FRIM REPORT NO. 97003 ODC 867:891

CHARCOAL PRODUCTION STUDY IN BLANTYRE AREA

STEPHEN DAVID MAKUNGWA

MARCH 1997

ACRONYMS AND ABBREVIATIONS:

BPMS	Biomass Production and Marketing Study
ESU	Energy Studies Unit
FRIM	Forestry Research Institute of Malawi
DBH	Diameter at breast height
m	metre
m^3	metre cubic
Km	Kilometre
Kg	Kilogram
MK	Malawi Kwacha
ZK	Zambian Kwacha
1US$ =	15 MK (as of May 1996)
Ka	Kangankundi charcoal production site
Ph	Phalula charcoal production site

Standard kiln size = 13.5 for Ka and 10.1 for Ph

Net charcoal weight per bag = 32.4 kg for Ka and 26.6 kg for Ph

Average basic density = 641kg/m^3

Stacking percentage = 57% for Ka and 54% for Ph

Volume = $9Ld^2_m/4$; (Huber`s formula)

EXECUTIVE SUMMARY:

Charcoal production study is one in a series commissioned by the Ministry of Energy and Mining on Biomass Production and Marketing Study (BPMS) in four main towns of Malawi. The objective of the Charcoal Production Study was to review the traditional charcoal production method, assess its efficiency and its production costs.

The study was conducted from mid April to mid May 1996 in Phalula main area, along the old Matope road (Zalewa road). The site was selected based on the existence of well-established charcoal production activities as revealed by the Biomass Production and Marketing Study (BPMS) undertaken earlier in the year. The site was also regarded as one of the main suppliers of charcoal to Blantyre City, the city most dependent on charcoal in Malawi. This report summarises the findings of this study and proposes areas of intervention in order to improve and make the traditional charcoal production sustainable.

The study area was stratified into three sites. The total of 32 households was chosen in all the sites to work with the study team for a period of one month. During the study, the team collected the socio-economic data about the charcoal producers using questionnaires and later examined in detail their production process from felling of the trees to the production of the final product - charcoal. Felled trees were also measured by species, for volume, weight and moisture content.

The study showed that over 50% of the charcoal producers were involved in charcoal production on a full-time basis. About 77% of all the charcoal producers were men of whom 60% were married. Most female charcoal producers encountered during the study were producing charcoal on a part time basis, an indication that charcoal business is predominated by men, probably due to the strenuous nature of the charcoal business itself.

The study also showed that social constraints such land ownership often limit access to potential wood resource for charcoal production. Charcoal is mainly produced on customary land where access is only granted to individuals upon consultation with the village headman.

Wood harvesting and crosscutting is solely done by using axes. The stump height of felled trees were 0.6m and 0.8m for Kangankundi and Phalula, respectively, and the difference was significant ($t = 2.25$; $p < 0.05$). Thus trees were cut higher up the stump in Phalula than in Kangankundi.

Felling of trees was done on a selective basis. Charcoal producers leave trees of species that produce charcoal of poor quality. These species include *Burkea africana*, (Mkalati) *Lannea discolor* (Chiumbu) and *Diplorhynchus condylocarpon* (Mthombozi). Some species are left standing because their wood is too hard to cut with axes. These uncut trees were dominated by *Acacia nigrescens* (Mkunkhu) and *Pericopsis angolensis* (Mwanga). The diameter structure of residual trees did not differ significantly from that of cut trees for charcoal making (chi-square test at $P > 0.05$). This observation suggests that tree felling for charcoal making is not selective for a particular diameter class.

The study showed that the type of kiln used for charcoal making was the traditional earth kiln. The site for kiln construction was cleared, levelled and compacted before the wood is piled layer by layer on top of the stringers. The pile is covered with grass and lumps of soil. The size of the kiln varies depending upon the proximity of the available wood and the level of experience of the charcoal maker in charcoal making. The standard sizes of earth kiln in the study areas were 13.5m^3 for Kangankundi and 10.1m^3 for Phalula. The mean moisture content on dry weight basis of piled wood ranged from 39% to 90% with an average of means of 72% (SE = 5.6).

The kiln was ignited soon after covering the pile. the time needed to complete the burn depended on the size of the kiln and the moisture content of the wood the time the kiln was ignited. About 83% of the charcoal producers said that the carbonisation (burning) stage was crucial in the production process and unless it is carried out as efficiently as possible it puts the whole operation of charcoal production at risk. At this stage tending of the kiln is 24 hours to ensure that any crack on the kiln is attended to, to avoid complete combustion of the wood. Harvesting starts a few days after ignition.

The mean dry weight of the wood put in a standard kiln for Kangankundi and Phalula were 4940 kg and 3493 kg respectively. The mean weight of charcoal recovered from such kilns were 1107 kg and 755 kg, respectively. Some charcoal was abandoned at the kiln site in the form of fines and pieces that were too small to be used. The mean weight of the abandoned charcoal was 26.9 kg (SE = 0.01) and 31.2 kg (SE = 0.004) for similar sites respectively.

The computed recovery and conversion efficiencies of charcoal production in Kangankundi using the earth kiln type of production method were 22.4% and 22.95%; whereas in Phalula the values were 21.5 and 22.56, respectively. The factors such as carbonisation temperature, wood moisture content and skill of the operator were the main determinants of the conversion efficiency.

During the study the daily productivity of charcoal production was estimated at 25 kg per day per producer assuming working 8 effective hours a day.

Labour, wood raw material and tools used in the production process were the factors considered in estimating the charcoal production costs. An opportunity cost of alternative employment (agricultural labour) was used to compute labour costs in charcoal production. The labour cost was estimated at MK16.00 per man-day at various unit operations. The costs of wood raw material and that of tools were estimated at MK3.37 and MK0.40, for a 32-4kg bag of charcoal for Kangankundi and MK1.22 and MK0.32 for a 26.6 kg-bag for Phalula, respectively.

The overall charcoal production cost in Kangankundi came to MK18.75 to produce a 32.4 kg-bag of charcoal. The selling price of such a bag of charcoal at the production site was MK20.00. In Phalula the production costs came to MK13.68 for a 26.6 kg-bag whose selling price at the production site was K15.00. At the roadside, five to seven kilometre away, the price of a bag of charcoal was MK25.00, regardless of the bag sizes.

Based on the assumptions that the current charcoal production situation is not intervened, the future charcoal production environment will be characterised as follows:

1 Unavailability of desired indigenous tree species for charcoal production such as *Brachystegia floribunda* (Tsamba), *Pseudolachynostylis maprounefolia* (Msolo), *Brachystegia bussei* (Mseza) and *Pterocarpus rotundifolia* (Mbalitsa) in the charcoal producing areas. During the study it was discovered that the charcoal producers could shift from using these preferred tree species to other species like *Diplorrhynchus condylocarpon* (Thombodzi) in making charcoal due to the scarcity of the preferred species.

2 Invasion of the catchment areas by charcoal producers.

3 An increase in a number of rural households involved in charcoal production business, which is a response to an increase in urban demand for charcoal. Arpaillange J (1996) estimated that charcoal consumption by urban households is anticipated to increase from current consumption of 54 percent to 64 per cent of the total regular households charcoal-users living in Blantyre alone by the year 2005.

Therefore, the main issues affecting charcoal production that must be taken into account when developing an intervention strategy in charcoal production process are:

- the environmental impact of charcoal production on forest resources; and
- the essential role of charcoal production as an income earner in the rural economy and as a supplier of indigenous energy resource to the urban people.

The study had shown that most of the charcoal wood comes from areas that are converted to agriculture either on shifting cultivation cycle or permanently converted to arable agriculture. In order to slow down woodland clearing, agricultural productivity has to increase. The strategy for increasing crop productivity, besides using organic and inorganic fertilisers and manure, would be planting agro-forestry tree species such as *Faiderbia albida (msangu), Gliricidia sepium* and others that will improve soil fertility. In areas where the main agricultural activity is shifting cultivation, then improved management of trees in the abandoned areas may lead to a quicker and better regeneration of the desirable wood species.

ACKNOWLEDGEMENTS:

The consultant would like to acknowledge all those individuals and institutions who directly or indirectly have by their work and co-operation greatly contributed to the successful completion of the fieldwork and this report. In particular, the consultant would like to acknowledge the important contribution of Dr S Khaila, Director, and Mr M Nyanda of Centre for Social Research; Mr LB Mhango of the Ministry of Energy and Mining; Mr D Kayambazinthu and Mr L Sitaubi of Forestry Research Institute of Malawi. To all the research assistants; U Nthenda, W Sabola, T Chauluka, F Nyasulu, M Chilunga and M Issa including Mr Kunje, driver; working with you boys in the field and later in data entry was an experience. Your perseverance, hard work and cheerfulness are highly appreciated. Also the moral support received from all FRIM staff especially during the writing up phase of this report is also appreciated.

I am also indebted to Mr Phillip Mbewe, the village headman of Kangankundi area for his understanding and co-operation throughout the field study period and all the 32 households who kindly answered the questionnaire and accepted to work tirelessly with the study team for one full month.

TABLE OF CONTENTS:

1.0 INTRODUCTION:

This report is one in a series commissioned by the Ministry of Energy and Mining covering the Biomass Production and Marketing Study (BPMS) in four main towns of Malawi. The study was planned to cover the four main towns of Malawi to detect regional differences in charcoal production methods. However, it was later realised that the cost would have been too high and the idea was, therefore, abandoned. It was finally decided to confine the study only to production sites supplying charcoal to Blantyre City, the city most dependent on charcoal in Malawi.

The report summarises the findings of this detailed study of the charcoal production process with particular emphasis on the techniques traditionally employed in this process. The results of this study would be incorporated into a working paper on woodfuel and other biomass energy production for urban sector of Malawi.

About 93 per cent of all wood taken from Malawi's indigenous forests are burnt as fuel, either directly or by first converting it into charcoal. Fuelwood and charcoal are the principal urban household fuels for cooking and heating, making up 94 per cent of the total urban households' energy requirements in Malawi, (Arpaillange J 1996).

A study conducted recently by Ministry of Energy and Mining (Arpaillange J 1996) showed that charcoal is the second largest source of energy supply to urban households in Malawi after fuelwood. About 65 per cent of all urban households use charcoal and the economic case for charcoal rests upon it being a more concentrated form of energy than fuelwood with some consequent advantages of saving on transport costs.

Most charcoal sold in Malawi's major cities of Blantyre, local people in adjacent forest areas surrounding these cities, (ESU 1984), produce Lilongwe, Mzuzu and Zomba. A survey conducted in 1996 (Arpaillange J 1996) revealed that 83 per cent of the households living in Blantyre use charcoal as opposed to 56 per cent in Lilongwe, 51 per cent in Mzuzu and 33 per cent in Zomba. This charcoal is produced by the traditional earth kiln method described by some researchers in other countries (Chidumayo 1990, 1987; Openshaw 1986). Although the different phases of this technology have been described, quantitative and scientific aspects of this production process are poorly understood. And yet for renewable energy planning and charcoal pricing, it is essential to quantify the efficiency and costs of a production method.

It was against this background that this study was undertaken and was designed to:

1. review the traditional charcoal production method including assessing its efficiency and cost of charcoal production. Production efficiency is here defined as the amount of charcoal produced from a given weight of wood;

2. gather socio-economic data about the charcoal producers;

3. identify areas of intervention to improve the efficiency of the production process.

2.0 METHODOLOGY:

The charcoal production study was conducted from mid-April to mid-May 1996. This meant that the study was largely done towards the end of the rainy season. The study involved observing and monitoring the charcoal production process, from the felling of trees to the production of the final product, over a period of one month. The charcoal production process was not studied in a chronological order in the field due to limited time. Typically, a charcoal producer had several production units at various stages of production and these were all studied despite the production phase they were in.

Besides monitoring the production process in detail, thirty-one sample producers were interviewed about the entire production process. This was done using a questionnaire prepared in consultation with an international consultant of the Biomass Production and Marketing Study. The questionnaire was designed to collect a different set of data about charcoal producers and their production process including their views about the charcoal business.

Charcoal production is mainly concentrated on customary land in adjacent peri-urban and rural areas near roads leading to cities and towns. Studies have shown that much of the Blantyre's charcoal comes from areas along the Chikwawa, Mwanza and Matope roads; Matope road being the main supplier, (ESU, 1984). Based on this information, areas along the Matope road were therefore chosen as the study sites for this project.

3.0 STUDY SITES:

The charcoal production study was conducted in Phalula area, 70 - 90 km northwest of Blantyre City along the old Matope road (Zalewa road). The study area was divided into three sites. Each site was selected based on the existence of well-established charcoal production activities as revealed by the Biomass Production and Marketing Study (BPMS) undertaken earlier in the year. The first site was located in Kangankundi area belonging to village headman Philip Mbewe in Traditional Authority Msamala in Machinga district. The site is 5 km to the east of Zalewa road and about 3 km before Senzani trading centre on the road to Blantyre. The second site was located about 7 km to the west of Phalula rural growth centre, in the area of village headman Machereza in Ntcheu district, and the third site was in Traditional Authority Simon Likongwe's area in Mwanza district.

The study sites were all under customary land with the main vegetation type being miombo woodland dominated by *Brachystegia* tree species. The woodland invariably consisted of mixed-age trees due to natural and/or human disturbances either for shifting cultivation or charcoal production.

The number of study samples from each study site were not uniform because the sampling system was dependent on the level of charcoal production and the presence of charcoal producers in the field at the time of sampling.
As the study focused only on one major source of charcoal supply, it was assumed that this differential sampling system could not unduly influence the accuracy of the results.

Lisungwi had a least number of study samples (5) (table 1) of the three sites. The data from Lisungwi was, therefore, pooled together with that of Phalula as there was no significant differences at 95% significance level in the parameters studied, besides being a small sample.

4.0 CHARACTERISTICS OF CHARCOAL PRODUCERS:

Table 1 shows the characteristic of the charcoal producers involved in the study. A total of thirty-one producers were interviewed about their production including studying their production process. The study showed that just over 50 per cent of the charcoal producers were involved in charcoal production as the only source of cash income and most of them were men (77 per cent) of whom 60 per cent were married and were working in family teams in producing charcoal. Thus the charcoal business is predominated by men, probably due to the strenuous nature of the charcoal business itself. The few females encountered during the study were working as individual producers with minimum or no assistance at all from other members of their families. Eighty-eight percent (88%) of the women were from female headed households who were either widowed or divorced; hence resorted to charcoal burning due to limited sources of cash income available to them.

Table 1: Characteristics of charcoal producers in the study sites.

Type of producer and sex	Kangankundi		Phalula		Lisungwi	
	Self Employed	Employee	Self employed	Employee	Self employed	Employee
Full time						
male	5	0	5	0	2	0
female	1	0	0	0	2	0
Part time						
male	3	0	9	0	0	0
female	3	0	0	0	1	0
Total	12	0	14	0	5	0

5.0 CHARCOAL PRODUCTION METHOD:

Charcoal is produced by the traditional earth kiln method in which wood is stacked on the ground and the stack covered with earth. The earth acts as a shield against oxygen and insulates the carbonising wood against excessive loss of heat. This method of charcoal making is very old and is widely used in many countries. It can be divided into the following distinctive unit operations:

(a) Wood accessing
(b) Wood harvesting and crosscutting
(c) Kiln building
(d) Earthing the kiln
(e) Carbonisation
(f) Charcoal harvesting and bagging

5.1 Wood accessing

Social constraints such as land ownership often limit access to potential wood resource for charcoal production in the study sites. Land ownership in the study sites is under one of the three forms, namely, Public, Private and Customary. The woody biomass in the study sites is under customary land where access is only granted to individuals upon consultation with the village headman.

The customary land is administered by village headmen who hold the land in trust and allocates to individuals as cropland. Trees are usually clear-felled to open land for crop production either on shifting cultivation cycle or permanently converted to arable agriculture. The felled trees are usually used for charcoal making and 93% of the charcoal producers obtain their wood through this means. The remaining 7% obtain their wood illegally from both private and customary land. The wood used for charcoal making was all obtained from indigenous natural woodlands

5.2 Wood harvesting and Crosscutting

Wood harvesting and crosscutting is solely done by using axes (Table 4). Mean stump height of felled trees in Kangankundi was 0.6 m (SE = 0.02) while that of Phalula was 0.8 m (SE = 0.05). The difference in stump heights between the two sites was significant ($t = 2.25$, $P < 0.05$). Thus the trees were cut higher up the stump in Phalula than in Kangankundi. The producers indicated that the stump heights had no bearing on regeneration of sprouts.

The felled trees were cut into logs at the stump in order to ease haulage to the kiln site. They were crosscut into 1 - 2.5 m long logs. Twigs and branches were also collected for filling in stackwood spaces and acting as stringers during kiln construction. Thus the only above ground cordwoods discarded *in situ* were stumps. This is in contrast to observations made in Zambia (Chidumayo, 1990) and Kenya (Western and Ssemakula, 1981) where charcoal producers discard branches with butt diameter smaller than 12.6 cm and 15 cm, respectively

Felling of trees was done on a selective basis leaving undesirable tree species. Charcoal producers leave trees of species that produce charcoal of poor quality. These species include *Burkea africana*, (Mkalati) *Lannea discolor* (Chiumba) and *Diplorhynchus condylocarpon* (Thombozi). Some species are left standing because their wood is too hard to cut with axes. These uncut trees were dominated by *Acacia nigrescens* (Mkunkhu) and *Pericopsis angolensis* (Mwanga). The distribution of diameter at breast height (DBH) of the uncut trees is given in Table 2. The diameter structure of residual trees did not differ significantly from that of cut trees for charcoal making (chi-square test at $P > 0.05$). This observation suggests that tree felling for charcoal making is not selective for a particular diameter class. This observation is similar to the observation made in Zambia (Chidumayo, 1987) but is in contrast to that made in Kenya where charcoal producers preferred trees with diameter at breast height of 64 cm, (Western and Ssemakula, 1981).

Table 2: Distribution of diameter at breast height (DBH) of uncut trees in the Study Area (in per cent)

			Diameter Range (cm)			
Species	**Local name**	**Basic Density**	**1-10**	**11-20**	**21.30**	**>30**
Bauhinia thonningi	(Chitimbe)	595	33.3	33.3	33.3	-
Lannea discolor	(Chiumbu)	-	36.5	45.5	18.0	-
Jubernadia globiflora	(Mchenga)	644	25.0	25.0	50.0	-
Diospyros kirkii	(Mchenje)	-	20.0	67.0	13.0	-
Acacia karoo	(Mpampa)	666	-	-	100.0	-
Burkea africana	(Mkalati)	-	25.0	50.0	25.0	-
Acacia nigrescens	(Mkunkhu)	-	20.0	20.0	40.0	20
Pterocarpus angolensis	(Mlombwa)	-	-	100.0	-	-
Xeroderis stulhmann	(Mulondo)	-	-	-	100.0	-
Albizia harveyi	(Njenjete)	-	-	100.0	-	-
Brachystegia boehmii	(Mombo)	598	-	50.0	-	50.0
Lonchocarpus capasa	(Mswamswa)	-	-	50.0	50.0	-
Pseudolachynostylis maprouneifolia	(Msolo)	595	22.0	56.0	22.0	-
Terminalia sericea	(Naphini)	-	-	50.0	50.0	-
Brachystegia bussei	(Nseza)	-	-	-	25.0	75.0
Diplorrhynchus condylocarpon	(Thombodzi)	-	14	86.0	-	-
Brachystegia floribunda	(Tsamba)	676	8.0	38.0	23.0	31.0

5.3 Kiln building

After crosscutting the logs are left out to dry for varying periods before they are gathered and piled into a stack at a kiln site. The drying periods vary depending on local conditions, species of wood used, and labour availability of the charcoal producers. Haulage of wood to kiln site is done manually.

Kiln siting is decided based on local site factors such as soil type, drainage and terrain. The majority (96 per cent) sites the kiln in an open place that gets plenty of sun and wind. The terrain is flat to undulating with well-drained deep soil in order to be able to get enough soil lumps for covering the kiln.

The site is cleared, levelled and compacted before a kiln is built. Stringers of about 5-8 cm in diameter and 2-3 cm in length are first laid lengthwise on the ground. The wood to be carbonised is then packed densely layer by layer crosswise on this platform. The purpose is to allow the fire and gas to circulate properly within the kiln.

Gaps between logs are packed with small wood to make the pile as dense as possible. The surface of the pile is packed out with small fuelwood that gives even profile and provides good support to the earth covering.

Once the kiln is built, it may remain uncovered for sometime to allow the pile wood to dry out further; but often covering follows immediately.

The moisture content of piled wood was measured at the time of earthing. The moisture content was measured using a Gunn's electronic moisture metre HT 75. This instrument gives moisture content on a dry basis ranging from 0.0-0.1 expressed in percent. The moisture content on dry basis is given by the formula: (wet weight - dry weight) / dry weight. The metre has a timber selector with range 1-4 positions that are suitable for different timber species. Unfortunately the appropriate timber selector for measuring moisture content of most of miombo woodland species is not shown in the metre handbook. However for unclassified miombo species timber selector three is recommended (Chidumayo, 1990) and this position was used to measure the moisture in this study. The mean moisture content of piled wood of different miombo species during earthing in the study area is given in Table 3. The mean moisture content ranged from 39 - 90 per cent with an average of means of 72 per cent (SE = 5.6) for different species (Table 3).

Table 3: Mean moisture content (MC) of wood during earthing process

Species	Local name	Moisture content (MC) dry basis (%)	Moisture content (MC) wet basis
Brachystegia floribunda	(Tsamba)	65	39
Brachystegia boehmii	(Mombo)	78	44
Brachystegia bussei	(Mseza)	39	28
Pseudolochynostylis maprounceifolia	(Msolo)	90	47
Pterocarpus rotundifolia	(Mbalitsa)	88	47

All kilns in the study were rectangular. In Kangankundi the average kiln size was 13.5 m^3 (n = 12, SE = 2.8) while in Phalula it was 10.1 m^3 (n = 13, SE = 1.9). The difference between the two sites was not significant (t = 0.29; P > 0.05). Therefore the mean kiln for the pooled data was 11.7 m^3 (SE = 1.7). This will be regarded as a standard kiln size and will be used in the proceeding discussions.

After cooling the charcoal is carefully separated from the soil and piled aside for bagging. During separation, the fully burned lump charcoal is separated from fines and 'brands' and these are piled separately. Usually partially burnt charcoal and fines are put in the lower parts of the bag while the fully - burned lump charcoal is bagged last to attract customers.

This harvesting, cooling and bagging of charcoal are done simultaneously but intermittently as the carbonising process proceeds. Sometimes charcoal is sold as soon as it is bagged at the production site. At the production site an average bag of charcoal (30kg) was sold at MK15 while along the road the same bag was sold at MK25.

5.7 Tools used in charcoal production

A variety of tools were used at the different stages of the production process. Table 4 shows the tools and the frequencies of their use at each stage of charcoal production process. The frequency was calculated based on the number of individual producers as a percentage of the total study sample using a given tool at each unit operation.

The table shows that an axe is the main tool in felling and crosscutting whereas a hoe and a shovel are the principal tools in digging soil lumps, building the kiln and in harvesting and bagging the charcoal.

Table 4: Tools used at each stage of charcoal production

Type of tool	Frequency in percent with which tools were used during different stages of production				
	Felling & crosscutting	Log haulage & piling	digging soil lumps	Building kiln	Harvesting & bagging
Axe	100	0	0	0	0
Hoe	0	0	100	100	100
Shovel	0	0	81	81	81
Panga	84	0	0	0	0
Sickle	61	0	0	0	0

5.4 Earthing the kiln

Covering of the kiln starts with building the lateral walls. In building the lateral walls the circular soil lumps are piled layer by layer against the wood. Instead of using only circular soil lumps, 60 per cent of sample producers first mowed grass and laid it at an angle such that the base of the grass lies against the kiln while the top of the grass touches the top of the kilns. The soil lumps are thrown on the lateral walls to cover the grass against the wood. The top of the kiln pile is covered with a layer of leafy material such as straw, leaf and course grass. These are spread over the pile and earth is spread over this layer. The leafy material prevents the loose soil from clogging empty spaces between the logs before carbonisation takes place.

The place at which the kiln will be ignited is left uncovered. Eighty - seven per cent of the sample producers position the ignition hole along the wind direction against 17 per cent who located it across the wind direction. In spite of these differences in locating the ignition hole, all respondents (100 percent) believe that the location of the hole affects the speed and efficiency of the carbonation process. The seventeen per cent believe that when the wind is bounced by an obstruction it gets into the mound through the hole placed across and slowly eases the ignition of the kindling wood. Several other air spaces ranging from four to ten depending on the size of the kiln are left uncovered at the base of the kiln. The air spaces (vents) act as 'breathing points' as the wood is carbonising.

5.5 Carbonisation

Immediately after covering, the charge (kiln) is ignited. A shovel of burning wood and charcoal is put in the hole and this ignites the kindling wood placed in the hole. Once dense white smoke is seen from the top in less than one hour, indicating that the fire has taken hold, the ignition hole is sealed with earth to allow controlled carbonisation of wood. Over a few days the smoke becomes bluish and finally becomes clear. The time needed to complete the burn depends on the size of the kiln and the moisture content of the wood during the earthing stage. Most of the charcoal producers (83 per cent) said that the carbonisation stage was crucial in the production process and unless it is carried out as efficiently as possible it puts the whole operation of charcoal production at risk.

As carbonisation proceeds, the volume of the kiln shrinks and this causes parts of the wall and ceiling to fall in and form cracks, these must be filled with fresh soil lumps to ensure efficient carbonisation.

5.6 Charcoal harvesting and bagging

Charcoal harvesting from kiln starts a few days after the kiln has been ignited, at the end where the fire started, and gradually moves along the kiln as carbonisation proceeds towards the other end. This harvesting is repeated every four to five days depending on the rate of carbonisation. The charcoal is removed from the kiln, spread out and immediately covered with fresh soil. Some charcoal producers (36 per cent), instead of removing charcoal from the kiln, just throw fresh soil directly onto the part of the kiln carbonised to cool the charcoal.

6.0 CONVERSION EFFICIENCY:

The conversion efficiency of the charcoal production method refers to the amount of charcoal produced from a given weight of wood. To calculate the conversion efficiency, the weight of the wood and charcoal made from the wood must be determined.

In this study the lengths and midpoint diameters of individual logs in 12 sample kilns were measured to find the volume. The volume was estimated using the Huber's formula;

$$V = \theta L d^2_m / 4;$$

Where V = volume of log (m^3),
L = log length(m)
d_m = diameter at mid-length of log.

As there are no local regression models developed yet for dry miombo in Malawi, a regression model developed in the Biomass Assessment Study in dry miombo of Zambia was used to convert the cord wood solid volume data to dry weight (Chidumayo, 1990). The regression model used is:

Dry weight of cordwood (Kg) = 536.65 sov + 7.25
where sov is solid volume (m^3).

Based on the regression model, the mean weight of cordwood in Kangankundi was 4940 KGs (SE 1.96) The mean weight of cordwood was 2780 KGs (SE = 1.6) in Phalula. The difference in mean cordwood weights was not significant between Kangankundi and Phalula, ($t = 0.87$, $P > 0.05$).

To find the weight of charcoal made from wood, the number of bags of charcoal produced at each sample kiln were counted and a subsample of the bags weighed. The weight of a sample of empty bags was also measured so that the net weight of charcoal in a bag is detected. Although charcoal is packed in bags after harvesting from the kiln, some charcoal is left at the kiln site. The abandoned charcoal is in the form of fines and pieces that are too small to be used. The amount of abandoned charcoal was assessed in plots of 1 x 1 m^2 in size located randomly in the area covered by charcoal remains on each sample kiln site.

The area with charcoal remains was measured and all the recoverable charcoal in 1 x 1-m^2 plots was gathered by hand and weighed. The weight of the abandoned charcoal in the 1 x 1-m^2 plots was extrapolated to the total area covered by charcoal remains at the kiln site to derive an estimate of the amount of recoverable charcoal left on site.

The standard net weight of charcoal was 26.6 kg (SE = 0.5) per bag in Kangankundi whereas the standard net weight in Phalula was 32.4 kg (SE = 0.6) per bag. The difference in bag weight between the two sites was significant ($t = 3.8$; $P < 0.05$). Thus the weight of 26.6 kg will be used in calculating conversion efficiency of charcoal production and its productivity for Kangankundi area while the standard weight of 32.4 kg will be used in calculating the conversion efficiency for Phalula area.

The mean weight of abandoned charcoal at the kiln site was 26.9 kg (SE = 5.2) in Kangankundi and 31.2 kg (SE = 4.7) in Phalula. The difference was not statistically significant ($t = 0.5$; $P > 0.05$). Although the difference was non-significant the value at each site was used in calculating the recovery efficiency of the earth kiln production method. Recovery efficiency refers to the amount of charcoal actually bagged from a given quantity of wood.

Table 5 shows the estimates of conversion and recovery efficiencies of the earth kiln production method in the study areas. The differences in recovery and conversion efficiencies between the two sites were not statistically significant ($t = 1.05$; $p > 0.05$). The overall mean conversion and recovery efficiencies were 22.76% (SE = 0.2) and 21.48% (SE = 0.08), respectively.

Openshaw (1986) reported that the woody biomass contains 50 per cent carbon by weight and as such it is impossible to obtain 50 per cent wood - to - charcoal conversion efficiency using any type of production technology. In Zambia the conversion efficiency of earth kiln technology was found to be 27 per cent (Chidumayo, 1990). Studies elsewhere have also shown that the upper limit of wood - to - charcoal conversion efficiency in earth kiln technology is 30 per cent. Judging by these figures, the conversion efficiency of the earth kiln method in the study areas of 22.76per cent is relatively acceptable.

Table 5: Cordwood to charcoal conversion and recovery efficiencies in Kangankundi and Phalula areas. (Figures in parentheses show standard error).

Area	Kiln vol.	Wood vol.	Stack%	Dry wt	Charcoal yield			Efficiency	
					Recovered	Abandoned	Total	Recovery	Conversion
				a	*b*		*c*	*b/a*	*c/a*
	m^3	m^3	%	(Kgs)	Kgs			Percent	
Ka	13.5	7.61	57	4940 (1.96)	1107 (4.2)	26.90 (0.1)	1133.90	22.41	22.95
Ph	10.1	5.45	54	3493 (1.6)	755 (1.6)	31.20 (0.04)	786.20	21.61	22.57

Says 2780 on previous page

However, it is reported that charcoal in an earth kiln is produced at a relatively low temperature of 300 - 500 °C (Ranta and Makunka, 1986). Low carbonisation temperatures give a higher yield of charcoal but this charcoal contains appreciable amount of tars between 16 - 31 per cent by weight. Thus the conversion efficiency of 22.76% observed in this study (Table 5) may partly be explained by a high content by weight of volatile tarry residues in the charcoal. At high carbonisation temperature, these tarry residues are either burnt or expelled resulting into an increase in the fixed carbon content and low tar content.

Wood moisture content and the skill of the operator are also known to greatly influence the conversion efficiency of charcoal production in earth kilns. The skill of the operator of earth kiln is difficult to measure quantitatively. During the study, 83 per cent of the sample producers mentioned experience as the main determinant of conversion efficiency. The aspect of experience that affects conversion efficiency was largely related to earthing and maintenance of the kiln during carbonisation process. The operator needs to be skilful and alert during these operations if the yield and quality of the product are to be high.

During the study only 13% mentioned wood moisture content as one of the main factors affecting the conversion efficiency; yet it is conventionally known to be the major factor. Wood moisture content affects the conversion efficiency because of its effect on the heat budget in the kiln. Extra heat is required to drive out the moisture before the wood is carbonised, therefore, the drier the wood the less energy is used inside the carbonising kiln in evaporating the moisture.

Wood moisture content and skill of the operator are both important in determining conversion efficiency. Both are linked to the heat and air budgets in the kiln. Little is known about the effect of the period of carbonisation on conversion efficiency. It is possible that a kiln with high wood moisture content may carbonise slowly over a longer period due to high-energy use for drying the wood, but still achieve high conversion efficiency. This relationship is not apparent in Table 7. It was also not possible to test the energy value of the charcoal from each kiln.

There may be variations that could affect the energy value of the charcoal when compared to a 'standard' charcoal with a specific energy value such as that assumed in this report of 28 MJ / kg at 5 per cent moisture content on dry basis and 4 per cent ash content. Clearly many factors may affect conversion efficiency and controlled field experiments are necessary to evaluate a role of each of these factors.

7.0 CHARCOAL PRODUCTIVITY:

Charcoal productivity is here defined as the amount of charcoal produced per given quantity of time and effort. In this study time and effort were estimated based on man-hours taken to complete a specific unit operation in the production process. As this study was done at the end of the rainy season, the sample producers were asked about seasonal variations in charcoal production. The majority (93 percent) said that the production was low during the rainy season. They spend more time on agricultural activities and kiln management is \difficult because of the rains. This implies that the time and effort provided for charcoal making varies with season. Thus the results given in Table 7 might be on the low side indicating high productivity in terms of labour inputs per unit operation than would be expected in the rainy season.

Table 6: Labour input in a standard charcoal kiln for Kangankundi and Phalula

Operation	Man-days	
	Kangankundi	Phalula
Felling	3.49	4.34
Cross-cutting	3.57	4.20
Haulage of wood	2.60	3.10
Building kiln	3.57	4.40
Carbonisation harvesting bagging	9.71	12.10

Table 6 show that the longest stage in charcoal production process is a combination of carbonisation, harvesting and bagging. It should be noted that tending the kiln during carbonisation process is an intermittent operation and other jobs are done at the same time.
It was observed during the study that 46 per cent of the sample producers were operating more than one kiln simultaneously, despite the kilns being at different stages of production. This observation has also been made in Zambia where charcoal producers operate several charcoal kilns simultaneously, (Chidumayo, 1990).

During the study it was observed that many producers were not working a full man-day in the production process. This was because of the strenuous nature of the work and agricultural activities were keeping them busy. Therefore, the average daily production was measured based on the number of man-hours worked each day as a fraction of the eight-hour man-day. This gave an estimated daily productivity of 25 kg per kiln per producer.

To find out the annual charcoal production per producer, the producers were asked about the number of months they were actively involved in charcoal making the previous year (1995) including the number of kilns managed and number of bags yielded from each kiln.
Direct extrapolation could not be done as this could underestimate production since some producers were managing more than one kiln at a time.

The results gave a mean of 4.1 (SE = 0.29) kiln per year per producer with an average charcoal production of 2.03 Tonnes (SE = 0.4) per kiln. Thus annual charcoal production per producer the previous year (1995) was 9.579 tonnes that gives a production rate of 28 kg per day, assuming 25 workdays per month. The value is higher than the 25-kg per day based on labour production figures recorded during this study.

8.0 COSTS OF CHARCOAL PRODUCTION:

Charcoal in Malawi, as in many developing countries, is produced in the traditional earth mound. This method is known to have a major advantage of requiring little capital outlays (Smith, 1985) and the kiln can be sited near the source of the raw wood material. This criterion of low capital input is important in Malawi where resources are small and access to loans is difficult. In assessing charcoal production cost during the study, three main variables affecting production were considered; namely labour, wood raw material and tools used in the production process.

8.1 Labour costs

The labour inputs for different unit operation in the charcoal production process vary, (Table 6), with carbonisation process being the longest and require the largest labour inputs. On average the charcoal production process involved 22.94 man-days for an average kiln of 572 kg of charcoal. However, in monetary terms it was difficult to calculate the total labour costs because there were no wage labourers involved at any stage of production on which the labour costs could have been based. More than 96% of the charcoal producers were self-employed, and their remuneration depended on the selling price of the charcoal.

Nevertheless, in computing labour costs, the opportunity cost of alternative employment (agricultural labour) was imputed which would reflect its value in charcoal production.
The average labour wage for cultivation in an agricultural field was MK100 per month. This was broken down to MK16 per man-day assuming 25 workdays in a month working 8 hours a day. The imputed costs should be treated with care as the labour rates in charcoal production usually differ according to the operation as was observed in Zambia (Chidumayo, 1990). In Zambia paid labour received ZK40 per day for crosscutting and kiln building, ZK30 per day for felling and ZK12 per day for log haulage and kiln tending. However, in our cost calculations we used the same rate of MK16 per man-day at various unit operations, Table 8.

8.2 Cost for wood raw material

It has been noted earlier that wood raw material is collected freely from customary woodland for charcoal making and there is no stumpage fee charged for such wood. During the study, most producers were found salvaging wood for charcoal making from customary woodlands being converted to farmland that would be wasted. However, in an economic analysis the wood material should be costed as the depletion of the resource is a cost to the society even if no money transactions are involved. The accounting price, in this case, was derived from the cost of wood at a local market in the study area.

The average cost of a one cubic stacked wood in the study areas was MK20. The average solid volume of wood to fill a standard kiln of 13.5m^3 in Kangankundi was 7.1m^3 with stacking percentage of 57% and for Phalula was 5.45m^3 for a standard kiln of 10.1m^3 with a stacking percentage of 54% (Table 5). This gave a stacked volume of 13.35m^3 and 10.09m^3, respectively. Therefore, the cost of wood enough for a standard kiln producing 1107 kgs and 755 kgs of charcoal for Kangankundi and Phalula with conversion efficiencies of 22.95% and 22.56% (Table5) is MK267 (MK7.85 for a 32.4-kg bag) and MK218 (MK7.78 for a 26.6-kg bag), respectively. This assumes that the charcoal producer buys already cut and stacked wood. However, this is very unlikely as producers fell standing trees and crosscut them into logs that are later stacked in mendles. Thus labour costs for these operations should be subtracted. It is estimated that, for a standard charcoal kiln of 1107 kg and 755 kg for Kangankundi and Phalula, respectively, labour requirements for the operations totals to 9.66 and 11.64 man-days (Table 6). The labour input for a 32.4 kg bag of charcoal is 0.28 man-days that gives a cost of MK4.48for Kangankundi and for a 26.6-kg bag is 0.41 man-days that gives a cost of MK6.56 for Phalula, respectively. Therefore the cost of wood raw material per a 32.4- kg bag of charcoal is MK3.37, (MK7.85 - 4.48) and for a 26.6-kg bag is MK1.22 (MK7.78-6.56), for Kangankundi and Phalula, respectively.

8.3 Cost for tools

A third type of production cost involves the outlay on tools used in charcoal making. Table 7 shows expected life expectancy and costs of tools that were commonly used at the study sites.

Using the values in Table 7 and assuming the charcoal production rate of 25 kg per day or 625 kg per month, the price of tools per a standard 32.4-kg bag of charcoal comes to MK0.40; (32.4/625*7.63) for Kangankundi and a 26.6-kg bag for Phalula comes to MK0.32; (26.6/625*7.63)

Table 7: Costs and life expectancy of tools. All values are means.

Type of tool	Price(Mk) per tool	Life expectancy (months) (full time working)	Price per month(Mk)
Axe	22.0	24	0.92
Hoe	20.67	18	1.15
Panga	23.23	18	1.29
Shovel	67.74	27	2.51
Sickle	11.80	12	0.98
Files	14.87	19	0.78
Total	160.31	118	7.63

Table 8 shows the total estimated production cost of charcoal in the study area. The cost of sacks (empty bags) is estimated at MK15 each, and these sacks last for 15 journeys. Overhead costs such as marketing or waiting for a lorry to come and loading charcoal on the lorry, if applicable; and also a profit margin, has been accounted for.

25% mark-up has been assumed to account for these costs. The production cost comes to MK18.75 per bag for Kangankundi and MK13.68 for Phalula as shown in the table.

Table 8: Estimated production costs per a standard kiln and per bag of charcoal in the study area (1996).

Cost component	Workdays	MK/workdays	MK Kangankundi /Kiln	Kangankundi /Bag	Phalula /Kiln	Phalula /Bag
Felling	3.49	8	53.04	1.56	35.84	1.28
Cross-cutting	3.57	8	54.06	1.59	36.68	1.31
Haulage	2.60	8	39.44	1.16	26.60	0.95
Building kiln	3.57	8	54.06	1.59	36.68	1.31
Carbonisation and harvesting	9.71	8	147.22	4.33	99.40	3.55
Total labour cost			347.82	10.23	235.20	8.40
Equipment tools			13.60	0.40	8.96	0.32
Wood raw materials			114.58	3.37	34.16	1.22
Bags			34.00	1.00	28.00	1.00
Sub total			**510.00**	**15.00**	**306.32**	**10.94**
Profit margin & overheads			127.50	3.75	76.58	2.74
Total costs and profit			**637.50**	**18.75**	**382.90**	**13.68**
Selling price			**680.00**	**20.00**	**420.00**	**15.00**
Residual value			**42.50**	**1.25**	**37.10**	**1.32**

The survey found that the price of charcoal at the production site was MK20 per a 32.4 kg bag giving a residual value of MK1.25 for Kangankundi; whereas the price of charcoal at the production site in Phalula was MK15 per a 26.6-kg bag, giving a residual value of MK1.32. At the road side where charcoal is oftenly sold, five to seven kilometres away from the production site, the price of the bag of charcoal was MK25, regardless of the bag size.
This price was uniform in all sites visited indicating that there must have been good communication between charcoal producers about pricing along the roadsides.

However, the charcoal producers indicated that the price is usually decided by one group of producers/retailers at one selling point and soon all producers and/or retailers followed. The actual criteria used in deciding this price did not come out clearly during the study.

9.0 CONCLUSION AND RECOMMENDATIONS:

Charcoal production is one of the rural activities that bring in cash income to poverty-stricken households in charcoal producing areas. This study estimated that over 50 per cent of the sample charcoal producers receive most cash income from charcoal production; an indication that this activity has an essential role in the rural economy and provides a considerable level of rural employment.

However, the activity is based on an indigenous wood raw material that is not managed and used properly in Malawi. Most areas are depleted of the wood through conversion of forestland to agricultural land, among other factors, and the depletion continues at a rate of between 1.0 and 2.8 per cent per annum.

Clearly, in order to slow down woodland clearing, agricultural productivity has to increase. The strategy for increasing crop productivity, besides using organic and inorganic fertilisers and manure, would be planting agro-forestry tree species such as *Faiderbia albida (msangu), Gliricidia sepium* and others, *which* will improve soil fertility. In areas where the main agricultural activity is shifting cultivation, then improved management of trees in the abandoned areas may lead to a quicker and better regeneration of the desirable wood species.

If the current situation of charcoal production is left unintervened, the future charcoal production environment will be characterised by:

1. Unavailability of desired indigenous tree species for charcoal production such as *Brachystegia floribunda*(Tsamba), *Pseudolachynostylis maprounefolia* (Msolo), *Brachystegia bussei* (Mseza) and *Pterocarpus rotundifolia* (Mbalitsa) in the charcoal producing areas. During the study it was discovered that the charcoal producers could shift from using these preferred tree species to other species like *Diplorrhynchus condylocarpon* (Thombodzi) in making charcoal due to the scarcity of the preferred species.

2. Invasion of the catchment areas by charcoal producers.

3. An increase in a number of rural households involved in charcoal production business that is a response to an increase in urban demand for charcoal. Arpaillange J (1996) estimated that charcoal consumption by urban households is anticipated to increase from current consumption of 54 percent to 64 per cent of the total regular households charcoal-users living in Blantyre alone by the year 2005.

Therefore, the main issues affecting charcoal production that must be taken into account when developing an intervention strategy in charcoal production process are:

- the environmental impact of charcoal production on forest resources; and
- the essential role of charcoal production as an income earner in the rural economy

including the increasing dependence of urban population on charcoal as a source of fuel.

As such the intervention to be developed is generally to address the need to decrease the pressure caused by charcoal producers on wood resources, and more generally on the environment; and a need to seek alternative sources of income to the charcoal producing societies.

Therefore, it is recommended that the proposed Technical Strategy Unit (TSU) in the Urban Household Energy report (Arpaillange J 1996) which the Government is to institute should go ahead. The Unit in collaboration with the Forestry Department should work with the charcoal producing communities through the department's Community Forest Management Programme. Through this programme, the charcoal producers will be trained on techniques of regenerating the devastated indigenous tree species and managing the natural woodlands so as to encourage regeneration of desired charcoal species. The techniques for establishing and managing such species in order to enhance their regeneration have been developed and are available at the Forestry Research Institute of Malawi (FRIM). Research at FRIM has shown that some indigenous tree species such as *Pterocarpus rotundifolia* (Mbalitsa), *Combretum molle* (Kadale), *Bauhinia petersiana* (Mpandula) and *Diplorynchus condylocarpon* (Thombodzi) grow and coppice vigorously, and within 3 years, light poles/fuelwood could be yielded from them.

Realising that most preferred indigenous tree species for charcoal making are slow growing, the TSU should make efforts to introduce technologies for charcoal making from the fast growing exotic tree species such as eucalypts. Forestry Department through the Wood Energy Project started producing charcoal from *Eucalyptus grandis* at a small scale in Mulanje Central Government Plantations. The quality of the charcoal made from eucalypts in terms of energy values and per cent fixed carbon is not significantly different from that made from indigenous tree species on weight basis, if carbonised under similar conditions. The eucalypts could provide an alternative source of wood raw material for charcoal making.

The proposed Technical Strategy Unit should encourage the charcoal producers to form producer organisations so that it can effectively mobilise resources including knowledge and technology, promotion, distribution channels and pricing through these organisations. The charcoal producers would also be provided with courses and on job training to improve their skills both on the production technique side and the proper and sustainable management of the wood resource. The training should be in such areas like tree management, tree harvesting, charcoal production and marketing techniques. This had worked well in Somalia where producers are organised in co-operatives principally for the collective hire of transport and sale to traders and/or consumers, as well as dealing with the authorities.

Some producers (56 percent) said that they were willing to move out of charcoal business only if they are given an alternative source of cash income for their living. Most of them especially female charcoal producers would like to go into small-scale businesses but they are limited by the financial investment required in the new business ventures. Therefore, it is strongly recommended that soft loans be made available to charcoal producers to start alternative businesses such as vegetable production and/or poultry production, thus, shifting from charcoal production to other form of businesses. This would save the little wood resource still standing in charcoal producing sites and allow the recruitment of the coppices into older woodlands.

It is unlikely that the charcoal business will be completely stopped as reflected in the charcoal producers' responses captured in the survey despite Government's campaign against it through policing and confiscating charcoal passing through designated road blocks. This is because the demand for charcoal by urban households is high and the charcoal consumption is anticipated to increase from 54 percent to 64 per cent of charcoal-users living in Blantyre alone by the year 2005. Therefore, it is recommended that efforts be made to investigate the possibility to legalise the charcoal business and make sure that the interests of the charcoal producers are taken into account in order to ensure that they conduct their activity in accordance with the law, and consequently, will not exercise an uncontrolled pressure on the environment. This task would be made easier if viable producer organisations existed.

If well managed, trees are a renewable resource, and their use whether for charcoaling and/or honey production should be encouraged. Again, if the land is being cleared then salvaging of the wood should be a high priority. Rather than looking on charcoal production as an illegal occupation, it should be viewed as a legitimate use of resources which is generating rural employment and supplying an indigenous energy resource to the urban people. What is required is government encouragement to expand this production and trade in a controlled rational way.

Some trees are being illegally felled. If charcoal production was regalized, then the Forest Department through the proposed Technical Strategy Unit could allocate areas for charcoal production, supervise the felling and run training courses on tree management and charcoal production and collect stumpage fees for the wood raw material.

The equipment used by charcoal producers seems barely adequate. No saws for felling and crosscutting were noted and the axes are inadequate to fell some trees because the wood was too hard. No rakes were used to build the kilns or to sort the charcoal. It is, therefore, recommended that training the producers in the use and maintenance of appropriate tools and to have loans for tool purchase.

Current earth kiln charcoal production method has a relatively low conversion efficiency and the factors that determine conversion efficiency are poorly understood. Therefore, detailed field studies to investigate the role of wood moisture content, kiln management practices and kiln size on conversion efficiency should be undertaken. It is only when the determinants of conversion efficiency are properly understood can a strategy be formulated for increasing conversion efficiency.

In Somalia, charcoal producers use an improved earth kiln charcoal production method. Metal sheets are used to cover the kilns before soil is placed on top, this gives an increased recovery percent and also a cleaner charcoal. In Senegal the earth kiln has been modified by inserting a central chimney made of old oil drums welded together. The chimney improves gas circulation that reduces the amount of brands and speeds up carbonisation process. Fewer brands mean an improved yield of charcoal. Therefore, these improved production techniques in these countries should be studied to see if they can be applied to Malawi's earth kilns.

Very little is known about regional differences in charcoal production techniques in Malawi as this study was only concentrated in one site (Blantyre). Therefore, there is need for similar studies in Lilongwe, Zomba and Mzuzu so that a comprehensive picture can emerge upon which a strategy can be formulated for charcoal production in Malawi which will be a representation for all main urban centres. The results of this study would only have a limited application to charcoal producing areas around Blantyre.

This study, in the limited time available, collected much useful data but in doing so it recognised that there were gaps in the information such as variation in seasonality of charcoal production and to what extent this effects price instability. This type of information is useful in making a rational reorganisation of the woodfuel industry in the country. Therefore, similar study should be carried out in the rainy season to discover any variations in kiln management as they affect the quantity and the quality of the charcoal output.

A proposed further study in charcoal production could as well pinpoint efficient producers. These producers could then be used to train other producers and encouraged to experiment with improved kilns such as the cassamance type kiln incorporating a chimney.

10.0 REFERENCES:

1 Abbot PG, Lowore JD and Khofi CF (1995). Properties and status of some indigenous firewood species in Malawi. FRIM Report 96003)

2 Arpaillange J (1996). Urban household energy demand side strategy report. Ministry of Energy and Mining, Malawi.

3 Chidumayo E.N (1990). Biomass survey report. World Bank/UNDP/Bilateral Aid Energy sector management assistance programme; Project working document.

4. Chidumayo E.N (1990). Charcoal production report. World Bank/UNDO/Bilateral Aid Energy Sector Management Assistance Programme; Project working document.

5 Chidumayo E.N (1987). A survey of woodstocks for charcoal production in the Miombo woodlands of Zambia. Forest Ecology and Management, 20 : 105-115.

6. Energy Studies Unit (ESU) (1984). Malawi Urban energy survey. Ministry of Forestry and Natural Resources Lilongwe, Malawi.

7 FAO (1987) Simple technologies for charcoal making. FAO Forestry paper 41, Rome.

8 Leach G and Mearns R (1988). Bioenergy issues and options for African Energy and Development programme, England.

9. Openshaw K (1986). Concepts and methods for collecting and compiling statistics on biomass used as energy. Paper prepared for U.N. Statistical office workshop in Rome, 29 September - 3 October 1986.

10 Smith A.E (1985). An analytical approach to the economics of small-scale charcoal production in developing countries. Tropical science Journal 25: 29 - 39.