centrifuge (Wardrobe Engineering, 2003).

The bagasse has a moisture content of 50-55% water, and this is also the moisture content of the cane when it is fed into the boiler. None of the sugar factories in Uganda predry the bagasse before it enters the boiler. The ash content varies from 2.5-6%, and the season of the year and techniques of harvesting are determining the ash content. If the harvesting is done in terms of mechanical loading, the ash content increases, and this is also happening in wet weather because more mud etc. is following the canes into the process (Polzin, 2004).

Kakira Sugar Works

The boilers are constructed for bagasse combustion. The bagasse is gravity fed into the combustion chamber through chutes at the top of the boilers. The primary and secondary combustion air is entering the combustion chamber through ports in the furnace walls. The combustion starts where the bagasse hits the surface pile.

Currently (2004) there are four boilers installed at Kakira Sugar Works. They have the following technical specifications:

- Boiler 1: 24 tons of steam per hour
- Boiler 2: 22 tons of steam per hour
- Boiler 3: 22 tons of steam per hour
- Boiler 4: 24 tons of steam per hour

The boilers are all operating at 20 bar pressure, and a combustion temperature at 300 ºC. A fifth boiler will be ready July 1th 2004, and it will be operated at 30 t MCR.

There are two turbines at Kakira:

- Turbo Alternator 1: 3 MW and 18 bar pressure. The water rate is at 11 kg/kW
- Turbo Alternatio 2: 1.5 MW and 18 bar pressure. The water rate: 13 kg/kW

Kinyara Sugar Works

The boilers at Kinyara have the following specifications:

- Boiler number 1: 35 tons of steam per hour at 2350 kPa and 350 ºC
- Boiler number 2: 35 tons of steam per hour at 2350 kPa and 350 ºC.

Recently the boilers have been modified, and pinhole grates have been installed to improve the combustion process. These grates promote suspension firing of bagasse instead of pile burning which gives a much better heat release from the fuel (Jobling, 2004).

There are two turbines installed at Kinyara, and they have the following specifications. They both have 1 MW steam driven back pressure Allen turbines. The pressure is 2350 kPa at the inlet and the exhaust gas is at 130 kPa. The water rate is estimated to 15 kg/kW.

Generally the turbines are operated 46 weeks of the year. However, maintenance work is done to the machines every third week when they are turned off 16 hours each time. The turbines are operated at a load of 750 kW each. To handle peeks in the system there are diesel generating plants, which consist of one generator at 800 kW and one at 400 kW.

3.2.3 The cement industry

Hima cement is utilizing coffee husks in their production process. Cement is produced from limestone, which is crushed and grinded. The materials are calcinated in a rotary kiln, where the so called clinker is produced. The clinker is cooled until it is mixed with gypsum. When the cement is finished it is milled, stored and bagged. The coffee husks are used in preheating of the lime. The consumption of coffee husks for that purpose is approximately 20 tons per day in 2003 (Norplan, 2003). No information is available on the number of operating days a year, but assumed that the factory produce 320 days (Kakira Sugar Works operates 320 days a year according to Polzin (2004)) a year, the total amount of coffee husks used is 6 400 tons.

4 Negative impacts caused by the existing situation

There are a number of negative impacts caused by the current waste management system and the way the energy system in general is working today. The aim of this chapter is to describe some aspects of this situation, partly because it is of interest to know for its one sake, and partly to serve as motivation for improving the system.

4.1 Waste management

4.1.1 Waste burning

Due to the fact that only 39 % of the waste generated in Kampala is collected, most of the waste ends up other places than at the landfill (KCC, 2002). Open air burning is a commonly used way to get rid of the waste that doesn't reach the deposit. According to DEQ (2004) open air burning is where unwanted material is burned releasing the emissions directly to open air without passing any chimney. There is no equipment to regulate the air supply and maintain steady combustion temperatures. The result is incomplete combustion, which implies emissions of several unwanted gases and particles, which will be assessed in detail in chapter 4.2.

Figure 13: Example of combustion of waste outside

4.1.2 Flies

Flies are a problem related to both the fact that they are irritating by their presence itself and the risk that they are spreading pathogens. Employee (2004) especially mentions the problem with flies as a major side effect of waste generation and storage. He is working in a hotel opposite the garbage skips located in the end of Martin road by the new taxi park in Kampala. The consequence is that they use insecticides in the entire hotel to get rid of the flies. The insecticides they use contain DDT, which is forbidden in most of the western world due to its persistency and poisonousness and hence negative influence on ecosystems. The flies are fought because there is a risk that they spread pathogens from excreta to food (Nakiboneka, 1998).

4.1.3 Smell

The problem is mostly associated with waste lying around in the streets and at illegal dump sites. At the landfill at Mpererwe the situation related to smell are controlled by using layers of soil (marram) to cover the waste. This method prevents the formation of bad odour from the landfill. The smell is regarded as a problem by Bosco (2004), while Employee (2004) doesn't seem to see any problems from bad odours, although both of them do business nearby the same waste skip at the end of Martin road. The open fires discussed in chapter 4.2 also represent a source of bad odour in Kampala.

4.1.4 Waste in the sewage system

There is also some waste generated in Kampala that is thrown away into the sewage systems of Kampala. Gowa (2004) is claiming the importance of that problem. She is also spending some effort in solving the problem. At the time the interview was made she was planning to give a lecture for leaders in KCC, Kawempe division, Bweise. In this part of the city the problem of waste in the draining system is a significant problem. Then, these people will spread the information further down in the society. Also Gubya (2004) mentions the problem of garbage in the drainage system. The problem is that the garbage makes plugs in the drainage system and may cause floods. Such floods can cause damage to the road system, hence representing huge economic costs for KCC.

Figure 14: Waste in the draining system, Katwe, Kampala.

4.1.5 Aesthetical

The aesthetical aspect of the waste problem is hard to address, because it doesn’t imply any direct economic or health impacts. However, the fact that waste is flowing around in the streets of Kampala is degrading the aesthetic impression of Kampala city.

4.1.6 Marabou storks

It is not clear whether the Marabou stork, *Leptoptilos crumeniferus*, is regarded as a problem or not by the citizens of Kampala. The fact is that the Marabou storks are quite many in the city of Kampala. They don't really meet our ideal of beauty, which is giving them a bad image among people. Kayiggya (2004) claims that the Marabou stork has quite a few myths connected to it, and he seems to believe on these myths himself. “The Marabou storks are poisoned. Even when they are dying, nothing will eat them. If a fly is sitting on a Marabou stork it will die. They are useless for the nature. Even maggots will not eat it, and if the flies try to lay eggs in it, there will be no larvae from the eggs. The storks will be left to dry when they die because no animal will eat them. They are dangerous” (Kayiggya, 2004). These statements are supported by Bosco (2004). He also claims that the birds are poisonous and acidiferous. However, neither Bosco nor Kayiggya regard the Marabou stork as a general problem.

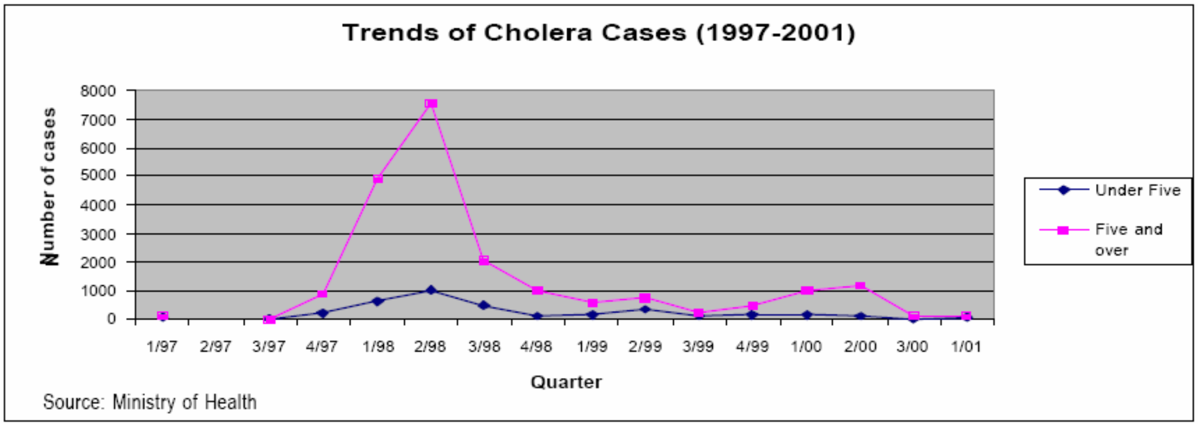
The fact that the storks feed mainly on scraps doesn’t help improving their reputation among human beings. However, this behavior is important for the ecosystem in which they live, the urban areas. By removing rotting substances and carcasses, the Marabou storks help to avoid the spread of pathogens (Animal Magazine, 2004).

Figure 15: Marabou storks feeding from a skip at Wandegeya, Kampala.

4.1.7 Diseases, epidemics

There is a link between the lack of sanitation systems and the spread of diseases. Solid waste disposed in uncontrolled conditions attracts rodents and vectors. These species can be carriers of diseases which can be transferred to human beings. This problem is also interrelated with the lack of latrines and the lack of waste water systems in general, especially in the low income areas or slums in Kampala (Nakiboneka, 1998). Cholera, malaria and dysentery are sanitation related diseases, according to Nakiboneka. Hence, it is important to improve the sanitation systems to fight these diseases. Some of the existing sanitation systems are not dimensioned to handle extraordinary situations like the heavy rains of the meteorological phenomena “El Nino” in 1997. During the rains that year the excreta was washed away by the rainwater, leading to contamination of the groundwater, which in next turn caused an outbreak of a cholera epidemic. The fact that solid waste can represent a source of infection is also known to the public to some extent.

Twasiima (2004) is an example of that. He argues that it is important to burn the waste lying in residential areas to prevent diseases to be spread from the waste. In that way the risk of diseases is an important motivation to get rid of the waste by open burning (refer chapter 4.2.



Source: Ministry of Health

Figure 16: This figure shows the outbreak of Cholera in 1997-98, because of the combination El Nino and the lack of sanitation systems (Ndayimirije et al., 2001).

4.1.8 Polyethylene

Polyethylene is a non biodegradable substance, and because of the lack of possibilities to recycle polyethylene in Uganda, this waste compartment is regarded as the most problematic of the different waste compartments. Kalungi and Mayanya (2004) collect dairy milk bags made of polyethylene for reuse. However, that is the only example of reuse of a polyethylene product, and even the dairy milk bags will be thrown away again after they have fulfilled their reuse-task as tool for the fishermen. Undoubtedly, the problem of the polyethylene is taken seriously in Uganda. The Cabinet of the Parliament of Uganda is considering various control options for the polyethylene carrier bags, and the options currently listed are (Parliament, 2004):

- Production of polyethylene carrier bags should be banned and replaced with degradable paper bags
- Incentives and disincentives measures including taxation for the producers and importers of carrier bags
- Collection and recycling of the already used bags in the environment
- Promoting production and use of bio degradable carrier bags
- NEMA authorities should sensitize the public about appropriate means of disposing polyethylene carrier bags

Gubya (2004) also mentions the polyethylene bags as the main problem when KCC is to choose options for waste treatment. “The main problem is the polyethylene bags that cannot be recycled” (Gubya, 2004). Also by Nicholas (2003), the problem of the disposal of polyethylene bags by travelers are focused on: “After consuming their eats or drinks, the polyethylene bags are thrown through the windows" (Nicholas, 2003). However, the polyethylene is not dangerous in it self, it is not poisonous, just non biodegradable. The structure is very simple:

$$[CH_2\ CH_2]_n$$

The simplicity and usefulness of this material make it one of the most widely used plastics in the world (Polymer, 2004).

4.1.9 Deposit of waste

The praxis of deposing the waste at Mpererwe landfill is not sustainable in the long run. This fact is acknowledged by Gubya (2004). She claims that KCC needs other methods to treat the waste, as she says:

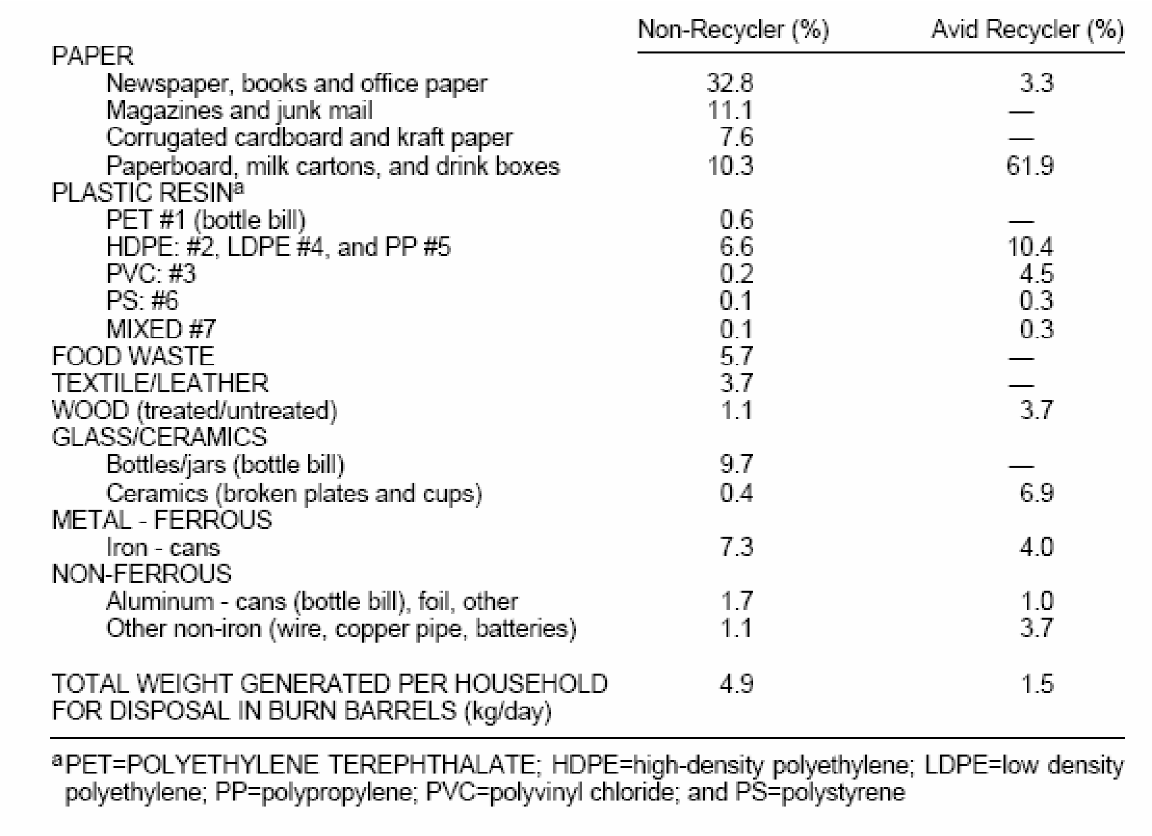
"Deposing is not sustainable. It is also expensive. We (KCC) don't earn any money from it. At least we have moved on from dumping the waste by the roadside, but what about our grandsons? We cannot continue doing something the next generation can't do. Every year the population is increasing by 4%. At the moment we are able to collect only 39% of the waste generated. What will happen when the population increases? The landfill is already full, and the "not in my backyard" syndrome is already here. We need a system that can last for 100 years" (Gubya, 2004).

At the existing landfill at Mpererwe the phase 1 of the facility has reached its capacity. The phase two of the landfill was planned to be opened in January 2002 (KCC, 2002), but at the time of visiting the landfill in February 2004 the extension was not in use. However, when the extension is ready, the landfill will have the capacity to accommodate waste for another 3-5 years (KCC, 2002). This fact confirms that the landfill system is an interim solution to the problem, and that KCC towards the year of 2010 has to look for other waste treatment options or to find new sites to develop another landfill. However, the last option will only be another postponement of the problem.

4.2 Case study: Risk assessment of emissions from open fires

Lemieux (1998) has conducted an experimental analysis of the emission composition from household waste fired in barrels. The use of barrels is due to the fact that this is a common way to burn household waste in the area of Michigan where the studies are carried out. Two different waste compartments were used in the study. One waste compartment was consisting of waste where recyclable items were removed, while the other compartment was untouched. The waste composition in the study is shown in Table 3. There were taken gas samples from the emissions, and these samples were collected using canisters and analyzed by chromatography/mass spectrometry for volatile organic compounds (VOCs). For semivolatile organic compounds (SVOCs), polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), chlorobenzenes (CBs), polychlorinated dibenzo- p dioxins and polychlorinated dibenzofurans (PCDDs/PCDFs), aldehydes and ketones, hydrogen chloride (HCl), hydrogen cyanide (HCN) and metals the analyzes were performed by extractive samples from the combined particulate and gas phase. Particulate emissions and the ash content were also measured.

Table 3: The waste composition of the compartments in the study.



	Non-Recycler (%)	Avid Recycler (%)
PAPER		
Newspaper, books and office paper	32.8	3.3
Magazines and junk mail	11.1	—
Corrugated cardboard and kraft paper	7.6	—
Paperboard, milk cartons, and drink boxes	10.3	61.9
PLASTIC RESIN[a]		
PET #1 (bottle bill)	0.6	—
HDPE: #2, LDPE #4, and PP #5	6.6	10.4
PVC: #3	0.2	4.5
PS: #6	0.1	0.3
MIXED #7	0.1	0.3
FOOD WASTE	5.7	—
TEXTILE/LEATHER	3.7	—
WOOD (treated/untreated)	1.1	3.7
GLASS/CERAMICS		
Bottles/jars (bottle bill)	9.7	—
Ceramics (broken plates and cups)	0.4	6.9
METAL - FERROUS		
Iron - cans	7.3	4.0
NON-FERROUS		
Aluminum - cans (bottle bill), foil, other	1.7	1.0
Other non-iron (wire, copper pipe, batteries)	1.1	3.7
TOTAL WEIGHT GENERATED PER HOUSEHOLD FOR DISPOSAL IN BURN BARRELS (kg/day)	4.9	1.5

[a] PET=POLYETHYLENE TEREPHTHALATE; HDPE=high-density polyethylene; LDPE=low density polyethylene; PP=polypropylene; PVC=polyvinyl chloride; and PS=polystyrene

4.2.1 The Uganda Case

The open fires in Uganda are not burned in barrels but directly on the ground. Though, the combustion properties are more or less the same whether the waste is combusted in a barrel or on the ground. The walls of the barrel might help the temperature rise to higher levels in a barrel than on the ground, while the air support probably will be lower because of the walls. However, there are small holes in the walls of these barrels, providing some air supply to the combustion zone.

The waste composition is quite different from these tests to the composition of the Kampala waste. The composition of the waste in the study can be compared by the waste composition in Kampala in Figure 18 and Figure 5. Paper is the largest fraction in the study with 61.7% of the total waste, while the largest fraction in Kampala is vegetable matter with 73.8 % of the total waste amounts. If the data from the test by Lemieux (1998) shall be applied on the waste composition in Uganda, the results have to be modified according to the differences between the test and the reality in Kampala.

In the study hundreds of emission components are counted for. It is beyond the scope of this thesis to cover all these emission components, so the most important emissions will be commented. One of the most important emission components are particulate emissions, respectively PM_{10} and $PM_{2.5}$. To determine the emissions of PM_{10}, the reference Method for the determination of PM_{10} in the atmosphere by the US Environmental Protection Agency was used. However, the measurements differed form the standard method in some aspects, due to practical considerations. The emissions were measured during two days, and the total result is the average of these tests. The results of the particulate emissions are presented in Figure 17.

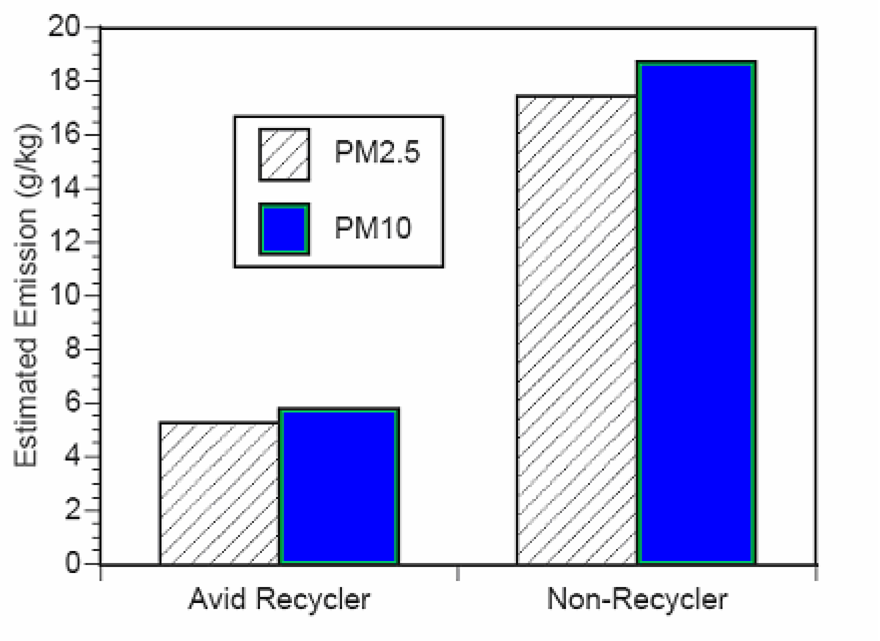


Figure 17: Particulate emissions from the study carried out in Michigan (Lemieux, 1998).

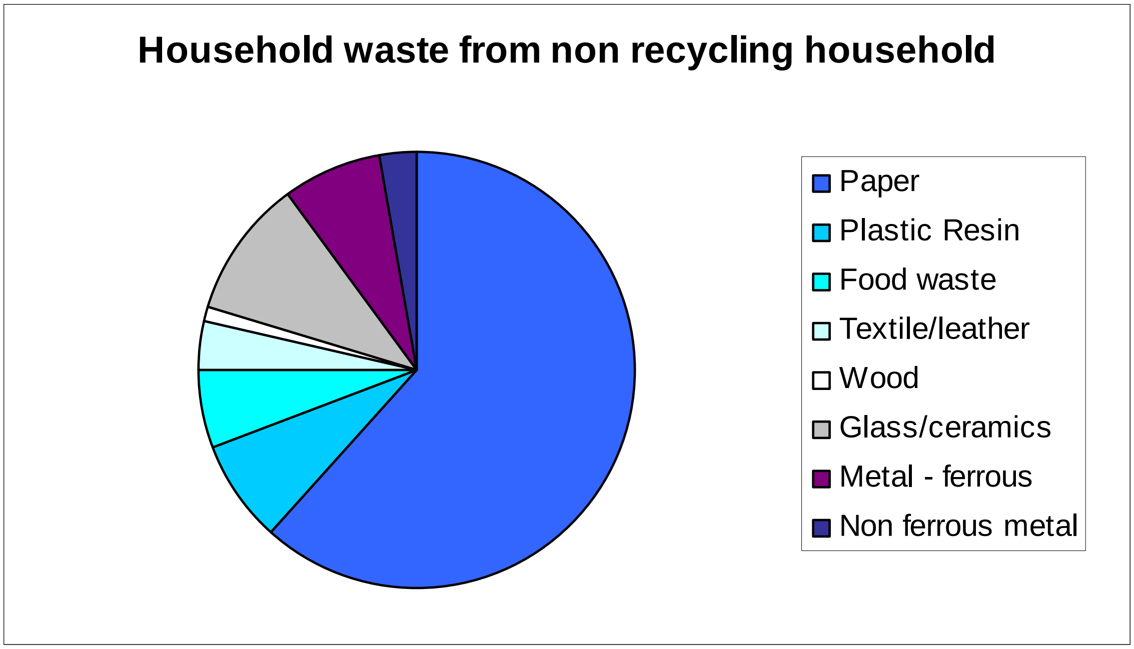


Figure 18: The composition of the waste compartment in the study from household without recycling.

4.2.2 Estimate of the extent of open burning in Kampala

The amount of waste generated in Kampala in 2002 was 430 000 tons (refer chapter 3.1.1), and out of this 39 % was collected and deposed or recycled. The amount that are not collected is then 258 000 tons. However, no research is done to fins out what happens with this part of the waste. There are two main paths for this part of the waste. Some of it ends up at illegal deposits, which can be places that were used for disposal before Mpererwe landfill was opened in 1996. Some waste is also ending in the drainage system, and this can also be regarded as illegal deposing. Much of the waste in this category is also ending in the surroundings of the skips from the KCC, or in the streets. The other category is the waste which is burned outside. The extent of this praxis is not known. A conservative estimate is that 30 % of the non-collected waste is burned outside. This imply that 77 400 tons of waste are burned every year (by 2002 waste amounts) in Kampala city. Provided that the particulate emissions are 18 g/kg as in the study by Lemieux (1998) the total particulate emissions from waste burning in Kampala is 1 400 tons of particles. Distributed on 365 days a year, the emissions every day is 3.8 tons of particles. To estimate the amount of particulates that are inhaled by one person, the volume of daily inhalation of air has to be known:

Total daily inhalation, provided that we breathe 12.5 breaths per minute and 1.2 liters in every breath (Hassenzahl et al., 1999):

$$\left(\frac{12.5\,\text{breaths}}{\text{minute}}\right)\cdot\left(\frac{24\cdot 60\,\text{minutes}}{\text{day}}\right)\cdot\left(\frac{1.2\,\text{liters}}{\text{breath}}\right)=22\,000\,\frac{\text{liters}}{\text{day}} \qquad [1]$$

Provided that Kampala city is 10 km in diameter, the capital covers an area approximately 78.5 km^2 (estimation based on Kampala map). We assume that the particles are spread equally around in this area and 50 meters above ground level before they disappear. Then, the concentration of particles in the air because of open burning will be:

$$\frac{3800\,\text{kg}}{(78500000\,\text{m}^2 \cdot 50\,\text{m})} = \frac{3800\,\text{kg}}{3925000000\,\text{m}^3} = 9.68 \cdot 10^{-7}\,\frac{\text{kg}}{\text{m}^3} = 0.968\,\frac{\text{mg}}{\text{m}^3} \qquad [2]$$

Or, provided that the particles disappear after one hour (158 kg of particles is emitted every hour):

$$\frac{158\,\text{kg}}{(78500000\,\text{m}^2 \cdot 50\,\text{m})} = \frac{158\,\text{kg}}{3925000000\,\text{m}^3} = 4 \cdot 10^{-8}\,\frac{\text{kg}}{\text{m}^3} = 0.04\,\frac{\text{mg}}{\text{m}^3} = 40\,\frac{\mu\text{g}}{\text{m}^3} \qquad [3]$$

Every person in Kampala is then inhaling the following amount of particles:

$$22\,\frac{\text{m}^3}{\text{day}} \cdot 0.968\,\frac{\text{mg}}{\text{m}^3} = 21.3\,\frac{\text{mg}}{\text{day}} \qquad [4]$$

Or, based on hourly removal of particles:

$$22\,\frac{\text{m}^3}{\text{day}} \cdot 40\,\frac{\mu\text{g}}{\text{m}^3} = 880\,\frac{\mu\text{g}}{\text{day}} \qquad [5]$$

As reference values, the recommended air quality standards from the Norwegian Pollution Control Authority (SFT) can be used. The average exposure limit to PM_{10} is 35 µg/m^3 (SFT, 2003). As the result of Equation [3] shows, the concentration of PM_{10} in the air is slightly above the recommended limit.

The dose response curve of PM_{10} is linear and there is no evidence of any threshold, and there is either no evidence that the dose response curve is steeper at higher concentrations. The risk associated with inhalation of the concentration of PM_{10} calculated in equation 3 can be calculated by applying a unit risk factor for PM_{10}. The risk factor available is estimated on the study of particulate emissions from diesel engines. The following calculations will be affected by the uncertainty of the difference between particulate emissions from waste combustion and that of a diesel engine. The unit risk factor of PM_{10} is $1.4 \cdot 10^{-4}$ (µg/m^3)$^{-1}$ (Denton et al., 2002).

$$\text{Lifetime cancer risk}: 1.4 \cdot 10^{-4}(\mu\text{g/m}^3)^{-1} \cdot 40\,\mu\text{g/m}^3 = 0.0056$$

The particulate emissions from open burning of waste in Kampala contribute to a risk of 0.56% for cancer during a person's lifetime. This implies that out of the population of Kampala at 1 200 000 inhabitants, 6720 will develop cancer due to these emissions. This number represent a hugh cost for society in terms of loss of labour and costs for treatment at hospitals.

4.2.3 Emissions of NO and CO

There are also other emissions that are interesting to map, like NO and CO. These emissions are measured continuously in the study, as a function of time. To estimate the emissions during one hour of combustion, the area below the graph has to be calculated. If we assume that all the gas is entering a box of 1 m3, the concentration in that box will reach the level calculated in equation 6. However, the emissions doesn't enter a box, but are spread by wind etc. due to the current weather conditions. So the information provided in equation 6 is only to be able to know the total emissions by weight during one hour. By approximate calculation of the area below the graph in Figure 19, the concentration reaches the level of 814.5 ppm during the first 60 minutes after ignition. This concentration is equal to 932.7 mg/m3 as calculated in equation 6 (The temperature in Kampala is set to 25 ºC).

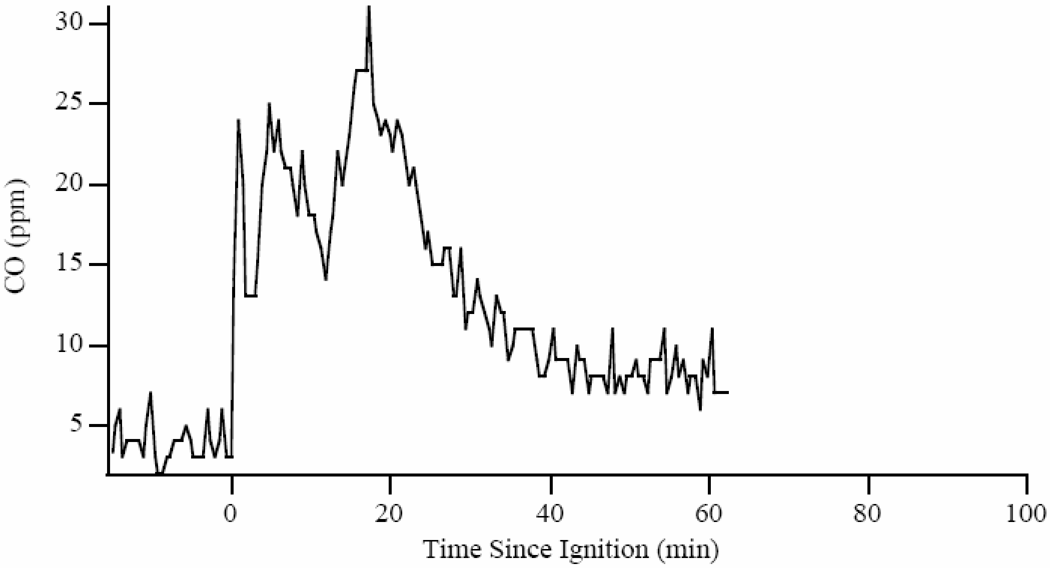


Figure 19: The emission of CO from barrel combustion of household waste containing recyclable items. This figure is measured on basis of test 4 in the study, where that mount of waste ignited was 6.4 kg and the duration of the fire was 62 minutes (Lemieux, 1998).

$$\text{By weight}: 814.5\ \text{ppm} \cdot \frac{28\ \text{g/mol}}{22.4\ \text{l/mol}} \cdot \frac{273\ \text{K}}{298\ \text{K}} = 932.7\ \text{mg/m}^3 \qquad [6]$$

The amount of waste burned in test 4 in the study was 6.4 kg, and the duration of the combustion was 62 minutes. The emissions of CO per kg waste combusted are then 146.7 mg/m3. Combined with the assumption that 30 % of the non-collected waste is combusted outside, the total emissions of CO from the 77 400 tons of waste combusted will be:

$$77400000\ \text{kg waste combusted} \cdot \left(\frac{146.7\ \text{mg CO emitted}}{\text{kg waste combusted}} \right) = 1.14 \cdot 10^{10} = 11.4\ \text{tons} \qquad [7]$$

The emissions every hour will be: $\dfrac{11400\ \text{kg}}{365\ \text{days a year} \cdot 24\ \text{hours a day}} = 1.3\ \text{kg/h}$ [8]

Assumed that the CO is equally distributed in the area of Kampala city up to 50 meters above ground, the resulting concentration will be:

$$\frac{1.3\ \text{kg}}{(78500000\ \text{m}^2 \cdot 50\ \text{m})} = \frac{1.3\ \text{kg}}{3925000000\ \text{m}^3} = 3.3 \cdot 10^{-10} \frac{\text{kg}}{\text{m}^3} = 0.33 \frac{\mu\text{g}}{\text{m}^3} \qquad [9]$$

Based on the amount of air inhaled during one day by a human being in equation 1, the amount of CO inhaled by an average person will be:

$$22 \frac{\text{m}^3}{\text{day}} \cdot 0.33 \frac{\mu\text{g}}{\text{m}^3} = 7.26 \frac{\mu\text{g}}{\text{day}} \qquad [10]$$

CO, carbonmonoxide, is poisonous due to its ability to form tight bindings to the protein hemoglobin in the red blood cells in the human body. The hemoglobin carries oxygen from our lungs to the cells in our body. If CO is present in the inhaled air, the hemoglobin will attract the CO molecules rather than the O_2. The fatalness of CO exposure depends on the duration of the exposure and the concentrations of which the person are exposed to. Exposure to CO at levels above 300 ppm for more than 1-2 hours can lead to death, and exposure to 800 ppm can be fatal after an hour (ILPI, 2004). The threshold limit value of CO is 35 ppm (Griffin, 2004), which is equal to 40.1 mg/m^3. The concentrations in Kampala at 0.33 µg/ m^3 as a consequence of open burning of waste in Kampala, is then considerably below the threshold limit. Hence, there is no risk connected to inhalation of CO from these combustion processes.

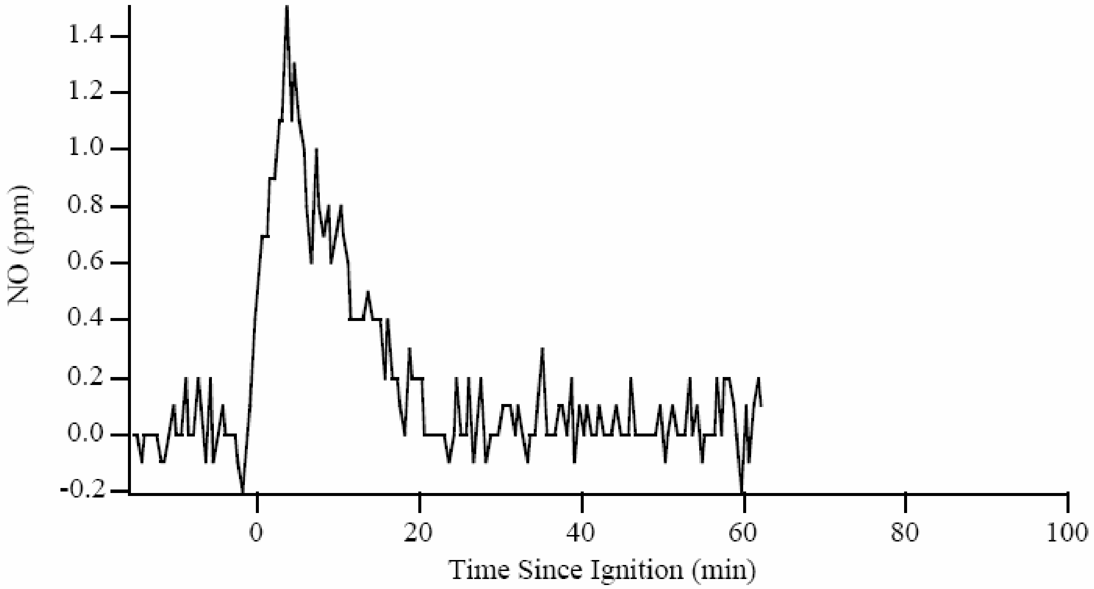


Figure 20: The emissions of NO from barrel combustion of household waste containing recyclable items. This figure is measured on basis of test 4 in the study, where that mount of waste ignited was 6.4 kg and the duration of the fire was 62 minutes (Lemieux, 1998).

The total emissions of NO during the combustion process can be estimated in the same way as in the case of CO. The

$$\text{By weight}: 19\ \text{ppm} \cdot \frac{30\ \text{g/mol}}{22.4\ \text{l/mol}} \cdot \frac{273\ \text{K}}{298\ \text{K}} = 23.3\ \text{mg/m}^3 \qquad [\ 11]$$

The amount of waste burned in test 4 in the study was 6.4 kg, and the duration of the combustion was 62 minutes. The emissions of NO per kg waste combusted are then 3.6 mg/m3. Combined with the assumption that 30 % of the non-collected waste is combusted outside, the total emissions of CO from the 77 400 tons of waste combusted will be:

$$77400000\ \text{kg waste combusted} \cdot \left(\frac{3.6\ \text{mg CO emitted}}{\text{kg waste combusted}} \right) = 2.79 \cdot 10^8\ = 279\ \text{kg} \qquad [12]$$

$$\text{The emission every hour will be: } \frac{279\ \text{kg}}{365\ \text{days a year} \cdot 24\ \text{hours a day}} = 0.032\ \text{kg/h} \qquad [13]$$

Assumed that the NO is equally distributed in the area of Kampala city up to 50 meters above ground, the resulting concentration will be:

$$\frac{0.032\,\mathrm{kg}}{(78500000\,\mathrm{m}^2 \cdot 50\,\mathrm{m})} = \frac{0.032\,\mathrm{kg}}{3925000000\,\mathrm{m}^3} = 8.2 \cdot 10^{-12}\,\frac{\mathrm{kg}}{\mathrm{m}^3} = 0.0082\,\frac{\mu\mathrm{g}}{\mathrm{m}^3} \qquad [14]$$

Based on the amount of air inhaled during one day by a human being in equation 1, the amount of NO inhaled by an average person will be:

$$22\,\frac{\mathrm{m}^3}{\mathrm{day}} \cdot 0.0082\,\frac{\mu\mathrm{g}}{\mathrm{m}^3} = 0.18\,\frac{\mu\mathrm{g}}{\mathrm{day}} \qquad [15]$$

The formation of NO is due to the nitrogen present in the material that is combusted. The temperatures necessary to form NO from nitrogen in the air, called the thermal NO_x mechanism, is 1300 ºC or higher, and such levels will not be reached in open burning (Van Loo et al., 2002).

The inhalation of the calculated concentrations of NO is not associated with any risk for human health. The emissions of NO are also contributing to the environmental problem of acid rain. The NO will react to NO_2 after some time in the atmosphere (Van Loo et al., 2002).

4.2.4 Open burning of excess bagasse

The combustion of excess bagasse in the fields represents an environmental problem because of the particulate emissions from the burning. It would be interesting to estimate the emissions of particulate matter from this process. However, no research has been done on open burning of bagasse in the fields. To estimate the emissions, the emissions from the boilers at one of the sugar factories can be used instead, because they don’t have any equipment for removal of particles. However, the quality of the combustion is much better under controlled circumstances than out in the fields, so the estimates made on this basis will be fairly conservative. The particulate emissions from boiler 1 at Kakira sugar works is 69 g/s. According to size boiler 1 consumes 26 % of the bagasse consumed for energy production at Kakira. The bagasse consumption a year in boiler 1 is then 74 620 tons. The consumption in one hour is 9.7 tons of bagasse. The emissions from boiler one in one hour is 248.4 kg particulate matter. The particulate emissions from 1 kg bagasse are then 25.6 g PM_{10}/ kg bagasse combusted. The excess bagasse produced at Kakira is 228 000 tons of bagasse and all of this is burned in the fields. Assumed that the emissions of PM_{10} in the fields are the same amounts as from the boilers, the emissions of PM_{10} from the burning of the excess bagasse will be:

$$\text{Emissions } 228\,000\,000 \text{ kg bagasse} \cdot 0.0256 \frac{\text{kg pm10}}{\text{kg bagasse}} = 5\,836\,800 \text{ kg} = 5\,837 \text{ tons/year} \qquad [16]$$

These emissions will be spread differently due to the wind and weather conditions throughout the year. Kakira employs 6000 people, and most of them live within the estate of Kakira (Polzin, 2004). There is no data available on the dominating wind direction, either not for the position of the main settlements, so there is not possible to make any conclusions on the risk associated with the emissions of particulates from this burning.

Figure 21: The existing treatment of excess bagasse in Uganda which is burning in the fields.

4.3 Exposure to indoor smoke from solid fuels

There are many studies showing correlations between respiratory diseases and exposure to smoke from the combustion of solid fuels. Another study by Ezzati et al. (2002) shows that indoor smoke from solid fuels contributes to 3.6 % of the mortality in developing countries. A study by Kammen et al (2001) focuses on the exposure from indoor combustion of biomass in Kenya. The households studied use charcoal and firewood as energy. The stoves used were simple, unvented stoves. The exposure of PM_{10} and CO were monitored in the study. The study shows that increased exposure to indoor PM_{10} increases the frequency of Acute Respiratory Infections (ARI). The rate of increase is highest in exposure levels below 1000-2000 μg/m^3. The aim should then be to reduce levels of exposure below 2000 μg/m^3.

5 The Ugandan crops

Residues from agricultural crops include a great number of materials, depending on the crop and the part of the plant. It can be straw of cereals, stover from maize and sorghum, maize cobs, coffee husks and bagasse (Sundstol, 1985). The amount available of the different crops will be determining for the theoretical energy potential from crop residues.

The crops grown in Uganda can be divided into two groups: the food crops and the cash crops (Uganda Bureau of Statistics, 2003). The food crops are grown for domestic use as food for the human population of Uganda, while the cash crops are grown for export, hence the term “cash crop” because these crops are delivering hard currency to the country.

The banana is the major food crop in Uganda, and it contributes to 44.7 % of the total volume of food crops[1] produced in Uganda. The other two most important food crops on volume basis are cassava and sweet potatoes, which contributes to respectively 24.5 % and 12 % of the total volume produced. These will be included in the analysis because of their great share of the total volumes produced. The other crops studied will be selected more because of the possibility to use the residues from the production as an energy source than because of their percentual share of the production volume. On this basis, maize, rice, Irish potatoes and ground nuts will be chosen for further studies. However, sweet potatoes and potatoes will be handled as one group because the residues from these crops are very similar in character.

The main cash crops grown in Uganda are coffee, tea and tobacco[2]. The production of sugar canes is neither regarded as a food crop nor a cash crop by the Uganda Bureau of Statistics (2003). Both coffee and sugar canes are interesting crops in terms of agricultural residues. The tea and tobacco industry are more interesting in terms of energy required for the processing of the crops than because of the residues from the crops itself.

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[1] The total number of food crops grown in Uganda is based on the crops included in the Statistical Abstract 2003 for Uganda. These crops are presented in Figure 22.

[2] The classification of what cash crops which belongs to the group of main crops are defined by the Uganda Bureau of Statistics (2003).

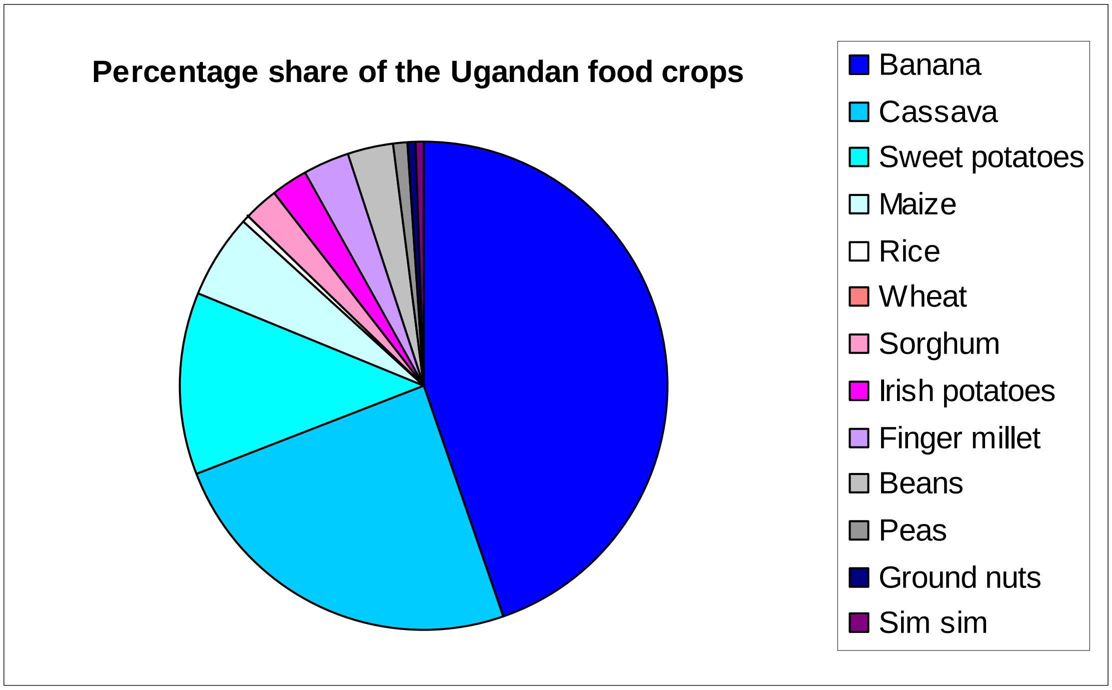

Figure 22: Percentual share of each of the Ugandan food crops out of the total food crops production of Uganda, based on data from Uganda Bureau of Statistics (2003).

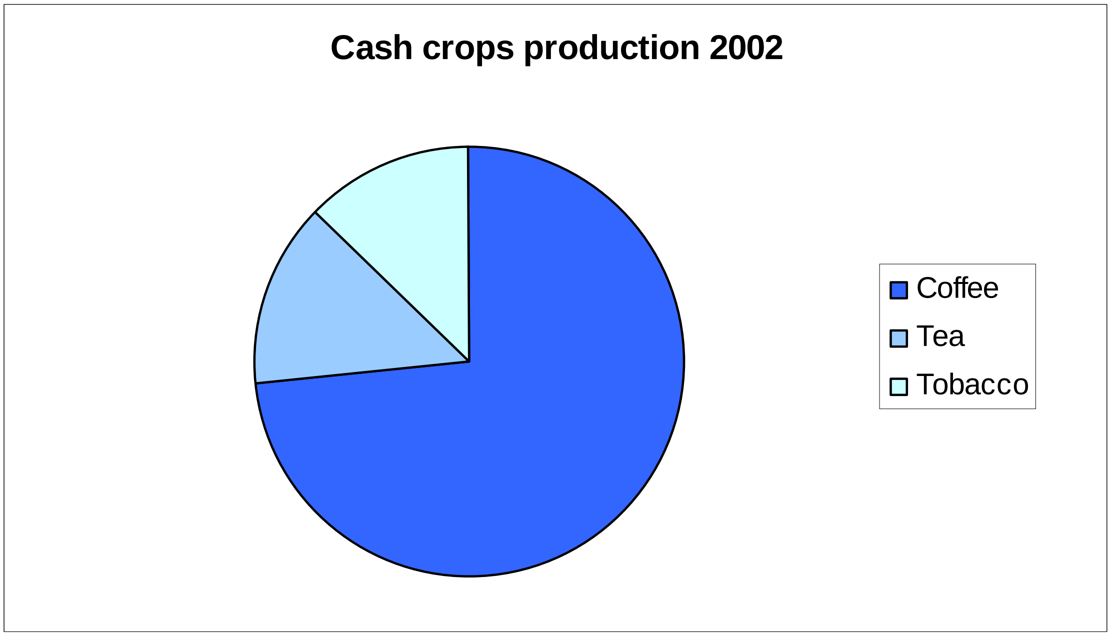

Figure 23: The percentual share of the main Ugandan cash crops produced in 2002, based on data from Uganda Bureau of Statistics (2003).

The residues from the crops can be divided into two groups: field residues and process residues (RWEDP, 2004). The field residues are generated in the fields during the harvesting, while the process residues are waste from further processing of the crops. The relationship between the crops and the residues are presented in Table 4 and Table 5.

Table 4: The relationship between some crops and the field residues generated from them. RPR is the residue to product ratio.

Field Residues			
Crop	**Residue**	**RPR**	**Moisture Content %**
Rice	Straw	1,76	13
Wheat	Straw	1,75	15
Millet	Stalks	1,75	15
Maize	Stalks	2	15
Cassava	Stalks	0,062	15
Cotton	Stalks	2,755	12
Soybeans	Straw + pods	3,5	15
Jute	Stalks	2	15
Groundnut	Straw	2,3	15
Tobacco	Stalks, etc.	2	-
Sugar cane	Tops/leaves	0,3	10

Table 5: The relationship between some crops and the process residues generated from them. RPR is the residue to product ratio.

Process Residues			
Crop	**Residue**	**RPR**	**Moisture Content %**
Rice	Husks	0,27	12
Maize	Cob	0,27	7 - 8
Maize	Husks	0,2	11
Coconut	Shells	0,12	8 - 9
Coconut	Husks	0,42	10
Groundnut	Husks	0,48	8,2
Oil Palm	Fiber	0,15	40
Oil Palm	Shells	0,065	10
Oil Palm	Bunches	0,23	50
Sugar cane	Bagasse	0,29	49
Coffee	Husks	2,1	15

To calculate the amounts of energy represented by the volumes mapped in the material flow analysis, the different heating values for the fuels have to be known. If the gross calorific value is known, the effective heating value (which is compensated for moisture content in the fuel) can be calculated by applying the simulation program Fuelsim (refer chapter 2.2.3). The necessary input information to do the simulations is gross calorific value and the element composition of the fuel. The calorific value is not known for all the residues involved, so the energy content of the fuel will only be calculated in cases where the calorific value is available.

5.1 Banana

The banana used most commonly in Uganda is the plantain banana that is mostly used to make the common dish called matoke. The banana consists of 35 % banana and 65 % banana peelings (Sentongo and Munyagwa, 2004). This is the most important crop when it comes to total volumes produced a year (refer Figure 22). The production of banana in 2003 was 9 605 000 tons, and 6.2 millions of this are banana peelings.

5.2 Cassava

Both the cassava root and the leaves are utilized for human food. The leaves are attractive for nutrition because of the relative high content of protein. It is the highest producer of carbohydrates among the staple crops. Cassava is a perennial woody shrub which grows 1-3 metres high. It can be grown up to 2000 metres above sea level. The roots of the cassava plant are used for food in Uganda as they are, as well as ground as cassava flour. The cassava flour is often mixed with sorghum or finger millet, and further enriched with groundnuts (Balogun et al., 2004).

The residues generated from the cassava are mainly the stalks and later the peelings. The RPR for cassava stalks is 0.062 (refer Table 4). The production of cassava in Uganda in 2003 was 5 265 000 tons, and the stalk residues were then 326 430 tons.

5.3 Potatoes

The residues from potatoes are the stalks, which are field residues, and peelings which are process residues. The production in 2003 was 3 125 000 tons. The ratio potatoes-residues are however not known, so only approximate values are available. Assumed that 10 % of the potato is skin, the amount of potato skin produced will be 312 500 tons.

5.4 Maize

Maize is the third most important food crop in the world, and is also grown widely in Uganda (Salvador, 2004). Unlike coffee and banana, the maize plant is annual, so the whole plant is harvested, which means that the straw also becomes a residue.

The production of maize in Uganda in 2003 was 1.2 million tons. The stalks produced at the same time was 2.4 million tons, due to the RPR for maize to stalk at 2 (refer Table 4). The RPR of maize to cob is 0.27 (refer Table 5), which imply a production of maize cobs in 2003 at 324 000 tons.

The net heating value of maize cobs is on average 14 MJ/kg (RWEDP, 2004). The theoretically available amount of energy from the maize cobs is then 3276 TJ or 910 GWh based on the available amounts of cobs at 324 000 tons.

5.5 Rice

The amount of rice produced in Uganda in 2003 was 109 000 tons. The RPR ratio of rice to rice straw is 1.76 according to Table 4, and the amount of rice straw generated was then 191 840 tons. During processing, the RPR of rice to rice husks is 0.27 (refer Table 5). Hence, the amount of rice husks produced in 2003 was 29 430 tons.

Rice husks are composed by the following materials: 47 % carbon, 6.7 % hydrogen, 45.8 % oxygen, 0.42 % nitrogen and 0.02 % sulphur and 0.109 % chlor (Lin et al., 1998). The theoretical available amount of rice husks is equivalent to 131 GWh of energy, based on the gross calorific value of rice husks at 4.44 kWh/kg (Lin et al., 1998).

5.6 Groundnut

The groundnut plant is harvested annually by pulling or digging up the roots from the soil. The stalks are removed from the nuts in the field and the RPR ratio is 2.3. The amount of groundnuts produced in Uganda in 2003 was 130 000 tons, and the amount of stalks was then 299 000 tons. The next step is called stripping where the groundnuts are removed from the haulm, which is often done by hand. The shelling can also be done by hand depending on the final use of the nuts. If they are utilized for peanut butter or crushed to make g-nut sauce, the shelling is often carried out by a mill, while hand power is usually the method for direct use in households (ITDG, 2004). The RPR of ground nut to shell or husks is 0.48 (refer Table 5) and the quantity of husks produced in 2003 is then 62 400 tons.

The groundnut shells or husks are well suited for energy purposes theoretically. The element composition of groundnut husks (measured as “dry ash free”) is 50.9 % carbon, 7.5 % hydrogen, 40.4 % oxygen, 1.2 % nitrogen and 0.02 % sulphur. The moisture content of the husks was 7.9 % as received by the analysts (Werther et al., 1998). The theoretical available amount of ground nut husks are 62 400 tons, which represents an energy content of 373 GWh by applying the gross calorific value of 5.98 kWh/kg (Werther et al., 1998).

5.7 Coffee

The coffee bean used to be the main export product of Uganda, but the share of exports of coffee has been declining the last years, mainly because of increased exports of fish (Hofsvang, 2004). However, the world coffee market has also been declining in a period, with lower coffee prices as a result. There has also been a problem with the coffee wilt disease and periods of drought (Nturanabo, 2001). These factors have contributed to the closing down of some coffee plantations and factories.

There are two commercially grown coffee species and they are named Arabica and Robusta and are both found in Uganda. Robusta is suitable for lower-lying areas and are regarded as quite easy to grow, while the Arabica needs to be grown the highlands (Chacko, 2004). In Uganda the most commonly grown specie is the Robusta. The distribution between these two species for the years from 1998 to 2002 is shown in Table 6.

Table 6: Production of Robusta and Arabica coffee in Uganda in the period between 1998 and 2002 (Uganda Bureau of Statistics, 2003).

Coffee Production in Uganda			
Year	**Robusta**	**Arabica**	**Unit**
1998	180684	24372	tons
1999	208764	27482	tons
2000	130358	24342	tons
2001	166729	30681	tons
2002	184404	25142	tons

The coffee beans are harvested from the coffee plant when they are ready. They are either dried while still hanging on the bush or they are dried later. The coffee husks are removed in a factory most commonly situated immediately nearby the fields. Then, the beans are sent for further processing at a coffee factory. The coffee factory sorts out the unshelled coffee beans that still remain in the mixture of beans, and then the beans are sorted after quality. After this step they are ready for export. The further processing of the coffee beans are undertaken in the country of destination (Chacko, 2004).

Most of the coffee produced in Uganda is exported. In 2002, which is the year the MFA will be based on, the exports were 95.5 % and the domestic use of the coffee was at 4.5 %. The coffee production in Uganda in 2002 was approximately 210 000 tons (Uganda Bureau of Statistics, 2003). According to Chacko (2004) 45 % of the coffee beans are coffee husks. That means that in the production of these 210 000 tons of coffee beans ready for export, 172 000 tons of coffee husks were produced.

The consumption of coffee husks at Uganda Clays is 7 tons of coffee husks a day, and the factory operates 365 days a year. The consumption of coffee husks is then 2555 tons a year. When the extension is finished, assumed that the capacity will be doubled, the consumption of coffee husks will be 5110 tons. The factory just opposite the road, Kajjansi Bricks and Tiles Works, also utilize coffee husks in their production process. They use two and a half lorry-loads (10 t lorry) of husks per week, which is approximately 5 tons of husks per lorry load. The consumption of husks a year is then 650 tons. The consumption of Hima Cement is 6 400 tons a year (refer chapter 3.2.3). The total consumption of coffee husks in Uganda now is then 9600 tons of coffee husks, and when the new kiln at Uganda Clays is ready the consumption will be 12 200 tons a year. Out of the total production at 172 000 tons, there are still 160 000 tons available for utilization. 7 % of the coffee husks produced are by now utilized for energy purposes.

The element composition of coffee husks is (measured as “dry ash free”) 43.9 % carbon, 4.8 % hydrogen, 49.6 % oxygen, 1.6 % nitrogen and 0.1 % sulphur (Werther et al., 1998). The moisture content of the husks is not measured neither by the suppliers or the users visited in Uganda (Chacko, 2004; Kayando, 2004). However, according to RWEDP (2004), the moisture content of coffee husks is 15 %. The theoretically available amount of husks at 160 000 tons is equivalent to 738 GWh by applying the gross calorific value at 4.61 kWh/kg (Werther et al., 1998).

5.8 Sugar cane

The average sugar content of the sugar canes is 9.3 % (Burning bagasse, 2004). The bagasse content of Ugandan sugar cane is depending of the area of growing. The Kakira Sugar Works operates with a bagasse content of 45 % (Polzin, 2004), while the bagasse content at Kinyara Sugar Works is 40 % (Jobling, 2004). The content of molasses is approximately 3 % on cane (Hugot, 1972).

5.8.1 Kakira sugar works

Total production at Kakira sugar works in 2004 is 3500 tons of sugar cane processed every day. The factory operates at this level 10.5 months a year. The total production in 2004 will be 1 145 000 tons of sugar cane processed. The bagasse content of the sugar cane varies according to subspecies. The one applied at Kakira now is a so called high fiber cane which consists of 45 % bagasse. The bagasse produced in 2004 will then be 515 000 tons.

The factory is operated 320 days a year, 24 hours a day. 1 kg bagasse is required to produce 2 kg steam, and the steam demand of the factory is 50 % on cane.

$$\text{Steam needed}: \frac{1\,145000 \text{ tons of sugar cane processed}}{2} = 573000 \text{ tons of steam}$$

$$\text{Bagasse needed}: \frac{573000 \text{ tons of steam produced}}{2} = 287000 \text{ tons of bagasse}$$

The excess bagasse produced is then 228 000 tons. The production of molasses is 34 350 tons in 2004.

5.8.2 Kinyara

Kinyara process 115 tons of cane an hour, which is 889 000 tons of cane crushed a year. The cane to bagasse ratio at Kinyara is 40 %, a bit less than that of Kakira. The amount of bagasse produced a year is then 356 000 tons of bagasse. The steam demand of the factory is 45 % on cane, which means that the annual amount of steam produced is 400 000 tons.

$$\text{Bagasse needed} : \frac{400000 \text{ tons of steam produced}}{2.19} = 183000 \text{ tons of bagasse}$$

The excess bagasse produced is then 217 000 tons a year. The production of molasses is 26 670 tons in 2004.

5.8.3 Sugar Cooperation of Uganda Limited Scoul

The production volume at SCOUL was 36 000 tons of sugar cane processed in 2002. The bagasse content of 45 % make this 16 200 tons of bagasse produced a year, and the excess bagasse produced is 7200 tons. The production of molasses is 1080 tons.

Figure 24: Excess bagasse at Kakira sugar works

According to Uganda Bureau of Statistics (2003), the total production of sugar in 2002 was 168 000 tons. This is equivalent to 1 800 000 tons of sugar cane. This imply a level of excess bagasse at 360 000 tons, assumed that the general bagasse content is 45 %. The numbers calculated for each of the three factories add up to 452 200 tons of excess bagasse for 2004. The total production of molasses is 62 100.

Bagasse is a cellulosic material, and is consisting of peripheral fibers enclosing a soft, central pith (Nassar et al., 1996). The moisture content of bagasse is around 50 % when it leaves the factory. The calorific value of bagasse at 50 % moisture content is 9.1 MJ/kg (Nassar et al., 1996), while the gross calorific value of dry bagasse is 18.9 MJ/kg. The sulphur content of bagasse is practically at 0, a fact that make bagasse well suited as energy source. An element analysis of bagasse shows that it consists of 51.7 weight % carbon, 6.3 % hydrogen and 42.0 % oxygen. The available excess bagasse at 452 000 tons a year represent 2374 GWh of energy by applying the gross calorific value of bagasse at 5.25 kWh/kg (Hugot, 1972).

6 MFA of some Ugandan crops

Material flow analysis will be used to map the flow of some important agricultural products of Uganda. According to the methodology in general (refer chapter 2.2.1), the analysis will include both the crop itself and all its components. The components that are included in the system boundaries will vary according to the properties of the specific crop. Some crops are annual and the whole plant is harvested at a time, while others are perennial with the consequence that only the eatable item itself is harvested. These differences are important when deciding the system boundaries for the different crops. The material flow analysis will provide an improved understanding of where the different parts of the crops are ending and combined with information on the energy content of the different streams, the most important flows with regards to energy can be detected. The material flow analysis will also provide information on whether the materials flowing are utilized in a proper way today or if there is a potential for improvement.

In the specific case of the crops mapped in this thesis, the main input factor is Domestic Extraction (Figure 4). The other input factor is imports, but the imports of the studied crops to Uganda are not significant (Uganda Bureau of Statistics, 2003), so domestic extraction remains as the only input factor as long as there are no hidden flows. The time limit of the material flow analysis will be set to the year of 2003. Note that the volumes used for the category of cash crops dates from 2002, because this is the newest data available. The aggregation of stocks in the period of one year is regarded as insignificant when it comes to the crops itself. Agricultural products are fresh products and in an economy like the Ugandan the rate of consumption of the food are the same as the rate of production. The urban population of Uganda is at 12 % (Uganda Bureau of Statistics, 2003), and it is only a small share of the urban population who has the possibility to store larger quantities of foods for a long period of time. Besides, the stocks itself are not important regarding the purpose of the MFA in this context, which is to develop options for the use of biomass residues as a source of energy. There are four Ugandan crops which are regarded as cash crops, which mean that these crops are exported. These crops are coffee, tea, cotton and tobacco, and they are the only crops were exports are an important output in the MFA. Apart from the standard system boundary mentioned above, the MFA in this thesis will be limited to the economy of Uganda. Then, the total system boundary for the MFA will be:

- The MFA includes the metabolism of the materials taking place in the technosphere.
- Geographically the MFA is limited to Uganda.
- The MFA is limited to the year 2003 for the food crops, 2002 for coffee, and 2004 for sugar cane.

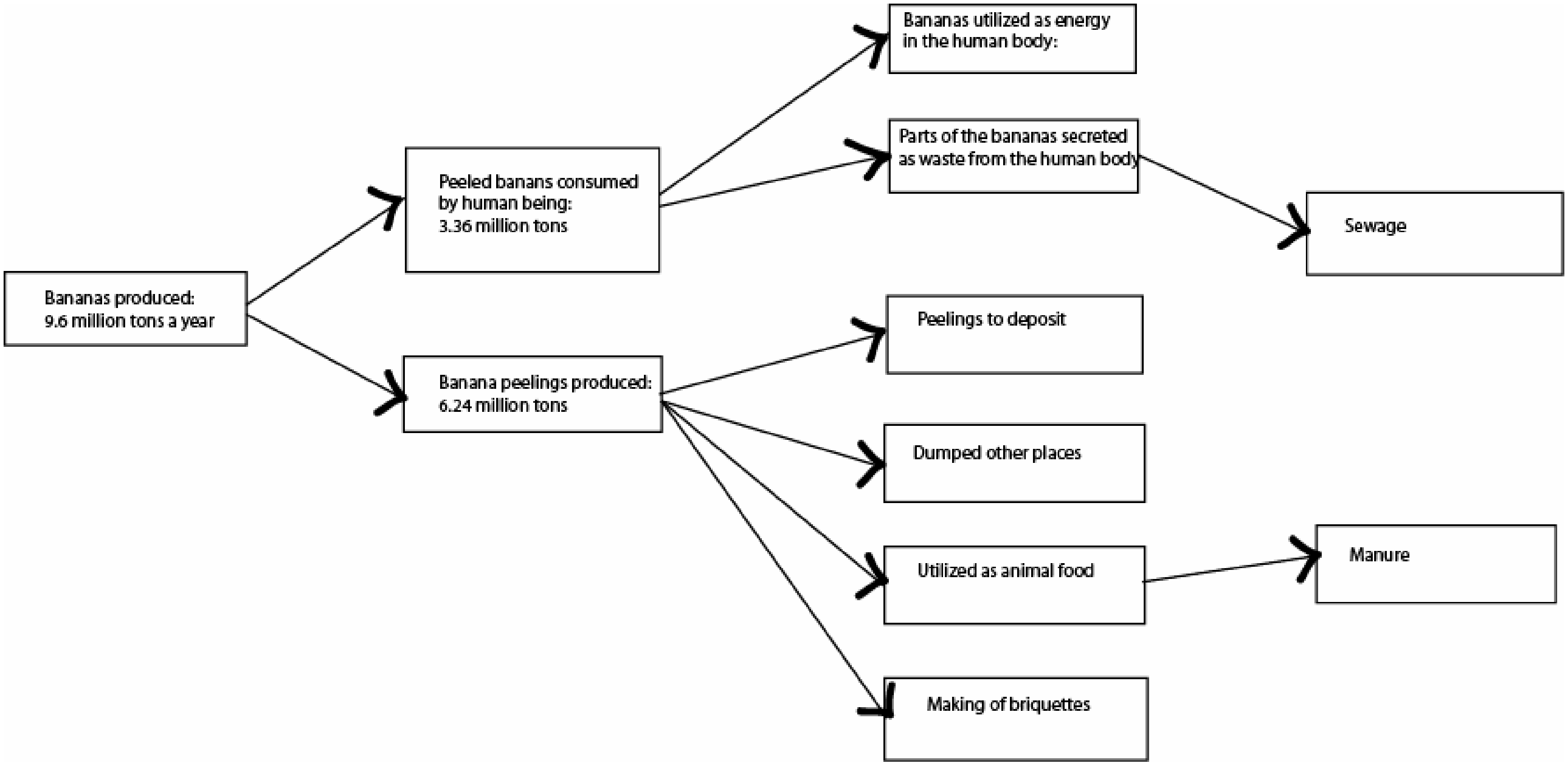

Figure 25: MFA, plaintan bananas in Uganda, 2003.

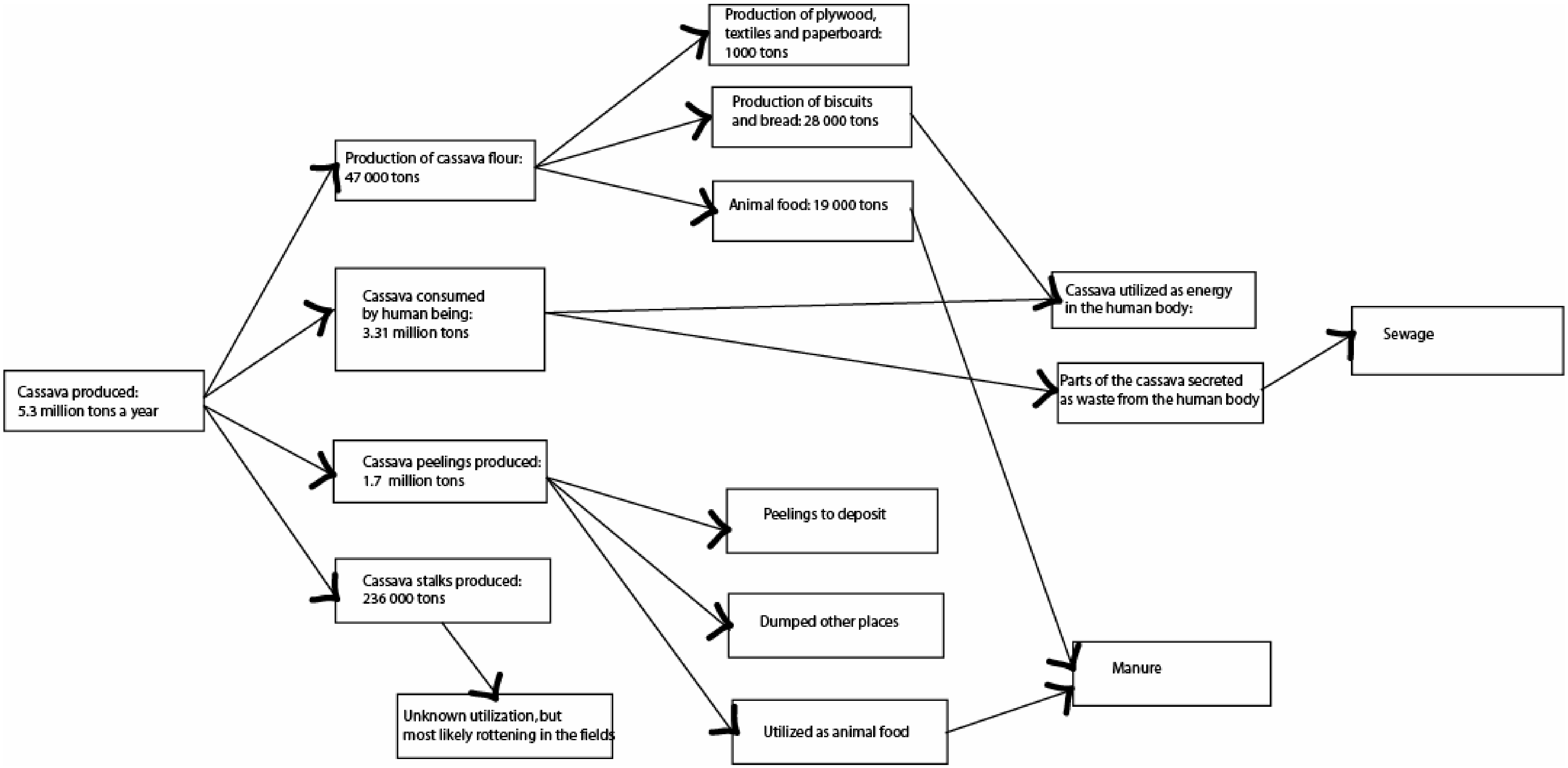

Figure 26: MFA, Cassava, Uganda, 2003.

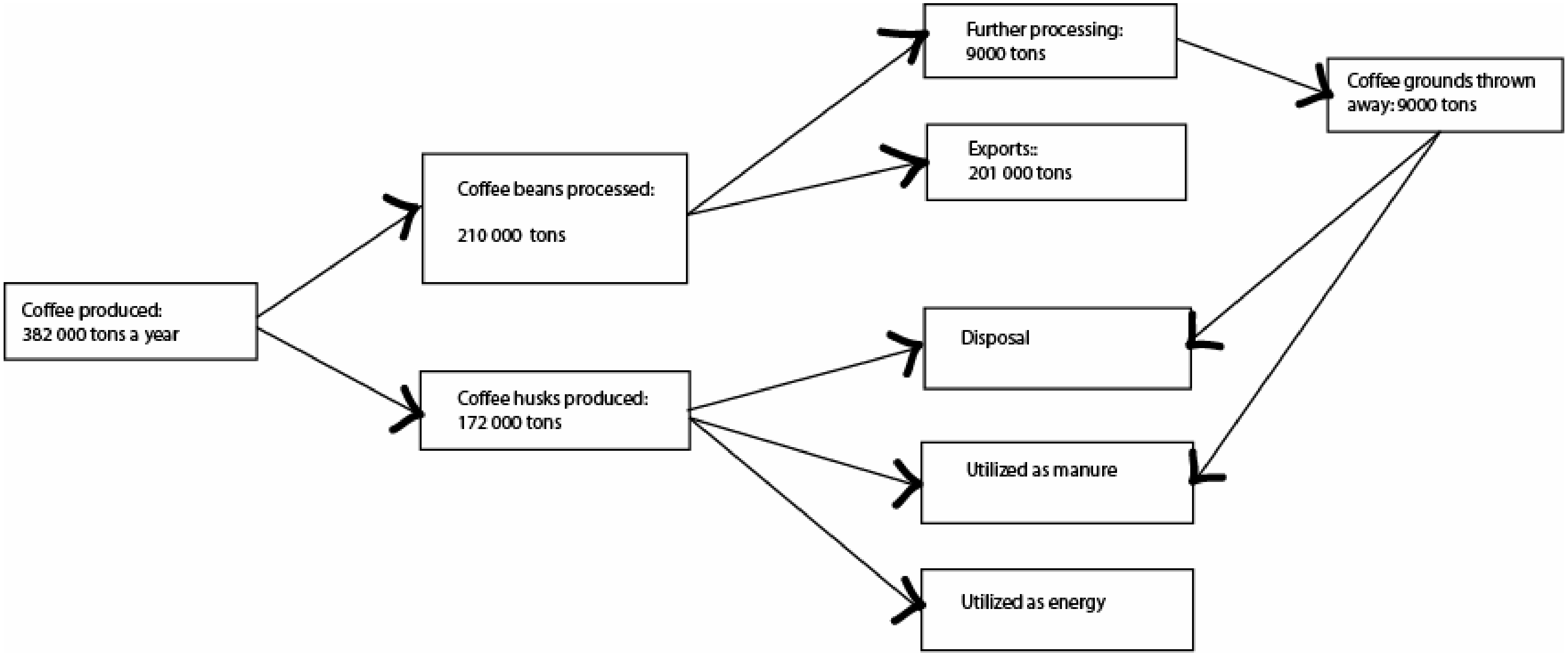

Figure 27: MFA, coffee, Uganda, 2002.

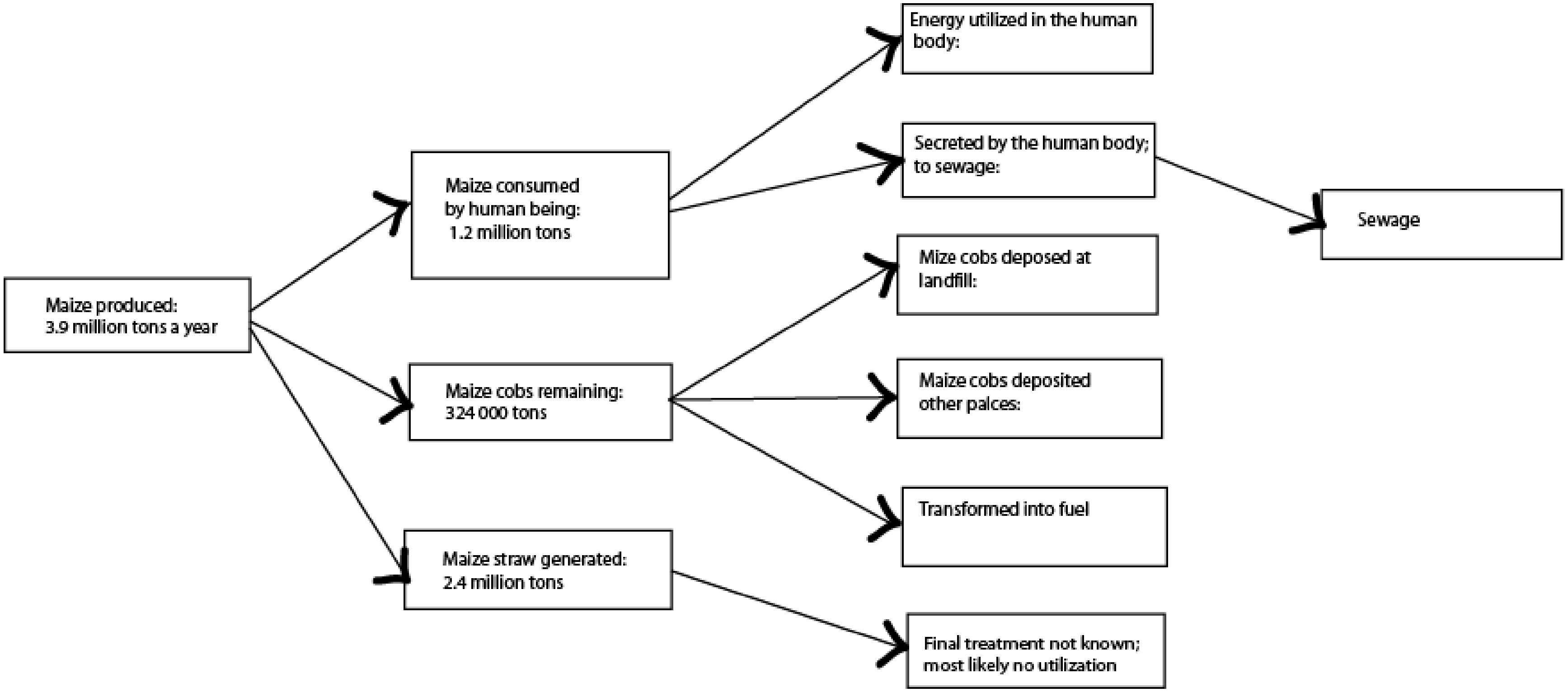

Figure 28: MFA, maize, Uganda, 2003.

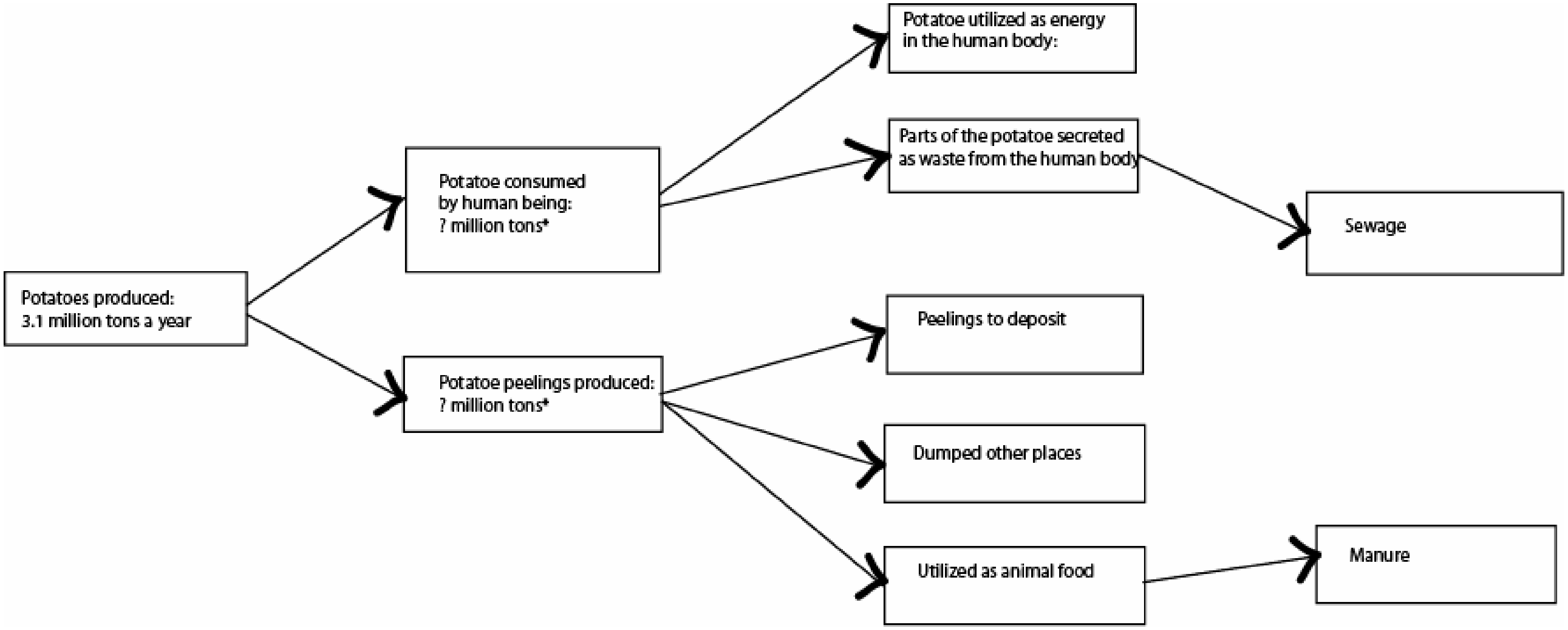

*Figure 29: MFA, potato, Uganda 2003 *The RPR of potato-potato peelings is not known.*

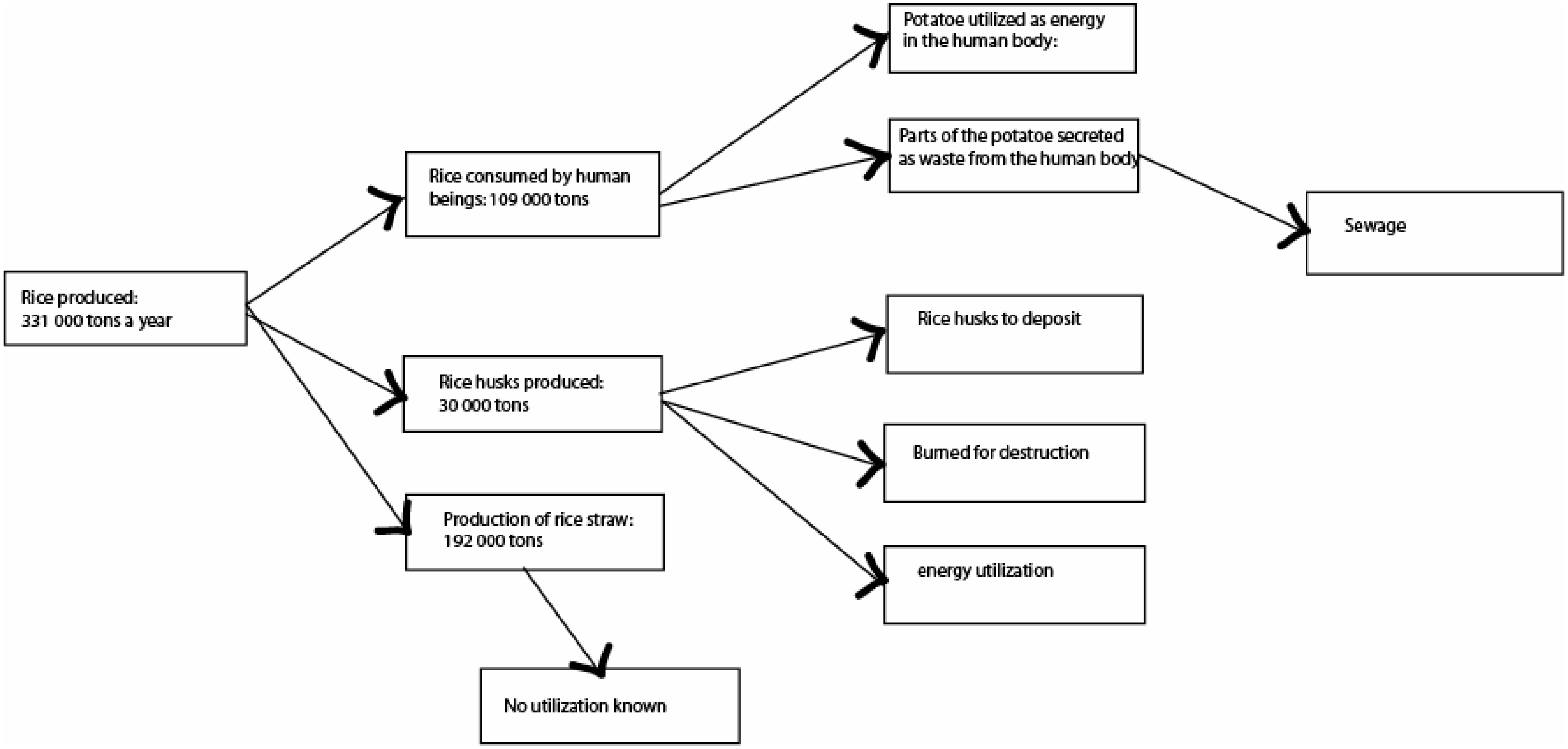

Figure 30: MFA, Rice, Uganda, 2003.

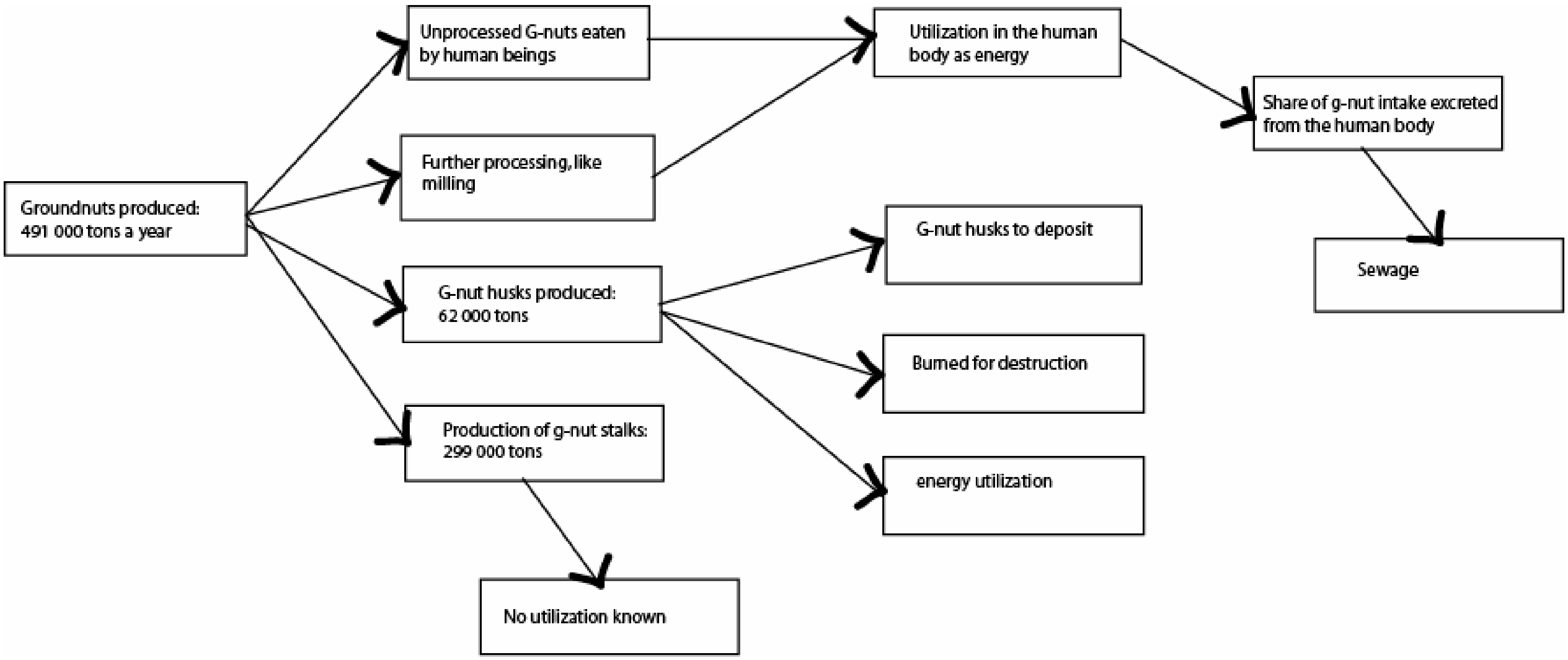

Figure 31: MFA, Ground nuts, Uganda, 2003.

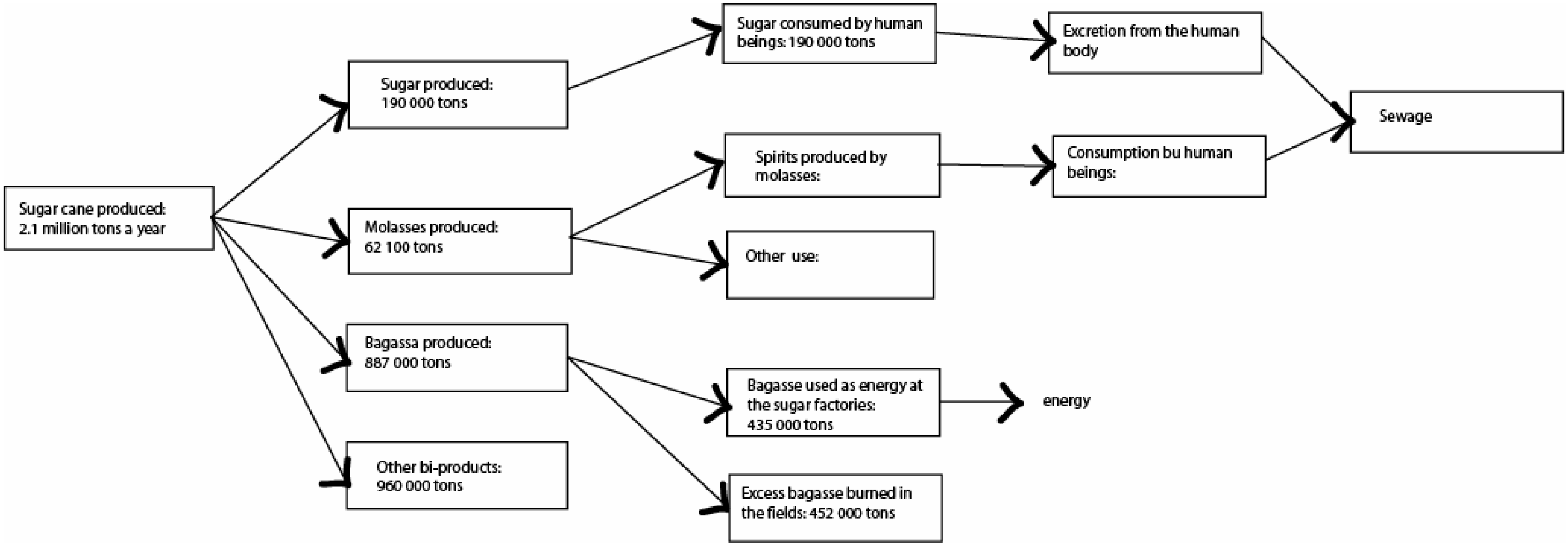

Figure 32: MFA, sugar cane, Uganda, 2004.

7 Results MFA

The figures from Figure 24 to Figure 32 show the material stream analysis of the crops studied in this thesis. There are only some of the streams where there is available data material to calculate energy content. It has not been possible to quantify the share of the crop that is ending up as waste material from the human body, but the maps provide an idea of the whole picture of the issue. The idea is to visualize that even the sewage is consisting of a share of the energy that originally entered the technosphere as a part of an agricultural crop. The sewage also represents a possibility for energy utilization, of where a share of the energy is originating from the energy in the crops. However, the sewage will not be a part of the topic in this thesis. The streams where there are available data on energy content will be discussed further, to find out more of their ability for energy utilization.

The theoretical available volumes of the most important crop residues were mapped in chapter 5, and the energy content of some of the residues were calculated. To get an idea of the real potential of these residues as an energy source, it can be interesting to compare the biomass energy currently consumed in Uganda and the potential represented by some biomass residues. The consumption of charcoal and firewood in 2001 measured in TWh based on the gross calorific value is compared with the potential of some residues (refer Table 7) in Figure 33. The consumption of firewood is much larger than the potential of the residues available. The consumption of firewood and charcoal totals to 97.5 TWh, while the crop residues represent 4.5 TWh. Hence, the theoretically available crop residues constitute to 4.6 % of the firewood and charcoal currently consumed. The potential is then not large enough to be a realistic alternative to the present consumption, but it can serve as a useful supplement to firewood. Some alternatives for utilization will be presented in the following chapters.

*Table 7: The potential of some important agricultural residues, based on the calorific values of dry matter. The Effective heating value is calculated in Fuelsim based on the gross calorific value and the moisture content. a) Gross calorific value, dry bagasse (Hugot, 1972) b) Higher heating value, dry (Werther et al., 1998) c) Higher heating value, dry (Lin et al., 1998) d) Net, heating value (RWEDP, 2004).*based on the net heating value of maize cobs. e) Polzin, 2004 f) RWEDP, 2004 g) Lin et al., 1998 h) Werther et al., 1998*

Potential						
Biomass	**Potential [tons]**	**Gross Calorific value [kWh/kg]**	**Effective heating value [kWh/kg]**	**Energy, Calorific value [GWh]**	**Energy, Effective heating v. [GWh]**	**Moisture content [%]**
Bagasse	452200	5.25[a]	2.09	2374.1	945.1	50[e]
Maize cobs	234000	3.89[d]	2.88	910.3*	673.9	15[f]
Rice husks	29430	4.44[c]	3.61	130.7	106.2	9[g]
Coffee husks	160000	4.61[b]	3.57	737.6	571.2	15[h]
Ground nut husks	62 400	5.98[b]	5.19	373.2	323.9	7.9[h]

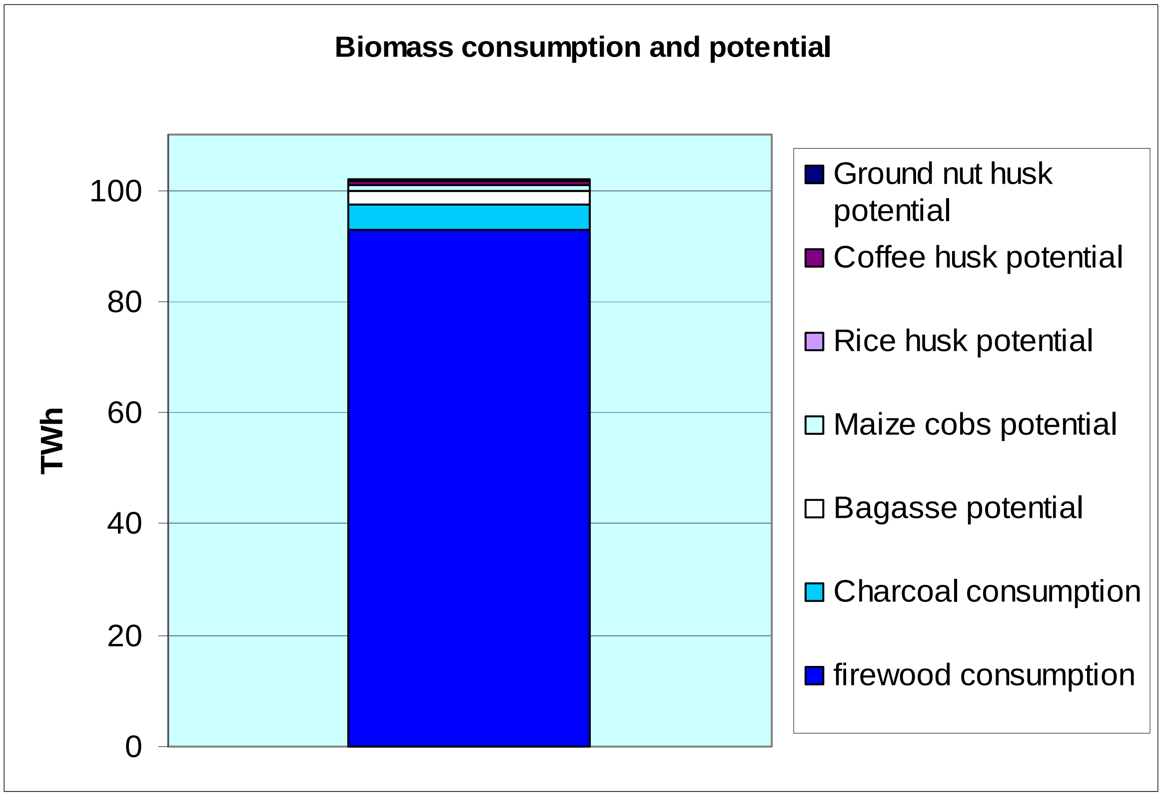

Figure 33: The consumption of firewood and charcoal in 2001 compared by the potential of some of the crop residues.

The energy content of the biomass residues are 2.6 TWh based on the effective heating values. This amount of energy represents 2.7 % of the total consumption of charcoal and firewood in 2001. In the effective heating value, the energy needed to evaporate the moisture content of the fuel is included. The energy content of the residues is significantly reduced when the moisture content is considered. As higher moisture level in the fuel, as greater savings can be achieved by predrying the fuel before it enters the combustion zone.

Drying can be done by drying the fuel in the sun. This method doesn't require any expensive technical equipment, but more manpower, which is quite cheap in Uganda. However, it is difficult to dry large quantities of biomass in the sun, and the sun isn't always there, a fact that will lead to fluctuations in the moisture content depending on the weather conditions. These fluctuations make it more difficult to regulate the combustion itself and make sure that the combustion conditions are optimal.

An alternative to dry the fuel in the sun is drying as a part of the process. Drying can be done either by recycling the flue gas, and let the rest of the heat dry the fuel, or by installing a system of drying where an independent burner is set up to dry the fuel prior to the combustion zone. Both of these solutions imply increased investment costs of the plant. More equipment is needed, and the process is getting a bit more advanced.

However, in the long term this cost will be justified by increased amounts of energy generated from the plant, which also means higher income.

8 Scenarios of utilization

The possibilities of utilization are depending on many factors. The technologically methods available is one aspect. The different residues have different calorific values, and their composition and shape are factors that make them more suitable for one technology than another. Another important aspect is the cost of the technologies. If the economic expenses of investment in one technology are too high, that technology will not be a realistic alternative to employ, even if it is the best alternative due to other requirements. Other important aspects of the technology are efficiency, environmental performance and its potential to be well adapted at the specific site of usage.

The possible options are also constrained by the amount of available residues as fuel for the technology. The theoretically available resources are described in chapter 5. However, there are many practical aspects that make it difficult to collect these resources. Their availability is depending on the way they are processed. The sugar cane is processed in three different factories, so the bagasse is produced at three specific sites, while peelings from sweet potatoes are generated in every household throughout the country, hence making it difficult to collect the reources.

The practical barriers of utilizing the existing resources are summarized in Table 8. Some of the groups of residues have a similar set of practical barriers of utilization. Banana peelings, cassava peelings, potato peelings and maize cobs are all generated several of places around the country, making it difficult to collect the resources. These resources are not processed industrially. These facts are the reasons why there haven’t been done so many studies on utilizing these resources for energy, while there has been done significantly more on the other residues, like rice husks, coffee husks and bagasse because of the availability of these resources. These differences make it advantageous to group the non-industrial residues in one group. In the area of Kampala where the MSW already is a part of the scope of this thesis, these groups of residues will in most cases be included in the MSW. In other areas, large scale utilization will be difficult because of the numerous sources and already existing utilization alternatives as animal fodder. Therefore, large scale energy utilization of these crops can be regarded as unrealistic.

Currently there is not any large scale utilization of banana peelings in Uganda. However, there are possibilities for utilization. The banana peelings are rarely processed industrially. The bananas are peeled wherever they are used, whether it is markets, restaurants, households or hotels. This means that there are many small sources of banana peelings waste, and there is no existing system were banana peelings are sorted out from other waste or collected. These facts make it difficult to collect the banana peelings, making the practically available amount of banana peelings significantly lower than the theoretical.

Rice husks are process waste (refer chapter 5.5), and are generated where the rice are processed. Usually these sites are factories immediately nearby the fields where the rice is grown. It has not been possible to quantify the number of processing sites, but the number is most likely in the same order of size as with coffee processing plants.

The coffee husks are generated at two stages in the coffee refinement process. The first step is the coffee processing plants in relation to the fields where most of the husks are removed. These sites are scattered around the country. Then there are some factories where the coffee is sorted after quality and made ready for export. Some of the beans are still unshelled, and there are some husks among the shelled beans. These factories don't generate that much husks. According to UCDA (2002) there are 60 farmers associations organized in the Uganda Coffee Development Authority. Some of these deliver to the same coffee processing plant, so an estimation of the coffee mills where most of the husks are generated is around 30. Then there are 30 registered exporters, where some husks also are generated. However, 18 of those have a market share below 2 %, which imply numerous sites where only a limited amount of coffee husks are produced (UCDA, 2002). This is one of the reasons that make it difficult to gather all the coffee husks available, and contributes to reducing the realistic potential. The realistic potential of coffee husk utilization is estimated to 26 567 tons by Norplan (2003).

The sugar cane is processed at three specific sites. It is processed industrially, and the residue product, bagasse, is then produced at the same sites. This means that it is easy to collect the residues, so all the theoretical available amount of residues is also practically available.

Table 8: The practical barriers of utilizing agricultural residues. The number of transport stages is depending on the use of the residue. If bagasse is used to produce electricity at the factory, no transport is necessary. However, if charcoal is made out of bagasse, the coal has to be transported to the customers, so the transport stages will be more. In the column "possibility to process at site", processing in a single household is not regarded as enough to qualify to a realistic possibility, because the volumes will be too small to be a real alternative.

The possibility to collect the theoretically available residues			
Residue	**Number of production sites**	**Possibility to process at site**	**Number of transport stages necessary**
Banana peelings	thousands	No	2 or more
Cassava peelings	thousands	No	2 or more
Potato peelings	thousands	No	2 or more
Maize cobs	thousands	No	2 or more
Rice husks	unknown	Yes	1 or more
Groundnut husks	unknown	Yes	1 or more
Coffee husks	60	Yes	1 or more
Bagasse	3	Yes	0 or more

8.1 Alternative 1: Electricity production

It is possible to produce electricity from these residues by combustion. The heat from the combustion heats water in boilers, and then electricity can be produced from the steam generated. It is possible to produce heat, heat and power (cogeneration) and only power from these resources. The technology which is suitable for this purpose depends on the size of the plant. For smaller plants in the range from 50 kW electricity generation capacity to 1 MW, steam engines represent the best alternatives. Steam turbines are available in the range from 0.5 MW to more than 500 MW. The efficiency of electric power production from biomass is approximately 20-30 %, so an average of 25 % is used in the calculations (Van Loo et al., 2002). The upper heating value is used as input factor for the calculations in Fuelsim, but combined with the moisture content of the fuel, the effective heating value is what is used in these calculations. In other words, it means that no predrying is done to the fuel before combustion. This is a realistic assumption because drying might be an economically or technical barrier (refer chapter 7). As an example, no drying is done to the bagasse in the sugar factories today, so the bagasse is burnt directly with its moisture content at ca. 50 %.

The equatorial climate in Uganda doesn’t require any heating of ordinary houses where people are living. The only case where there is a need for heat is as process heat is in factories. The efficiencies achieved by such plants are higher when both electricity and heat are produced and not only electricity, so the output of usable energy will be higher per kg of biomass input by choosing cogeneration.

8.1.1 Rice husk

The technical potential of utilizing rice husks is 9760 tons according to Norplan (2003). The fuel rate in a hypothetic combustion plant will be 3360 kg/h based on the theoretically available resources (29 430 tons), while the practical available resources will result in 1114 kg/h. The heat output from the theoretical amount of resources will be 12 316 kW (effective heating value) by calculation in Fuelsim (2002). By assuming 25 % efficiency of generating electricity from the heat, the power output will be 3 404 kW, and the energy produced in one year will be 29.8 GWh. The calculation of the output from the practically available resources results in 4083 kW heat out put (effective heat value), and 1128 kW assumed electricity generation at 25 % efficiency. The energy output from that effect level will be 9.88 GWh.

8.1.2 Groundnut husk

The amount of g-nut husks produced in 2003 was 62 400 tons, which is equivalent to 7123 kg/h. the effective heat output value is calculated by Fuelsim (2002) to 33 071 kW. If the heat is used to produce electricity, the effect capacity will be 9 107 kW by 25 % efficiency in the heat to electricity transfer. The amount of electricity produced a year will then be 79.8 GWh.

8.1.3 Coffee husk

The theoretically available amount of coffee husks is 160 000 tons (refer chapter 5.7). The coffee husks already in use are not included in this number. Assumed that this amount is fired in a combustion plant, the hourly feeding rate will be 18 265 kg/h. The heat output (based on the effective heating value) is then 54315 kW, calculated in Fuelsim (2002). Assumed an efficiency of 25 % heat to electricity conversion, the effect of electricity generation will be 15033 kW. The electricity generated a year will then be 131.7 GWh, provided maximum capacity, 24 hours a year.

However, the realistic utilization level of coffee husks is 26 567 tons, which means that only 14 367 tons still is free for utilization. The feeding rate of a combustion plant will then be 1640 kg/h. The output is then 4877 kW heat, and 1350 kW electricity, assumed the same conditions as above. The energy output in generated electricity will then be 11.8 GWh.

8.1.4 Bagasse

Production of electricity from bagasse is the only established way to utilize the energy potential in the bagasse in Uganda today. All of the three sugar factories in Uganda generate electricity from bagasse to fill the demand for electricity at their own factories and estates. This technology is described in detail in chapter 3.2.2 where the existing technologies for biomass utilization in Uganda are presented.

As an example of the amounts of energy possibly generated from bagasse, the currently production at Kinyara Sugar Works can be calculated. The turbines at Kinyara are operated 46 weeks a year, which is 7728 hours (refer chapter 3.2.2). Additionally, the turbines are stopped every third week for maintenance work, which means that they are shut down 15 times during those 46 weeks a year. Each of these times they are turned off for 16 hours. Total maintenance time is then 240 hours. Summarized, this mean that the turbines are operated 7488 hours a year, both at 750 kW load. The electricity produced is then:

$$\text{El produced}: 1.5\,\text{MW} \cdot 7488\,\text{hours} = 11\,232\,\text{MWh} = 11.2\text{GWh}$$

This energy is consumed by the factory itself and the surrounding estate of Kinyara, where the schools, hospital etc. provided by the firm are supplied by electricity produced here.

To produce this amount of electricity, the consumption was 183 000 tons of bagasse. Assumed that electricity was produced out of all the bagasse available, and that the efficiency levels were the same as in these calculations, the electricity produced could be:

$$\frac{\text{Amount of electricity possibly produced}}{\text{Total amount of bagasse produced in Uganda}} = \frac{\text{Electricity produced at Kinyara}}{\text{Bagasse consumed at Kinyara}} \qquad [17]$$

$$\text{El possibly produced}: \frac{11.2\ \text{GWh}}{183000\ \text{tons of bagasse}} \cdot 452200\ \text{tons of bagasse} = 27.7\text{GWh} \qquad [18]$$

The amount of electricity generated in Uganda in 2002 was 1701.7 GWh. The possible production level of electricity from bagasse is then only 1.6 % of the amount of electricity generated in Uganda in 2002.

This is a very conservative estimate, and by more efficient technology, a higher amount of electricity can be produced out of the same amount of bagasse. According to Bhattacharyya (2004) an efficient boiler and turbine system could turn three kilograms of bagasse into one kWh of electricity. If such efficient systems were applied in Uganda, the excess bagasse of 452 200 tons could produce 150.7 GWh, which is considerably more than the estimate of equation 18.

Table 9: Electricity generation potential from some agricultural residues

Comparison, utilization of agricultural residues		
	Teorethical potential [GWh]	**Practical potential [GWh]**
Electricity from bagasse	150.7	150.7
Electricity from coffee husks	131.7	11.8
Electricity from g-nut husks	79.8	0
Electricity from rice husks	29.8	9.9
Total	392	172.4

The total amount of electricity generated from these four residues is 392 GWh from the theoretical available residues. The total amount of electricity produced in 2002 was 1702 GWh (Uganda Bureau of Statistics, 2003), so the electricity generating potential is representing 23 % of the current electricity potential in Uganda. The realistic potential is representing 10 % of the electricity currently consumed.

8.1.5 Electricity generation from MSW

There are several opportunities for energy production form MSW. The most common and well proven method is combustion. Other alternatives are pyrolysis and gasification However, combustion is the only established technology for large size plants today (Sørum, 2000). One option is combustion of the waste and then electricity production. The hot gases produced by the combustion can be used to heat a boiler and produce steam to run steam turbines. If there are industries nearby where process heat is required, some of the heat can be delivered to fill these requirements by cogeneration of heat and power.

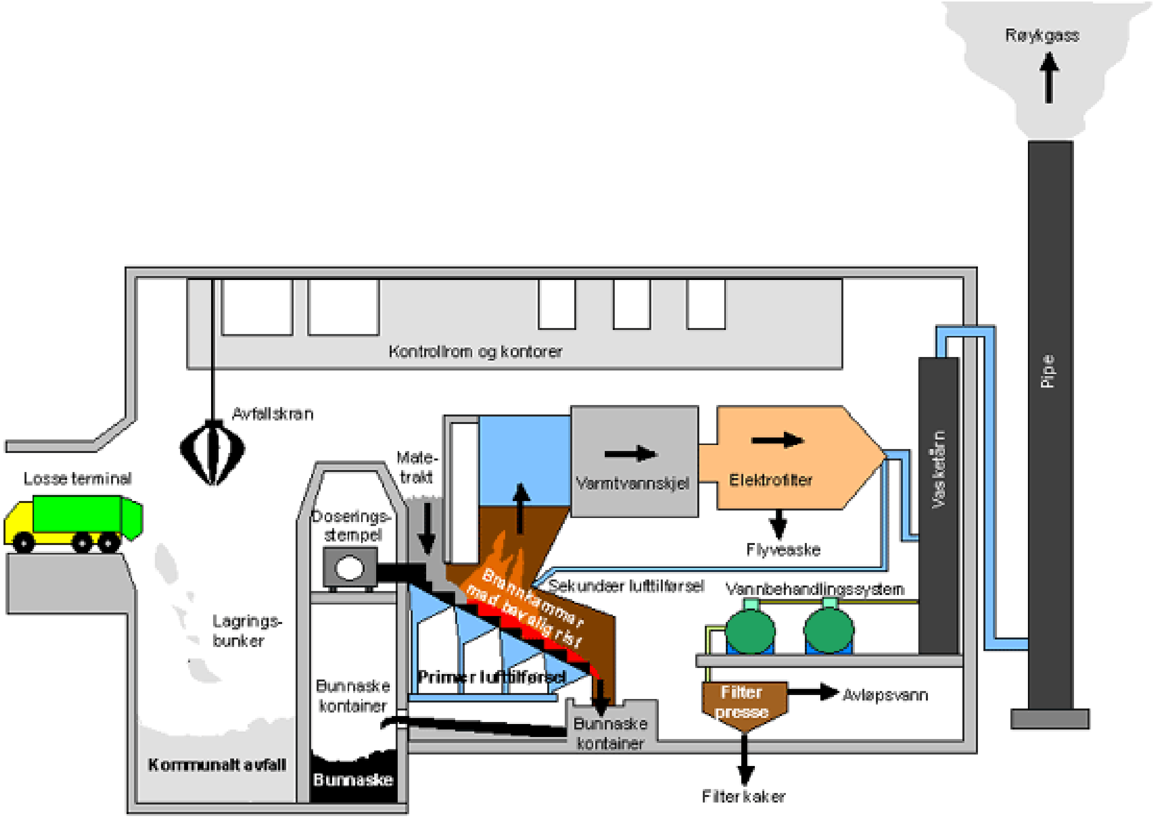

Figure 34: Schematic figure of a grate fired waste combustion system (Sørum, 2000).

One of the most well proven combustion technologies are grate fired combustion technologies, as shown in a schematic illustration in Figure 34. Such systems have advanced combustion control facilities to provide complete combustion and stable temperatures. In advance of entering the combustion zone, the waste can be mixed to improve the combustion properties (Sørum, 2000). This is also a tool to improve the possibilities to control the combustion process. After mixing, the waste is fed on a moving grate. The moving grate is formed like an endless band which is moving constantly through the combustion chamber. The waste is fed in one end of the grate, and then transported by the grate into the combustion zone (Van Loo et al. 2002). There is no mixing in the combustion zone itself by the moving grate system, so fuel mixing prior to the process is a necessity.

Another possibility is fluidized bed combustion. A fluidized bed system consists of a cylindrical vessel with a perforated bottom plate. The essence of such a system is the hot, inert material which is supposed to transfer the heat to the fuel. The bed material can be made up of materials like silica or dolomite, and represents a share of 90-98 % of the mixture fuel and bed material. This technique provides good mixing of the fuel and heat transfer and hence high combustion efficiency is achieved (Van Loo et al. 2002). The particle sizes of the fuel have to be kept low, so the fuel has to be treated prior to the combustion. Recyclable material has to be removed, like ferrous metals. Also glass, sand and aluminum can be removed to increase the calorific value of the fuel (Sørum, 2000). A fluidized bed system is quite costly both regarding investment and operation costs, so only combustion plants with boiler capacity above 30 MW are realistic (Van Loo et al. 2002). The need to install cyclones etc. to remove particles is one factor which is increasing the investment costs. The fluidized bed systems easily produce lots of dust because of bed material that is leaving the combustion chamber. The advantage of fluidized bed system is slightly higher efficiencies, but because of the high investment costs, such a system will be less suited for Uganda than cheaper technologies.

Table 10: The table shows the higher heating values of the waste compartments in the Kampala MSW and the total heating value of the mixed waste calculated on basis of the waste composition after removal of recyclable items. a) The heating value of polythene is used, because it is mainly this plastic that is deposed (assumed HHV)(DOW, 2004) b) The moisture content of the vegetable matter is 60-70 %, so the effective heating value is very low compared to the other compartments(Bionett, 2000) c) The value is based on forest saw dust from Sweden (Bionett, 2000) d) Assumed values on basis of the other values. . e) Warman, 1998 f) Baardsen, 2002.

Component	**Percentage composition after recycling [wt. %]**	**Higher Heating Value [MJ/kg]**	**Weighted heating value [MJ/kg]**	**Weighted heating value [MJ/kg]**
Vegetable matter	77,7	20,7[b]	16,09	16,09 [e]
Tree cuttings	8,4	19[d]	1,6	1,60
Street debris	5,8	13[d]	0,75	0,75 [c]
Paper	2,8	16,62	0,47	0,47 [c]
Metal	1,6	0	0	0,00
Saw dust	1,8	20,54[c]	0,37	0,37 [f]
Plastic	0,8	46[a]	0,39	0,39
Glass	0,9	0	0	0,00
Sum	100		19,67	19,67

The higher heating value of the MSW actual for combustion in Kampala is estimated in Table 10, based the HHV of every single of the MSW compartments. The HHV for MSW is used as basis for calculation of the electricity generation potential from MSW. The calculations are done in Fuelsim (2002), and the inputs were the HHV (Table 10) and the moisture content which is estimated to 47.64 %, based on values from the single compartments (Warman, 1998; Skreiberg et al, 2000; Baardsen, 2002). An efficiency of transformation from heat to electricity is set to 25 %. Three different scenarios of output is provided. All are based on steady growth rate in the capital population at 3.4 %, steady rate of waste production at 1 kg per capita and 5 % recycling rate. The first scenario is based on the theoretical available waste amounts provided 100 % collection rate. The second is based on the practically available amounts by applying the current collection rate at 39 %. The third scenario involves an increase of the collection rate by 5 percent points annually, starting at 39 % in 2004 and reaching 89 % in 2014. The results are presented in

Table 11 where the corresponding MSW volumes also are presented, while a graphical presentation is given in Figure 35.

Table 11: This table shows the potential for electricity generation from MSW. The level of waste generation in 2002 (KCC, 2002) is the basis for the calculations. Steady growth rate in the capital population at 3.4 %, steady rate of waste production at 1 kg per capita is assumed and 5 % recycling rate. 1) The theoretical available waste amounts provided 100 % collection rate. 2) the practical amounts are based on the current collection rate at 39 % 3) This scenario involve an increase of the collection rate by 5 percent points annually, starting at 39 % in 2004 and reaching 89 % in 2014.

Power output from waste combustion							
Year	**Waste produced [tons]**	**Feeding rate, combustion [kg/h]**	**Heat output, based on EHV [kW]**	**Effect, Power generation [kW]**	**Electricity output [GWh], theoretical[1]**	**Electricity output [GWh], practical[2]**	**Electricity output [GWh], practical[3]**
2004	430247	49115	102925	28563	250	98	98
2005	444876	50785	106425	29534	259	101	114
2006	460002	52512	110043	30538	268	104	131
2007	475642	54297	113785	31576	277	108	149
2008	491813	56143	117653	32650	286	112	169
2009	508535	58052	121653	33760	296	115	189
2010	525825	60026	125790	34908	306	119	211
2011	543703	62067	130066	36095	316	123	234
2012	562189	64177	134489	37322	327	128	258
2013	581304	66359	139061	38591	338	132	284
2014	601068	68615	143789	39903	350	136	311

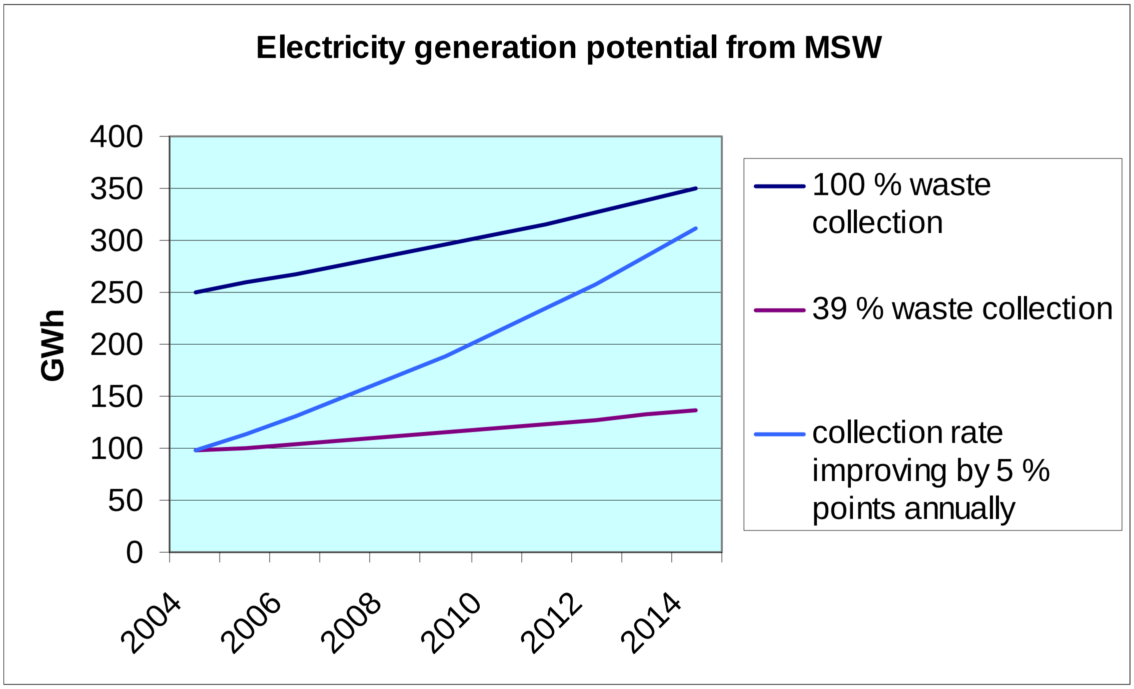

Figure 35: Three scenarios of electricity generation from MSW. One scenario based on the theoretical available waste amounts which means 100 % collection rate. The practical amounts are based on the

current collection rate at 39 % and the last scenario involve an increase of the collection rate by 5 percent points annually, starting at 39 % in 2004 and reaching 89 % of the waste collected in 2014.

8.2 Alternative 2: Making briquettes or charcoal

8.2.1 Carbonization in general

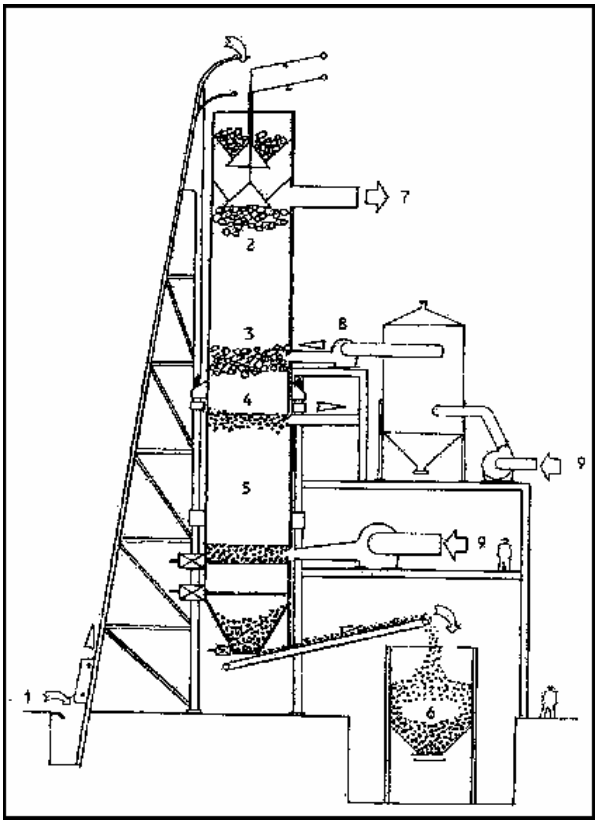

Figure 36: The schematic steps Lambiotte process. 1)Raw material 2)Drying stage 3) Distillation stage 4)Carbonization stage 5)Cooling stage 6)Charcoal 7) Retort gas 8)Hot stove gas 9)Cold inert gas

Production of charcoal can be done by other means than the traditional processes. The traditional method is to place the fire wood in pits, cover it by earth to keep oxygen outside, and then light it (Henriksen, 2003). There are several advantages by industrial carbonization. Industrial carbonization is far less labour intensive, the carbonization process is faster, and the conversion rate from wood to charcoal is higher. The “Lambiotte” or “SIFIC” process is the most successful industrial carbonization technology. The process steps are presented in Figure 36. The Lambiotte retort is achieving high thermal efficiencies. The main reason of this is the fact that the charcoal and volatile gases leaves the retort at approximately the same temperature as when the wood enters it. The efficiency is about 35 % transformation from wood to charcoal. The pant is heated by electricity and oil or gas for start up (UNFAO, 1985).

8.2.2 Pyrolysis in general

Pyrolysis is a process where biomass is processed in high temperatures in absence of oxygen. The temperature has to be above 300 ºC (Bionett, 2000). The devolatilization of the materials starts at 200-250 ºC, which means that volatile matter is released from the rest product. The rest product consists of charcoal and ash. The volatile matter consists of hydrocarbons, and the larger hydrocarbon molecules will condense when they are cooled to room temperature. The non-condensed gases consists mainly of CO_2, CO, H_2 and CH_4 and other lighter hydrocarbons

8.2.3 Charcoal from bagasse

Charcoal can be produced from bagasse by drying and then carbonizing the bagasse. The steps in the production process are described by Apolinario et al. (1997). The bagasse is first dried from the moisture content of 50 % at the moment of leaving the factory to 19 %. Then the bagasse is charred for 3-4 hours in a carbonizer where a gas stove can be used as heater. The temperature was kept between 250 ºC and 450 ºC during the carbonization process, and a closed process was applied. The temperature has to be kept below 450 ºC to prevent the creation of ash instead of char. Then, a binder is necessary to form briquettes, and in the study by Apolinario et al. (1997) gelatinized starch were used. The amount of starch used was 15 weight percent of the total mass. The charcoal were left to dry for 3-4 days after moulding. The resulting calorific value of the charcoal is 22.9 MJ/kg. The rate of conversion of bagasse to char was 35 to 40 %. The ash content of the charcoal is 16 %, which is approximately the same as in a study implemented in Kenya (Karstad, 2003). The characteristics of the charcoal studied by Karstad are presented in Table 12.

Table 12: Performance of charcoal from bagasse compared with regular charcoal from wood.

	Charcoal from bagasse	**Regular wood charcoal**	
Time from lighting to boiling	15,6	22	minutes
Duration from lighting to end of simmering (average)	173	159	minutes
Water loss from lighting to end of simmering	2462	2531	gram
Residual ash	16	7,5	%
Hardness in % powder, dust and chips under 2cm diameter after dropping from 2m on concrete	28	17	%

The rate of transformation of bagasse to charcoal at 35 to 40 % means that the potential of charcoal production from bagasse in Uganda is as the following equation shows (based on the excess bagasse from the three sugar works):

$$\text{Potential}: \frac{452\,200 \text{ tons of bagasse} \cdot 37.5}{100} = 170000 \text{ tons of charcoal} \qquad [19]$$

According to Uganda Bureau of Statistics (2003), the total production of charcoal in Uganda in 2001 was 586 000 tons of charcoal, which means that theoretically charcoal from bagasse can replace 29 % of the charcoal produced in 2001. By applying the energy content at 22.9 MJ/kg, the resulting energy potential is 3893 TJ, which equals 1081 GWh.

8.2.4 Briquetting of coffee husks

Chardust Ltd. (2004) in Kenya will during 2004 establish a factory where charcoal briquettes are made out of coffee husks, as well as nut shells from macadamia and cashew nuts. There is also a company named “Black Power” in Uganda which has developed a simple, home made system to make charcoal from coffee husks (Ladefoged, 1996).

8.2.5 Briquettes from banana peelings

Some companies and NGOs have tried two make use of the banana peelings to make briquettes. Sentongo and Munyagwa (2004) are working in Uganda Youth Voluntary Effort in Advancement and Environment Protection and they are trying to motivate people to make briquettes out of their banana peelings trash. In their demonstrations they use 10 bags of banana peelings on average every week (the volume of the bags are not known, but they are approximately 60 kg). The first step in making briquettes out of the peelings is drying. The banana peelings are dried in the sun for two weeks. Then, the peelings are halfway burned to produce char. After this process is finished the peelings are crushed in smaller pieces, and brown soil are added to the mixture to make it sticky. After some water is added it is possible to form briquettes out of the mixture. The last step is drying of the briquettes, which is done in the sun for about one day. No research is done on the performance of these briquettes, so important parameters like calorific value, the burning time, ash content and maximum temperature are not known. However, the fact that soil is added to form the briquettes implies that the ash content of these briquettes is higher than that of ordinary charcoal. Anyway, the users of such briquettes have made practical experience of the use of the briquettes. Nalulie (2004) prefers briquettes made of banana peelings because they burn longer and are cheaper.

As long as the production of the briquettes are done by idealistic means or because of economical savings in households, it is hard to imagine that the use of banana briquettes can be anything else than a small supplement to ordinary charcoal. To make such briquettes a realistic alternative they have to be commercially available in the market. Sentongo and Munyagwa (2004) hoped to get financial support to industrialize the production of briquettes and make business out of it. However, the effort to get the financial support failed. There are examples of businesses in Kenya producing briquettes out of agricultural residues, like Chardust Ltd. They have machinery bought from India to do the labour intensive parts of the briquetting process.

8.2.6 Discussion

There are some important barriers of utilizing charcoal or briquettes as fuel. The most important is probably the economical factor. Most people living in the rural areas of Uganda rely on firewood as fuel. The firewood is a resource that is freely available, so other fuels cannot compete on price, which is the decisive factor (Thumuhimbise, 2004). The dynamics of fuel change will most likely follow the energy ladder (described in chapter 2.2.4). However, if better quality charcoal produced from bagasse can compete with ordinary charcoal in the urban markets, the lower quality charcoal will maybe replace some of the firewood used in the rural areas, as the households there move up the energy ladder, or the revised one (refer chapter 2.2.4).

Such a project will involve investment in plants more advanced than the present production of charcoal from firewood, and the prices of ordinary charcoal are too low at the moment to justify such investments. Kakira sugar works has considered producing charcoal from bagasse. The cost of doing this has been regarded as too high so far (Polzin, 2004).

One important reason why the prices of the charcoal are low is that the raw material, wood, is freely available in the forests, leading to low wood prices. A possible action from the government could be to illegalize logging in the major forests. This can be done on basis of scientific arguments showing that deforestation is a problem in Uganda. The goal must be to reduce the wood available for charcoal production and other use, which will lead to higher prices of wood. However, it is important that this attempt doesn't affect the poor population relying on free firewood as fuel. But, because this wood mostly is consisting of dead branches, the collection of firewood will not be largely affected by this legislation. The dominating cause of deforestation is agricultural expansion, which is caused mainly by population increase (Serenje, 1994). This fact is hard to respond to, and will probably make it hard to make the legislation work practically. Such a legislation would be almost impossible to maintain anyway, because it is impossible to control activities in forests and woodlands.

Another argument is that a more technically advanced plant implies more centralized production than the case is of production of charcoal today. A side effect of this might be that many of the charcoal producers will loose their jobs. However, this can also be seen as an adaptation to a more modern society, where people have to find new niches of work. Such shifts have happened many times in the developing of what is called the developed world today. Professions like log drivers, shoemakers etc. have been competed by new and more modern solutions.

Briquettes from biomass residues can replace some charcoal from firewood without depending on imports of fuel from abroad. Such imports involve large expenses in foreign exchange, which is negatively influencing the national economy and in next turn leading to unemployment and reduced income both in urban and rural areas (Serenje, 1994). The negative impacts of such imports will be higher than the contribution to decreased deforestation, because the deforestation mainly is agriculturally driven (Serenje, 1994). The agricultural land clearing is also driving the charcoal process further down. Cleared land leads to almost free availability of wood for the charcoal makers, which in next turn results in increased charcoal production. The increased production leads to reduction in the prices which in next turn leads to increased demand. Although this is the most important reason, the use of woody biomass is also contributing to deforestation to some extent (Henriksen, 2003). However, most of the firewood is collected is already dead branches.

8.3 Alternative 3: Biogas

8.3.1 Gasification in general

The purpose of gasification is to turn the biomass material into gas. This can be done with careful control of the temperature and oxygen level. The gasification process is divided into two steps. The first step is more or less like pyrolysis, where producer gas and charcoal are formed by partially burning of the biomass. Then, in the second stage, the water and CO_2 produced in the fist stage are chemically reduced by the charcoal to form CO and H_2 (Van Loo, 2002). Gasification requires temperatures above 800 ºC or more to minimize the formation of tar and heavy hydrocarbons in the product gas. The finished gas consists of 18-20 % hydrogen, 18-20 % carbon monoxide, 2-3 % methane, 8-10 % carbon dioxide and the rest nitrogen (Larsen et al., 2003).

8.3.2 Bagasse

It is possible to produce biogas from bagasse, and then also to produce electricity from the biogas. The biogas can be produced by gasification, and it is usually named producer gas when it is produced by gasification. One way to do this is to make use of an indirectly fired fluidized bed gasifier. Only steam is injected to the gasifier, to promote biomass gasification. The objective is to convert the bagasse into a combustible gas containing CO, H2, CO2, CH4 and H2O as well as small quantities of impurities as char, alkali components and unburned carbon residues (Dellepiane et al., 2003). The impurities have to be removed from the gas to prevent damage to the equipment. This clean up can be done by cyclones to remove some of the char before a char cracker can be applied to reduce the tar molecules. The molecules that not are cracked will be condensed at the catalyst surface and then removed from the gas.

8.3.3 Biogas

Biogas is another option of utilizing the MSW. The produced gas can in next turn be used to produce electricity, or direct for cooking in households. The gas has to be cleaned to be utilized for energy purposes. The microbiological step in producing biogas is called anaerobic digestion. The word anaerobic refers to the fact that this is a process going on in absence of oxygen. Figure 37 shows the principal steps of anaerobic digestion. These steps are not clearly separated from each other, but coexist while the process is going on. The bacteria decompose the materials in the reactor to provide energy for their own metabolism. The byproduct of this process is methane (Engebretssen, 2003). The methane content of the biogas ranges from 55 to 80 % (Biogas works, 2000).

Anaerobic digestion is a more environmental friendly option than composting of the waste (or land filling). By landfilling or composting there will be formation of methane and CO_2 which will be released directly to the atmosphere, unless there are any methane collection systems at the landfill (Gallert, 2003). While applying anaerobic digestion the methane is the wanted product, which is burnt for energy purposes. By burning the methane, the contribution to global warming is reduced by a factor of 21, because methane has 21 times the global warming potential of CO_2.

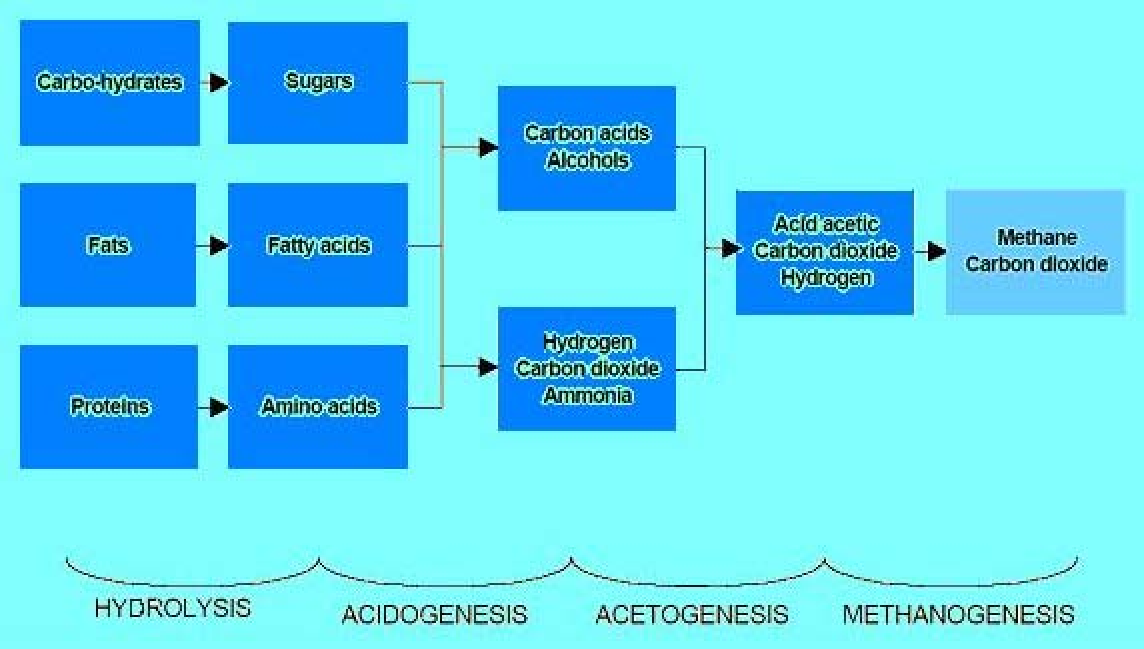

Figure 37: The principal steps of anaerobic digestion (Seadi, 2001).

8.3.4 Methane utilization from the existing landfill

One possibility is to utilize energy from the existing landfill by collecting methane gas. This is probably the cheapest option within a short time limit, because the existing landfill can be continued. However, when the capacity of the existing landfill is fully utilized, investments have to be done anyway. The sustainability of the landfill will increase if the methane is utilized, because this will imply a reduction of the global warming potential caused by methane, which is 21 times the GWP potential of CO_2

9 Energy needs

How can the biomass residues described in this thesis represent a potential for improving and developing the energy system? To answer this question some of the energy needs where biomass residues may represent an alternative have to be known.

9.1 How the needs are filled today

The firewood consumption in 2001 was 20.89 million tons which represents an energy level of 92.8 TWh (refer Table 13). The share of firewood consumed by industry, commercial actors and households were respectively 9.9%, 14.9 % and 75.2 %, based on consumption statistics from 2001 (Uganda Bureau of Statistics, 2003). The share of the firewood consumed in the households is 69.8 TWh, assumed that the efficiency levels are approximately the same in these three groups (the truth is probably that the efficiency is higher in the industry and in the commercial sector, but no general data are available on this issue). The three stone fire which is used for cooking fired by fire wood in households has efficiency of heat transfer from fuel to food between 5 and 15 % (Pedersen et al., 2003), 10 % on average. The term efficiency in this setting means amount of heat generated which is transferred to the medium which is to be heated, the food in this case. Out of the 69.8 TWh consumed in the households, only 7.0 TWh is the real requirement in terms of heat transferred to the food, and 90 % is lost to the environment. Mark that the energy levels calculated from the consumption of firewood can be a bit higher in these calculations than they really are, because the calorific value applied in the calculations is from air dry wood. The reality is probably that not all of the wood consumed as energy is sufficiently dried before the combustion starts. However, given the lack of more accurate data the estimates made here should be a reasonable approximation to the real situation.

The energy content of the charcoal consumption in Uganda is 4.7 TWh, as shown in Table 13. The traditional char coal stove has a maximum efficiency of 24 %, with 20 % as an average for use in calculations (Pedersen et al., 2003). 97 % of the cooking stoves used in households are the traditional ones, while 3 % of the households make use of an improved stove which has efficiency levels around 30 % (Pedersen et al., 2003). The average efficiency is then 20.3 %. This efficiency can be used to calculate the amount of energy which enters the food, which represents the specific need to be met. The energy needed for the energy service itself is then 0.95 TWh.

*Table 13: Biomass consumption 2001. The data are based on statisitics of consumption from 2001 (Uganda Bureau of Atatisitcs, 2003). *Air dry (Henriksen, 2003)*

Biomass consumption 2001, traditional sources			
Biomass	**Calorific value [kWh/kg]**	**Mass consumed [million tons]**	**Energy [TWh]**
Firewood consumption	4,44 kWh/kg*	20,89	92,8
Char coal consumption	8,06 kWh/kg	0,586	4,7
Firewood as raw material for charcoal		4,64	20,6

The need for energy in the tea industry is largely based on biomass. The production of tea in 2001 was 32 857 tons of processed tea (Uganda Bureau of Statistics, 2003). The demand of firewood is 1 kg processed tea produced out of 1 kg firewood (Uspacious, 2004). Assumed that the ratio is the same in other tea factories, the consumption of firewood is then 32 857 tons. The energy content of this firewood is 145.9 GWh or 0.15

TWh. The industrial share of the total firewood consumption is 9.2 TWh, so the tea industry contributes only to a small share of this total.

These calculations show that there is a difference between the energy need and the actual consumption. The consumption levels are determined by technology, in terms of the efficiency performance of the technology applied, and the fuel applied for the service, as well as the need the consumption is caused from. The energy needs for the areas discussed here are summarized in Figure 38.

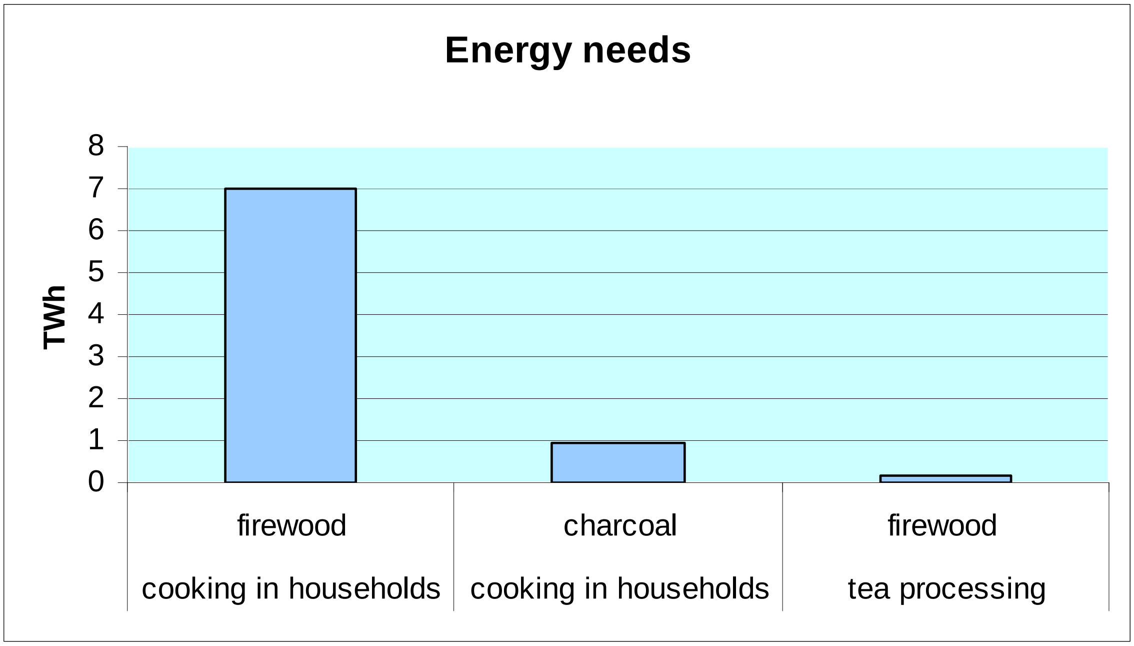

Figure 38: The energy needs of three important areas of use.

There are two main reasons for the huge loss of energy. One reason is the low efficiency of the charcoal production. This loss is due to an extra step in the energy cycle before the fuel reaches the end-user. The firewood is not used directly to fill the energy needs in the households, but it is processed to charcoal, a fuel of higher energy content. This processing is done at 12.5 % efficiency, and the consequence is that 16.2 TWh is lost to the environment in this step. Charcoal is a preferred fuel in the urban areas because of its higher energy content than the alternative firewood, a fact that also makes it cheaper to transport per kWh energy. The charcoal is also less polluting than the firewood per kg of fuel fired, a fact that makes it better suited for the urban environment with large concentrations of people.

The other main reason is the efficiency losses in the households, where 87.7 TWh are lost. The low efficiency of the three stone fire and the efficiencies of the charcoal stoves is the reasons why. An improvement of these stoves will easily lead to large savings of energy, so the real challenge is to overcome these efficiency losses. The fuel itself is only a part of the problem. However, the characteristics of the fuel are determining the possibilities to utilize the energy it represents effectively.

9.2 How can biomass residues fill the energy demand for cooking?

One of the most basic needs to be filled is energy for cooking. This need can be filled by all the energy sources and energy carriers discussed in this thesis. However, the performance is varying among the different energy carriers, due to factors as moisture content and number of energy transformations in the fuel chain. A comparison between the existing energy carriers and the potential ones discussed in this thesis are made in Figure 39, where energy for cooking is the energy need to be filled. The efficiencies of the firewood and charcoal stoves are the same used in chapter 9.1. The efficiency of an electric stove is 74 % (APS, 2004). The efficiency of the improved stoves is set to 35 % efficiency, as the stoves available at ICCS (2004) have for sale. Equivalent improvement can be done to the firewood stoves, where the efficiency can be increased to 30 % (Ndawula, 2003).

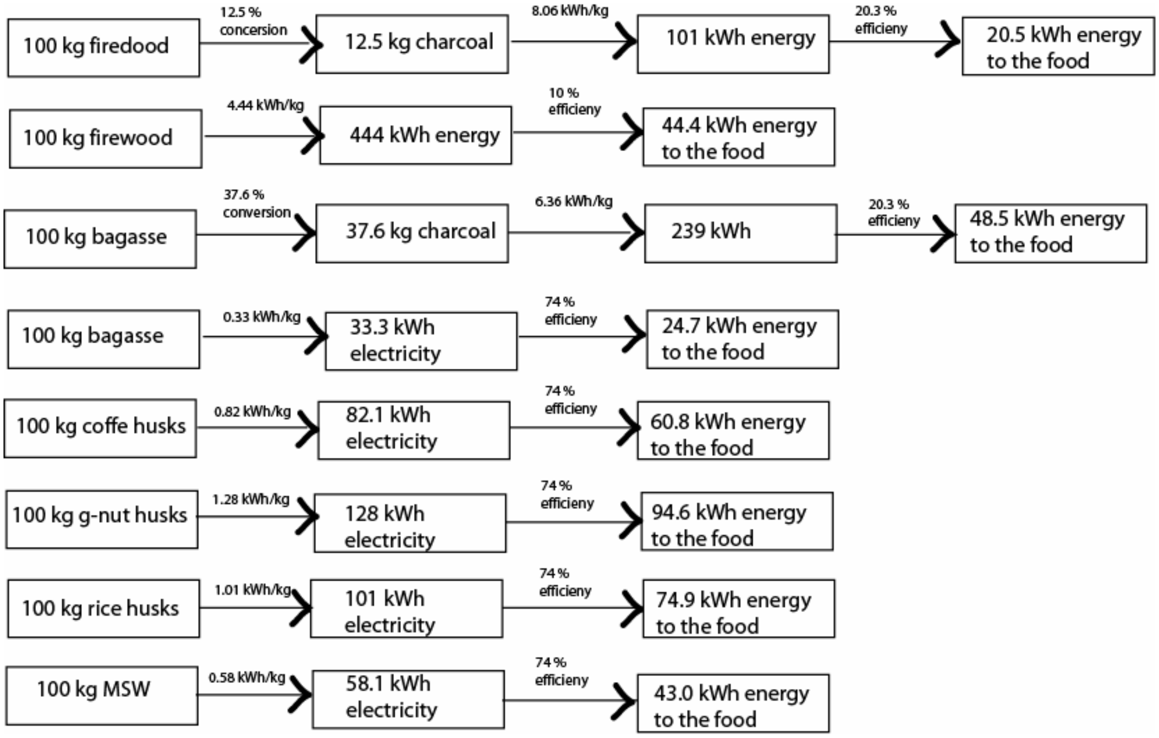

Figure 39: The energy chains of two existing and six potential ways to fill the need of heat for cooking. The figure shows how much energy which enters the food after the conversion steps from 100 kg input of the energy source in the beginning of the chain.

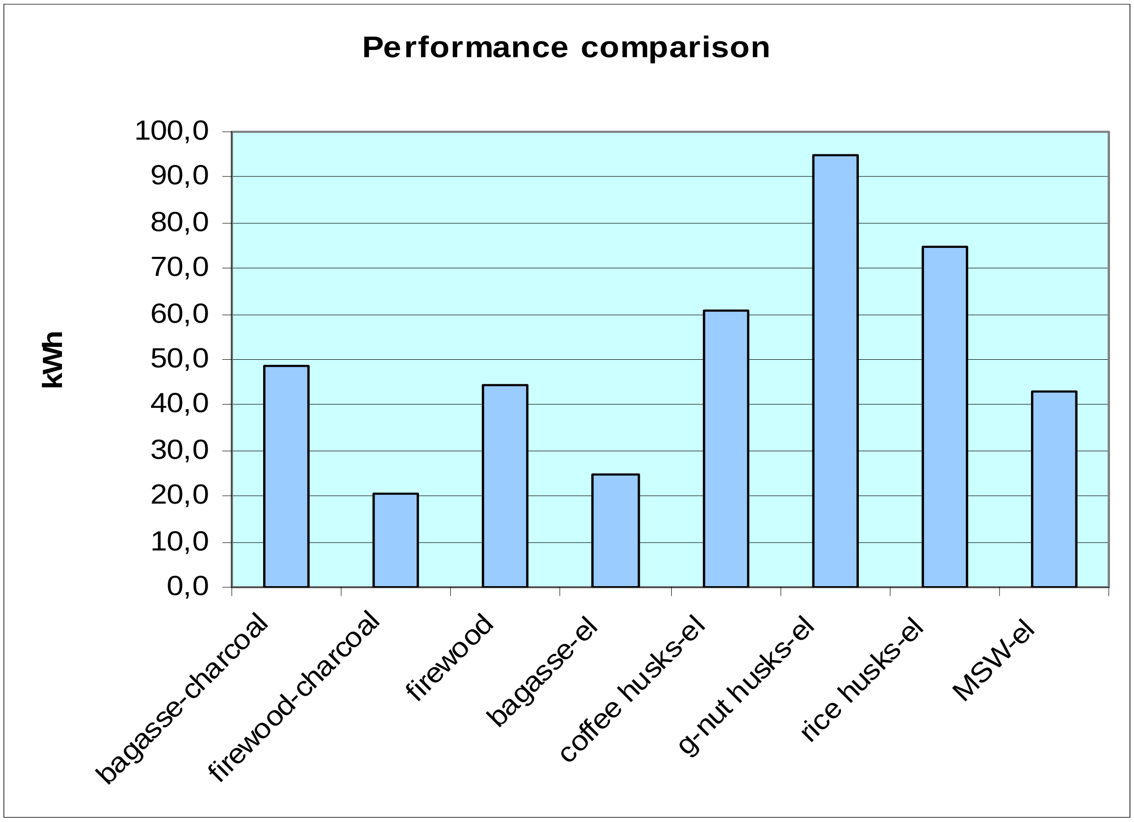

Figure 40: The performance of some energy carriers and energy sources assumed that the energy-need to be filled is heating of food.

Charcoal from firewood is the energy carrier showing the lowest performance of the energy carriers discussed. The reason is the combination of low efficiency of the charcoal productions and the efficiency of the charcoal stove. By using an improved charcoal stove, the energy output from the firewood-charcoal chain can be improved significantly, as shown in Figure 41. The three most effective energy chains is based on electricity as energy carrier and with rice husks, coffee husks and g-nut husks as energy source. The moisture content is one factor which is contributing to the good performance of these energy sources. Bagasse, however, is performing quite low, and the main reason is the high moisture content at 50 %.

By predrying (as presented in chapter 7) the fuels with high moisture content, the electricity output will increase. The highest effect of drying will be achieved from the fuels with highest moisture content, as bagasse and MSW. The performance of the MSW is probably a bit higher than the real values will be, because the calculations in Fuelsim (2002) don’t include corrections for the fact that the composition of MSW is not as homogenous as the other fuels. The MSW also contain traces of incombustible materials like glass and metals.

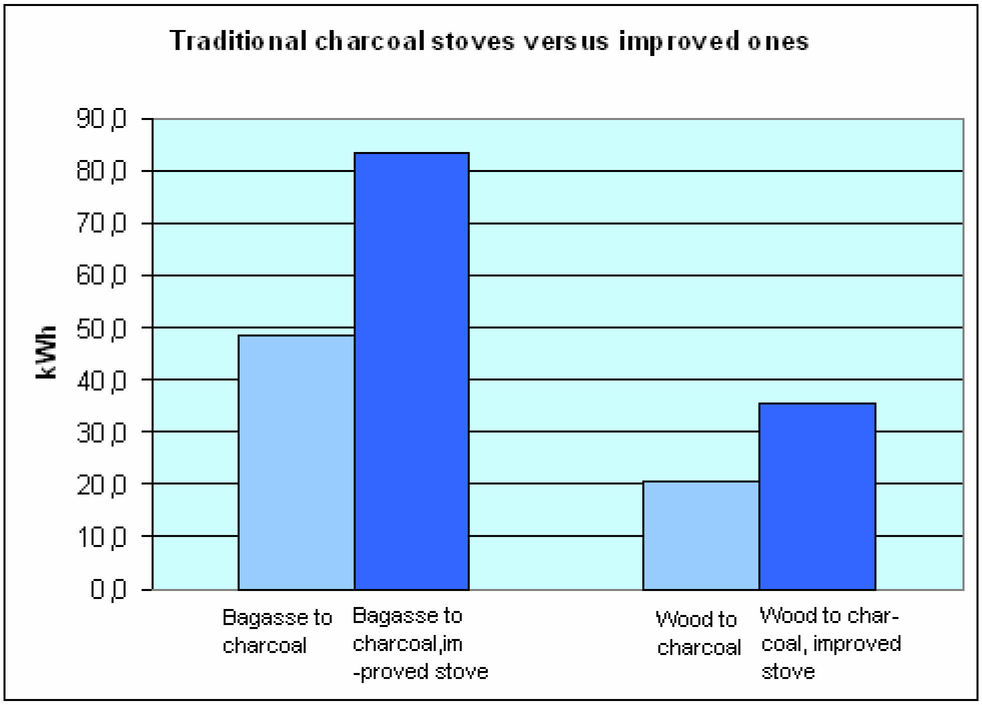

Figure 41: The energy output from the bagasse to charcoal energy chain and the firewood-charcoal chain compared with the same chains with improved charcoal stoves at 35 % efficiency.

But, even though the performance of the different fuels varies, the availability is also a factor which is determining to what extent the fuel is able to fill the need. The average household size in Uganda is 4.7 persons (Uganda Bureau of Statistics, 2003). The average consumption of energy for cooking in households is 1463 kWh per year per capita (Henriksen, 2003), based on information from households in the area of Fort Portal. The annual energy need for cooking is then 6749 kWh for an average Ugandan household. Figure 42 shows how many households that can be served with energy for cooking based on the theoretically and practically available resources.

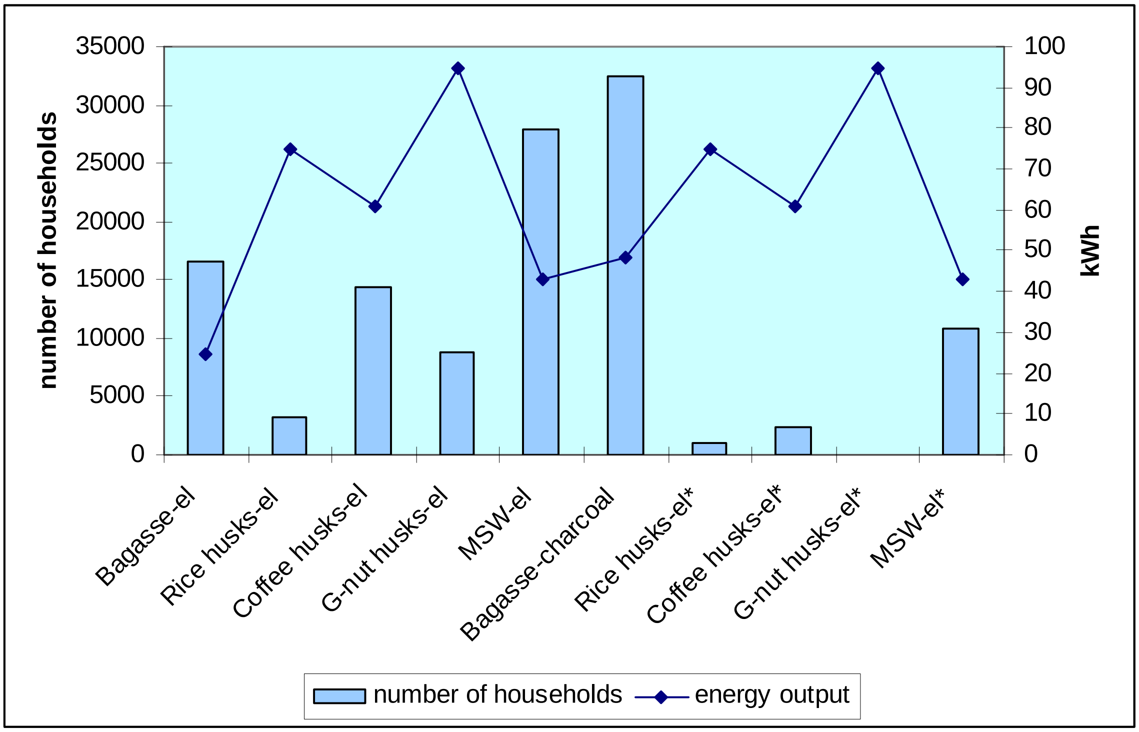

*Figure 42: This figure shows the potential for the different biomass residues to supply energy for cooking the Ugandan households during a year. The line graph shows the energy output pr. 100 kg of input raw material of the given fuel to fill the energy needs for cooking. *) The number of households supplied in these three categories is based on the practical available amount of residues (refer chapter 8). For bagasse the theoretical and practical potentials are equal. For MSW, the waste levels from 2003 were used, based on a collection rate at 100 % for the theoretical outcome, and 39 % for the practical.*

Figure 42 shows that the availability of some of the residues in some cases compensates for the lower out put from the energy chain for some residues. One example is MSW, where the energy output is less than half of that of g-nut husks per unit mass of raw material input, while the MSW can serve around three times as many households because of the larger volumes present of MSW. The same relationships are found between other of the residues too, like between electricity from bagasse and electricity from rice husks.

The comparison of the performance of the different biomass residues shows that g-nut husks achieve the highest output of energy per mass unit of input. This implies that the profit gained by production of electricity from g-nuts will be larger per unit input than for less effective alternatives, provided that other costs are the same for the different residues. The transport costs per unit energy provided in the end will also be cheaper then the less effective fuels. On the other hand, the g-nut husks have the second smallest volume produced annually of the residues studied in Figure 42. So the total energy outcome is smaller than bagasse, coffee husks and MSW. However, the practically available amount of g-nut husks is set to 0 by Norplan (2003), so based on that assumption there is no possibilities to utilize coffee husks as energy.

Charcoal production from bagasse is the alternative that can serve the greatest number of households with energy for cooking (Figure 42), even though the energy output per unit mass of input is among the lowest. Figure 42 shows that the production of charcoal from bagasse lead to a higher energy output than electricity produced from bagasse. So, provided that the demand for electricity and charcoal is the same, charcoal production will be the best solution. However, there are also other factors to be considered when the decision is to be taken. The alternative where the highest profits can be made will probably be preferred, and it is not given that any of the alternatives will be economically advantageous.

10 Discussion

The energy needs have to be met in the best way possible. The challenge is to meet the needs in the most effective manner, with as little harm as possible caused to the environment and human health, as well as economical and practical interests are fulfilled. The possibilities of utilization of the biomass residues are sketched in chapter 8. These alternatives make up some ideas of how the biomass residues can serve as excellent contribution to the energy system. The existing use of coffee husks in Kajjansi Clays, Uganda Clays and Hima cement are all examples of successful use of coffee husks as energy source (refer chapter 3.2), as well as the sugar factories are good examples of utilization of bagasse for energy purpose (refer chapter 3.2.2).

10.1 How can the biomass waste as energy lead to more sustainability?

All the scenarios calculated by Henriksen (2003) (refer chapter 1.1) imply that the annual consumption of firewood is higher than the annual increment to the forests. This has two important consequences concerning the degree of sustainability of the consumption. Biomass is a renewable energy source as long as the annual increment to the forests is the same or higher than the yield. This requirement is not filled, so the firewood cannot be defined as a renewable energy source in this case. Biomass is also defined as CO_2 neutral given the same premises as set for biomass to be renewable. This requirement is not fulfilled either, making the firewood a net contributor to the greenhouse gas emissions as long as the consumption is higher than the annual increment.

In most cases the increment to the stock of agricultural crops is equal to or higher than the annual harvest, a fact that make the biomass residues a more environmental friendly alternative than the firewood at present, by the means of global warming and resource depletion. However, the quality of the residues have to be good enough to make sure that the cooking is causing less harm to the members of the households than the present exposure from charcoal and firewood. This quality will be achieved by applying more technically advanced process equipment than the methods for charcoal production used today.

By using biomass as energy in large scale there is a risk that nutrient substances are removed from the soil (Clarke et al., 2002). If the agricultural residues are decomposed in the fields some of the nutrition substances are given back to the soil. When the residues are used as animal feed, some of the nutrition salts are also given back to the soil as manure. However, when the biomass is utilized as energy, the soil gets nothing back after harvesting. So it is important to make sure that the soil is kept healthy by adding manure. The consequence of intensive use of agricultural residues as energy source can be dependence of industrial fertilizers to a larger extent than before. The extent of sustainability of using agricultural residues therefore has to be looked upon in a life cycle context, where issues like increased consumption of industrial fertilizers are included.

Prevention of human exposure to indoor smoke is another important aspect of changing the energy system of Uganda. The efficiency of stoves used for cooking is one aspect that will improve on this situation. If less fuel is used to make one meal, the emissions will also be reduced, independently of whether the same fuel is used or not. By changing the fuel however, the exposure levels can be reduced even further.

The performance of different energy carriers to fill the need for cooking was assessed in chapter 9.2. However, be aware that electricity is not the most realistic energy carrier for cooking at the moment. A study by Henriksen (2003) shows that the consumption of solid fuels by households near Fort Portal in Uganda is independent of whether they have installed electricity or not. The electricity was not used for cooking in the households with access to electricity anyway. The cooking needs were filled by firewood or charcoal, while the electricity supplied energy for light, radio, fridge etc. (Henriksen, 2003). This view is supported by Masera et al. (2000) (refer chapter 2.2.4). So, according to her studies, the exposure to indoor smoke will be the same whether the household has installed electricity or not. However, a study by Røllin et al. (2004) shows that introduction of electricity in households in South Africa significantly reduced the levels of indoor respirable particulate matter and CO in kitchens. These results were observed even though some households still used some solid or liquefied fuel for cooking. The study was carried out in households where background pollution, socio-economic status and household density were similar.

As long as the fuel for cooking not is changed to electricity, electricity produced from the biomass residues will not replace any of the firewood or charcoal used for cooking today. Instead, it will help on the situation to provide enough electricity in Uganda, and make pave the way for further extension of the electricity distributions system and connect more households to the grid (refer chapter 1.2.1). So, neither health issues in the households nor the problem of deforestation will be improved by electricity generation from the biomass residues. But, if electricity is used for cooking, the exposure to indoor smoke will be eliminated or reduced as described by Røllin et al. (2004).

Charcoal or briquettes from bagasse or other crop residues is also an alternative for substitution of charcoal or firewood as fuel. There are no studies available showing whether these alternatives will improve on the situation in the households regarding exposure to indoor smoke. However, the quality of the charcoal will be improved by applying more modern production methods (as described in chapter 8.2.1), but this can probably be achieved by both regular wood and crop residues as input.

10.2 Which resources are realistic for utilization, and how to make it happen?

The character of the residue has to be evaluated when deciding the best way of utilization. The residues available at numerous sites all over the country are not so well suited for electricity generation, because it will be too expensive to transport all the resources to the plant (Table 8). The bagasse for instance is produced at three specific sites, which makes it suitable for electricity generation. The sugar companies already have competence on these issues, and could easily use this knowledge to produce more electricity for export to the national grid. One of the barriers of doing this is investment. There is a lack of money to invest in the required technology, and the uncertainty of whether the investments will result in profit or not. The uncertainty is an issue which the government is better suited to handle than the potential producers themselves. An example of a well functioning reform to provide a higher share of electricity from independent power producers (IPP) is the case of Mauritius. The electricity market has been liberalized, and the government is providing profitable pay back prices for electricity to the IPPs (Beeharry, 2000). This is contributing to more predictable prices for the producers, a fact that is contributing to reducing the uncertainty associated by the investments. This thinking can be well worth testing in Uganda, where almost all the electricity currently produced is supplied from The Owen falls hydro electric plant (Owen falls has 300 MW of the total installed capacity of 303 MW in Uganda (Uganda Bureau of Statistics, 2003)). The distribution losses in the national grid are 40 %, due to both transmission losses and theft (Langaasen, 2004). Having this fact in mind, the efficiency of the system will improve if the electricity generation plants are more scattered around the country. The production will then be closer to demand, implying a reduction in the distribution distances, a fact that also should be contributing to a reduction in the losses.

A paradox is that Kinyara sugar works the spring 2004 is investing in a new boiler to destruct the excess bagasse without utilizing the energy in it (Jobling, 2004). However, this investment is a step in the right direction, because it is possible to add systems for energy utilization to this boiler later by lower investments cost than by constructing the whole system from scratch. The environmental consequences of open burning of bagasse (refer chapter 4.2.4) will also be reduced, because the destruction of the excess bagasse will be handled under more controlled circumstances in a boiler than in the fields. The degree of complete combustion will be higher, hence reducing the emissions from the combustion. Electricity generation from bagasse is the most promising residue in this context. There are already three established companies producing electricity from bagasse, but they all utilize around half of the bagasse they produce.

The future prospects for the agricultural residues and MSW is a factor which is influencing the decision of the most promising resources. The world coffee prices has been low so far in 2004, a trend which has been continued from the last year. This trend has also influenced the economy of Ugandan coffee growers, leading to the closing down for many coffee growers (Hofsvang, 2004). If this trend is continuing, it will lead to a reduction in the potential of coffee husks as energy. The volumes of MSW will most likely increase, as described in Table 11, so also the production of bagasse, because both Kakira and Kinyara sugar works plan to increase the processing of sugar cane in the near future (Polzin, 2004; Jobling, 2004).

10.3 MSW

There are two important areas to improve. One aspect is to improve the rate of collection from the current level at 39 %, and the other aspect is to find a sustainable alternative for final treatment of the MSW.

10.3.1 Why is the rate of collection only 39%?

The reason why the collection rate is at only 39 % of the total amount of waste generated in Kampala is complex. One aspect is the resources available in KCC. KCC serves more people than they are supposed to because of the migrating population. Every day Kampala receives a great number of workers from the surrounding Wakiso district who spend the day in Kampala, and they also produce most of the waste they generate in Kampala. But KCC gets only money to serve the residential population, a fact that is contributing to the shortage of money in KCC, which prevent their solid waste management system running smoothly (Gubya, 2004).

There are not enough money to be spent on waste management. The trucks and most of the skips were bought in 1993 as a part of Uganda First Urban Project. After 11 years the existing stock of trucks and skips are getting old, and the consequence is frequent breakdowns and costly maintenance work which is delaying the collection work (KCC, 2002). The shortage of money also leads to inefficient use of the human resources in KCC. There is not enough money for fuel to keep the trucks running a full working day. While the fuel supply is only for 6 hours working day, the workers are paid for full day work (Gubya, 2004). The system would be more effective if the drivers could be used more effectively.

The attitude of ordinary people is also important when it comes to the collection rate of waste. It seems like the waste is only regarded as a problem if it is too much of it in one load. “If we have big quantities of garbage it is taken away by KCC. Small quantities are burned by the roadside (Twasiima, 2004)”. This statement is also supported by Naluwooza (2004): “We are only two people in the household, so we don't generate that much waste. Then we don't have to pay any fee to get rid of the waste”, she says as an answer of why her household doesn’t deliver their waste to the KCC.

Many people also seem to be unaware of the problems of throwing some small piece of waste away why they are walking, driving and so on. An example of unawareness is described in Annex 1, which partly consists of observations made by the writer and statements by Betty Fred (2004). Such attitudes are also described by Nicolas (2003). She argues that many of the people polluting the environment with garbage are well educated people. “Many times you see plastics thrown out of posh cars and you really wonder at the extent to which the occupants are informed as far as the environment is concerned” (Nicholas, 2003). The educated people are role models for other people, so it is important that they start acting like that.

The cost of delivering the waste to the KCC is also representing a problem for some people, and that cost barrier makes it some times impossible for these people to deliver their waste to KCC, simply because they can’t afford it. Especially in the areas where people are poor there are many people who can’t afford the fee. The result is that people move out at night and dump their waste on the roadside, in the wetlands and in the drainage (Munyagwa and Sentongo, 2004). However, in the information on the cost of waste collection there is some inconsistency. While Munyagwa and Sentongo (2004) in Uganda Youth Voluntary Effort in Advancement and Environment Protection as well as Lubowa (New Vision, 2004) argue that people even in low income areas have to pay a small fee to get their waste collected by either private actors or the KCC, Gubya (2004) states that KCC collects garbage from low income areas without charging any fee. If Gubya is representing the true picture of the situation, it is harder to address the reasons why people don’t deliver their waste to KCC. She explains the situation in terms of shortage on the available resources from KCC: “The problem is that the skips are so few. By mid day they are already full. Even if the skip is full, people throw their garbage there because they have no where else to put it. People have told me that they want to put the waste in the skip, but always when they get there it is full” (Gobya, 2004). The lack of money is also described by Munyagwa and Sentongo (2004). In the area of Rubago, a skip situated near a market was removed in 2002, probably due to lack of resources. The consequence is that the waste is thrown away other places.

10.3.2 Solutions

The National Environment Management Authority is currently (2004) developing a public awareness program on waste management. The plan is to develop a five years strategy on this issue. They will try to reach people by different types of information, including folders, radio, television, newsletters, stickers in newspapers, and information spread by talking to people in positions. One of the most important goals is the world environmental day the 5th of June where they will make a lot of publicity. The theme of that day will be solid waste management this year. They are also communicating with the education ministry, trying to incorporate waste management issues in the school system (Gowa, 2004).

The present praxis of landfilling is not sustainable, and according to Gubya (2004), other alternatives have to be found. This politic is also in line with other areas, like the European Union where the aim is to reduce the amount of waste deposed at landfill by 65 % of the 1995 level, because there are other, more preferable ways to handle the waste (IEA Bioenergy, 2003). The main reason is that the wastes are resources that can be reused in new products. The waste hierarchy ranges the preferred options for waste management, which shows that landfill is the least preferable option (Figure 43). However, the waste hierarchy doesn't include the alternatives less preferable than landfilling, like no collection and open burning as discussed in this thesis.

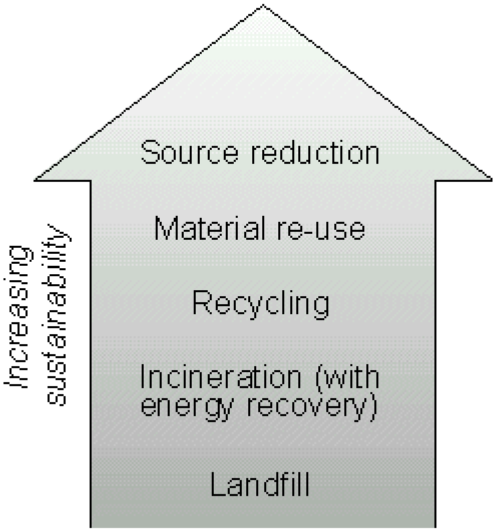

Figure 43: The waste hierarchy shows the best and worst waste treatment options (Imperial College, 2003).

There is already some recycling and reuse taking place in Kampala. It is important to continue the development of recycling systems, and put these systems into more organized forms.

In this thesis particulate emissions from open burning of MSW in Kampala is described as a problem. The socio-economic costs by the current praxis is high, and the example given by the assessment of cancer risk from particulate emissions shows that this problem alone represent a large socio-economic to society (refer chapter 4.2). The solution to this problem is in this thesis presented as increased focus on waste management, and alternatives to the current waste handling situation. However, this study does not include any assessment of the other sources to particulate emissions in particular and air pollution in general in Kampala. There are other sources of pollution that clearly also contribute to the current concentrations of dust in the air surrounding Kampala. The estimations in this thesis have only assessed the part of the problem created by open burning, but it might be that the emissions from other sources are easier and cheaper to reduce. Other sources to particulate emissions are factories, cars and trucks, dust from the soil and emissions from cooking in households. One example of action on these issues is construction of pavements on walkways in the city centre. This will be done in some areas of Kampala to prevent the formation of dust from the soil (Lubowa, 2004). Other actions could be cleaner production at the factories in the city and cleaner fuel for the cars and trucks. It is out of the scope of this thesis to discuss which of theses actions that represent the best way to fight the high levels of particulate emissions in the air. This thesis presents a solution to the specific problem of open burning, but it might be that other actions will be more effective in fighting the concentration of particulate matter in the air in general.

It is important to understand the reasons behind the problem of emissions of particulate matter from the open burning of MSW to make proposals for the solution. This way of handling the waste is chosen because it is the cheapest, easiest and the most sanitary solution available (Kihumba, 2004). To provide solutions to the problem there is a need to develop better methods for collection of the waste, as well as more sustainable alternative treatment methods. An alternative to deposing the waste is not enough to solve this problem. An important aspect is to increase the rate of collection from the current rate of 40 %. It is the uncollected waste that represents the real problem in Kampala. The deposing of the collected 40 % is a well functioning way of treatment. KCC (2002) has proposed some strategies to improve the waste collection. One important issue is to increase the public understanding of the waste management issues. This can be implemented through (KCC, 2002):

- Public information campaigns
- Litter clean-up campaigns

The public need to be aware of the fate of the waste they generate. The fact that the waste may represent a source of energy may increase the motivation of handling it properly. Such motivation is not present today, because there is no energy utilization from the current waste treatment method which is landfilling. To make such motivation possible there is a need to develop other waste treatment methods that generate energy, such as those presented below. If such investments are going to be realized, it is very important that there is a steady supply of fuel. To utilize the fuel potential there is a need to implement stronger strategies to improve the rate of collection. The recycling which is done in Kampala by now is based on the ability for some people to earn some money on selling waste (or resources) for refinement. The idea of economic reward could be extended to the whole waste management system in Kampala. If every single household receives a small amount of money when they deliver their waste the incentive to collect the waste will be dramatically stronger than today. The reality today is exactly the opposite, where the poorest people cannot afford to deliver their waste because of the fee, resulting in illegally dumping. In this setting, where the waste is used as fuel to produce energy, it must be defined as a resource rather than waste. It is normal practice to buy other kinds of fuel for energy production, like oil and gas, so why not compensate the delivers of the fuel called waste by money? The profit in the recycling system is not very large, so large amounts of money should not be necessary. However, it is important that the net result of the energy recovery from the waste will be net profit for Kampala City Council. Even a small profit from this praxis will be an improvement from the current system, where the landfill is an expense for KCC. However, this provides that the investment costs are repaid.

The investment costs will be a barrier to implement such a system. One way of handling this cost can be by contribution from international development aid. Another possibility can be to define such a project as a Clean Development Mechanism (CDM) project. However, this will involve adjustment of the project to make it fit the specific requirements of approval, and there is a need of a prestudy to find out whether it is likely that the project will fill the requirements of additionality etc. Undoubtedly the bureaucracy expenses of the project will increase that way, but on the other hand there is a possibility to receive income from the sale of carbon quotas.

There are many practical barriers to overcome to introduce this system. One aspect is how to differentiate the payment system. To make such a system function after its intentions the delivers of waste have to receive money after how much they deliver, either by volume or weight. The easiest is probably to base the measurement on volume basis. By providing the households, restaurants and cafes by standardized waste bags, these can be delivered to the waste collectors when they are filled up. The system will imply a bit more organization than before. There must be a system of registration for how much waste the suppliers deliver and a system to pay them back. Easier systems based on experience on how much waste a supplier usually generates are also a possibility. However, this will not include a direct incentive to collect as much of the waste as possible, so it will not be as effective as the other proposal. On the other hand, it is important that a new system doesn't affect other sustainable ways of utilizing the waste. Currently, some of the waste is recycled and other waste, like banana peelings, are sometimes used as animal fodder. The recycling systems can be kept working by making sure that the profit of delivering these waste compartments for recycling is higher than if they were delivered to energy recovery. The same argument can be used regarding banana peelings as fodder. The alternative cost of buying other fodder than banana peelings will probably be higher than the income generated by delivering the banana peelings to the waste collectors.

The level of waste generation is 1 kg per day per capita in Kampala. A household of 5 persons will then generate 35 kg of waste during one week. However, this is average values, so most people will probably generate less waste than this, because some large units like hotels and businesses are contributing more than every single person.

10.4 Uncertainties

The process of finding information is by many means quite difficult on this topic. One aspect is the reliability of the information. The extent of research in Uganda and many developing countries in general are not as high as in the developed world, making it difficult to find information on all issues. This is why there are many references referring to unpublished work like first hand conversations and interviews made during the fieldwork period in Uganda. The list of references is divided in two parts, the regular one and the one referring to the talks made during the fieldwork. This is to make it easy for the reader to reflect on the reliability of the information provided. In many cases, the verbally given information will be more reliable than other, because this is first hand information coming from the people who are working on these issues in everyday life.

Some of the written literature does not always go together with other studies handling the same topic. On example is the overview over the energy system in Uganda provided by Jacobsen et al. (2003), where the total energy consumption in Uganda is far less than the numbers presented by Henriksen (2003) and Uganda Bureau of Statistics (2003), where the consumption of firewood consumption in it self represents more energy than the total presented by Jacobsen et al.. Another example is the production of bagasse from the sugar companies. The quantities presented by Norplan (2003) are far larger than the ones calculated based on first hand information from engineers on the sugar factories (Jobling, 2004; Polzin, 2004).

The statistics provided by Uganda Bureau of Statistics is for some sectors largely based on projections. The reason is that many sectors in the Ugandan energy and agricultural sector still is operated by non-monetary means (Mayinza, 2004). This fact makes it harder to make statistics for these sectors, and the consequence is that there is a lack of data or only estimations available on many issues.

The calculations on electricity generation and charcoal production from some residues are made on general facts about the residues and their availability and the technology utilized. To get more accurate data on the energy potential, more detailed design of a specific plant has to be carried out, like the specific technology applied (like traveling grate combustion or fixed grate combustion), the moisture content of the residues available at the specific site etc. The fact that general data on moisture content, calorific value and element composition for the fuels are applied in this thesis is contributing to increase the uncertainty of the results. However, as long as the general data is the only one available, this will be the most certain results possible.

The limited access to data has made it difficult to be consequent on using data from the same year. The first hand information collected in Uganda is mostly describing the present situation, while information available through statistics often is a bit older. The fact that the information not always is from the same year is reducing the value of comparing the data, but the errors should not be serious. As far as possible data closely related in time is used.

11 Conclusion

In the energy situation of Uganda in the introduction, the crop residues is said to be represented by 4 % of the energy mix in Uganda, which made a clear motive for assuming that the potential of energy utilization from biomass waste would be quite large. However, the results of this study has shown that the theoretically available crop residues constitute to 4.6 % of the firewood and charcoal currently consumed, and that the practical available amount represents 2.7 % of the total consumption of charcoal and firewood in 2001 (the data includes rice husks, coffee husks, g-nut husks, bagasse and maize cobs). If the potential from MSW is included as well, the theoretical potential represents 7 % of the current consumption of firewood and charcoal. The potentials of biomass waste are not as large that they can represent an alternative to firewood and charcoal, but it can be a useful supplement. The data from this study is not coincident with the allegation that the crop residues represent 4 % of the energy consumption in the current energy system of Uganda.

However, the biomass residues mapped in this thesis shows that there is a large potential of utilizing these resources more effectively than today. There are only two of the residues which are utilized in a large scale today, coffee husks and bagasse. The others represent an unexploited resource that can gain the society if it is used in the right way. Anyway, bagasse represents the most promising residue for further utilization. The reason is that the bagasse is already available at three specific sites, and the technology and knowledge is already present. The only barrier is that of investment and economy. The other residues share the economic barrier, but they have practical barriers too, like the challenge of gathering the available resources at one or a few specific sites for processing. Bagasse is suited both for electricity production and charcoal production, but the production of charcoal is the alternative which is representing the largest energy output. On the other hand, the production of electricity is already done at all the three sugar factories, so the knowledge and skills favour electricity production, and the need for electricity is also more acute. To allow electricity production from bagasse, the government should implement the system changes equal to those of Mauritius to provide an exactable framework for independent electricity producers.

The proposals for new organization of the collection of MSW should be implemented, to fight the negative effects of the present open burning of waste, and other risks associated with the low collection rate, like the risk of epidemics. The idea is to change the system from being based on punishment to being based on reward. Then, people will earn a small bit of money on delivering their waste to the skip, while the KCC receives a valuable resource to transform into usable energy. This will also imply more resources available for energy utilization of the MSW, because the collection rate will increase due to a strengthening of the incentive of collecting the waste. The ripple effects of this will be more positive if a system for energy utilization of the MSW is constructed. If landfilling still is the final treatment of the MSW, the incentive for KCC to improve the collection rate is not as clear as if the MSW is utilized for energy. Therefore, the construction of a combustion plant for MSW is recommended. This will be a sustainable way of handling the MSW, it will deliver electricity to the Ugandan grid and KCC will earn money from selling the electricity produced.

Production of briquettes or charcoal from biomass residues can serve as an additional supply of solid fuel to fill the increasing demand the next years and even also replace some of the charcoal used today. If charcoal from bagasse is marketed as a fuel of higher quality than the existing charcoal, a slightly higher price may also be justified. But, it is important to as far as possible to be competitive on price. A fuel change from wood based charcoal to charcoal from agricultural residues should also be followed by an improvement of the stoves used for cooking.

The results have shown that the efficiency as much as the fuel is determining the resource consumption and the environmental and health impacts associated with the consumption. This is even more important than the fuel. It is important that the effort to introduce improved charcoal and firewood stoves is continued, like the energy advisory project. The work to improve the stoves used in the households should also be paid more attention to by development aid organizations.

12 Further research

There are many residues from the crops studied in this thesis that is only mentioned in this thesis, and not studied in detail. The residues covered in this thesis are the most well proven ones, with numerous examples of successful utilization around in the world, and also in Uganda for some of them. But also some other parts of the crops represent an energy potential. One example is sugar canes, where cane tops, leaves and trash represent an energy potential (Beeharry, 2000), as well as molasses (Hugot, 1972). In terms of usable energy, the use of cane tops and leaves represent a potential to increase the energy production with a factor of 1.62 compared to the current energy from bagasse, and 3.25 in the case of trash. These resources represent a further potential to utilize energy from sugar canes, and can be an interesting topic after solutions for utilization of bagasse has been developed. The utilization of leaves, stalks and straw from other residues are also among the issues only discussed to some extent in this thesis, and further research also on these groups will be interesting.

The proposals of action sketched in the conclusion all need further development and research to be realized. One example is the reorganizing of the waste collection system to a system where the waste represents a resource to pay for and not a problem to collect money to get rid of. There is a need of further research and development of the system before an eventual realization.

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Appendix

Appendix 1: The interview log from the field work in Uganda is attached electronically in the cd attached to the document.

Program for industriell økologi (IndEcol) er et tverrfaglig universitetsprogram etablert i 1998 for en periode på minst ti år ved Norges teknisk-naturvitenskapelige universitet (NTNU). Programmet omfatter et studieprogram opprettet i 1999 og et stort antall doktorgradsprosjekter og forskningsprosjekter rettet mot vareproduserende industri, energi- og byggesektoren. Tverrfaglig forskning og undervisning står sentralt ved IndEcol, og målet er å knytte sammen teknologiske, naturvitenskapelige og samfunnsvitenskapelige bidrag i letingen etter bærekraftige løsninger på produksjon og forbruk av energi og ressurser.

The Industrial Ecology Programme (IndEcol) is a multidisciplinary university programme established at the Norwegian University of Science and Technology (NTNU) in 1998 for a period of minimum ten years. It includes a comprehensive educational curriculum launched in 1999 and a significant number of doctoral students as well as research projects geared towards Norwegian manufacturing, energy and building industries. The activities at IndEcol have a strong attention to interdisciplinary research and teaching, bridging technology, natural and social sciences in the search for sustainable solutions for production and consumption of energy and resources.

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