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<th>Full Form</th>
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<tbody>
<tr>
<td>DNR</td>
<td>DEPARTMENT OF NATURAL RESOURCES</td>
</tr>
<tr>
<td>DOE</td>
<td>DEPARTMENT OF ENERGY</td>
</tr>
<tr>
<td>ECZ</td>
<td>ENVIRONMENTAL COUNCIL OF ZAMBIA</td>
</tr>
<tr>
<td>ESMAP</td>
<td>ENERGY SECTOR MANAGEMENT ASSISTANCE PROGRAMME</td>
</tr>
<tr>
<td>FD</td>
<td>FOREST DEPARTMENT</td>
</tr>
<tr>
<td>MENR</td>
<td>MINISTRY OF ENVIRONMENT AND NATURAL RESOURCES</td>
</tr>
<tr>
<td>MEWD</td>
<td>MINISTRY OF ENERGY AND WATER DEVELOPMENT</td>
</tr>
<tr>
<td>NCSR</td>
<td>NATIONAL COUNCIL FOR SCIENTIFIC RESEARCH</td>
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<tr>
<td>NEC</td>
<td>NATIONAL ENERGY COUNCIL</td>
</tr>
<tr>
<td>NGO-CC</td>
<td>NON-GOVERNMENTAL ORGANISATION COORDINATING COMMITTEE</td>
</tr>
<tr>
<td>SADC</td>
<td>SOUTHERN AFRICAN DEVELOPMENT COMMUNITY</td>
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<tr>
<td>SEI</td>
<td>STOCKHOLM ENVIRONMENT INSTITUTE</td>
</tr>
<tr>
<td>SIDA</td>
<td>SWEDISH INTERNATIONAL DEVELOPMENT AUTHORITY</td>
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<tr>
<td>UNDP</td>
<td>UNITED NATIONS DEVELOPMENT PROGRAMME</td>
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<td>UNIVERSITY OF ZAMBIA</td>
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<tr>
<td>ZAFFICO</td>
<td>ZAMBIA FOREST AND FORESTRY INDUSTRY CORPORATION</td>
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**UNITS AND ABBREVIATIONS**

C Elemental Carbon
CEC Cation Exchange Capacity
CO Carbon Monoxide, a poisonous, invisible and odourless gas
CO₂ Carbon Dioxide
GBH Girth at Breast Height, Circumference at 1.3 m above ground
H Elemental Hydrogen
ha Hectare, 1 ha = 10,000 m² = 2.2 acres
J Joule, 1 joule = 1 watt*second (ws) = 0.239 calories
kJ Kilojoules, 1 kilojoule = 1000 joules
kWh Kilowatt hours, 1 kWh = 3.6 MJ
m³ Cubic metre, 1 m³ = 1000 litres = 37 cubic feet
Meq Milli-equivalents
mg Milligramme, 1 mg = 1/1000 g
MJ Megajoules, 1 MJ = 1 million joules = 0.278 kWh
N Elemental Nitrogen
NO₂ Nitrogen dioxide
NOₓ Nitrous Oxides (several forms, measured as NO₂)
°C Degrees Celsius (°C = 5/9(°F - 32))
°F Degrees Fahrenheit (°F = 9/5(°C + 32))
PH Acidity, negative logarithm of the hydrogen ion concentration
S Elemental Sulphur
SO₂ Sulphur Dioxide
t Tonne, 1 metric tonne = 1000 kg
yr Year
µg Microgramme, 1 µg = 1/1,000,000 g
FOREWORD

This Charcoal Production Manual, the first of its kind in Zambia, is produced as part of a cooperation between the Department of Energy (DOE), Ministry of Energy and Water Development (MEWD), and the Stockholm Environment Institute (SEI) of Sweden. The major thrust of the cooperation has been to gather detailed information on the charcoal system, from the resource base through to end-use, which would help in the formulation of sound and feasible policies for addressing the issues associated with this energy source.

The process of information gathering, analysis and interpretation culminated in a Charcoal Policy Workshop which was held at Siavonga, 10 - 14 May 1993. At the workshop, the need for a charcoal production manual was recognised and it was strongly recommended that it be prepared. In 1994, the MEWD finalised and launched a National Energy Policy (NEP), which incorporates charcoal production and utilisation issues. The Government for example, seeks to 'improve the technology of charcoal production by training charcoal producers in better organisation and management of charcoal production using the earth kiln method'. The purpose of producing this manual, is therefore, two-fold. Firstly, it should provide an intending or practising charcoal producer a step by step account of the process and point out useful hints for obtaining better yield. In the long run, this is intended to achieve a saving on the wood resource as production efficiency will be raised. Secondly, the manual is intended to be a source of information for researchers, environmentalist and development workers. There is at present very little understanding of the Zambian Charcoal Industry. This manual will therefore make an important contribution to filling the existing information gap.

In order to fulfil this dual purpose, it has been decided to prepare the English version of the Manual in two parts. Thus Part I gives a more detailed account of the process and provides the context in which charcoal is produced and utilised in the country. Part II provides a step by step description of the charcoal production process with illustrations. This is done in a simple and easy-to-follow manner. Initially, Part II has also been produced in Nyanja and Bemba in order to enable ordinary producers to use the Manual without the need for assistance on account of language. Translations into other local languages will be done as funds are found for such a purpose. The authors recognise that much as efforts were made to ensure that the Manual is comprehensive, the understanding of the charcoal system and its dynamics is still growing. There will be need, therefore, to update this Manual from time to time, as the knowledge of charcoal production improves.

Charcoal in Zambia is produced using the earth kiln. The Manual describes this production method and does not deal with other methods as these are not yet practised in Zambia.

Lusaka, March, 1996.
Silvester H. Hibajene
Oscar S. Kalumiana
PART I: TECHNICAL DESCRIPTION
1 OVERVIEW OF THE CHARCOAL INDUSTRY

1.1 Charcoal as an Energy Source in Zambia
Charcoal is an important energy source in Zambia. It ranks second to firewood (fuelwood) in terms of primary energy supply. In 1994 for example, it accounted for about 33% of total primary energy supply, while fuelwood accounted for 43%, electricity and petroleum 10% each and coal 4%. Due to losses arising from converting wood into charcoal, the contribution of charcoal to final energy consumption is 11%, putting it at the same level as electricity and petroleum.

1.2 Charcoal Production and Utilisation
Basically all the charcoal in Zambia is produced using the earth clamp method, details of which are provided in Chapter Two of this Manual. The process of charcoal production involves felling trees and cross-cutting them into short logs, piling the logs into a clamp, covering the clamp with soil lumps, ignition of the kiln, carbonization of wood into charcoal, harvesting and packaging the charcoal into bags. The process is labour intensive and largely involves the use of only rudimentary tools. The charcoal supply chain comprises three main activities namely, production, transportation and marketing.

During 1995, charcoal production was estimated to be 721,000 tonnes, while the total amount of wood used for charcoal production was estimated at 4,290,000 tonnes (Banda et al, 1996). Charcoal production is mostly a rural based activity. This segment of the industry is estimated to provide employment to more than 41,000 people on a full-time basis. Considering the fact that not all charcoal producers are full-time, the number of people involved in charcoal production is quite substantial. There are many reasons that lead people to engage in the charcoal trade. Reasons cited, during surveys in charcoal production areas, in order of increasing frequency are: to avoid wood in cleared fields going to waste; obtain money for debt payments/funerals; as payment for field clearing; to obtain money for children's school uniforms, household use and for buying farm inputs, especially fertilizer (Kalumiana et al, in press).

Charcoal is mostly transported from production areas using lorries and pick-ups. The distance from production areas to demand centres varies from 30 km to 200 km. Motor vehicles account for about 99% of the charcoal transported. The rest is carried as headloads or on bicycles, wheelbarrows and ox-carts. These transport modes are mainly used for short distances within production areas, from production areas to roadsides and from retail markets to user households in urban areas (Hibajene & Ellegard, 1993). The transport demand for charcoal is high. For instance in 1990 at a consumption level of about 620,000 tonnes per annum, it was estimated that about 74,000 lorry trips were required to take charcoal to the demand centres. This required a fleet of about 740 trucks to be regularly involved in
charcoal haulage. Charcoal transportation provides employment to at least 3,500 people.

One major characteristic of charcoal utilisation is that it is predominantly consumed in urban areas. Eighty Five percent (85%) of all charcoal is consumed in urban areas, with rural areas accounting for the other 15%. It is estimated that about 85% of urban households, about 3 million people, use charcoal to varying degrees. Therefore, with an urbanisation level of 42%, about a third of Zambia's population are dependent on charcoal for cooking and other stove related activities such as water and space heating. The estimated 1994 consumption of charcoal was 670,800 tonnes. The consumption pattern was such that households accounted for 95.8%, industry and commerce 4.0% and mining 0.2%. At the household level, charcoal again ranks as the second dominant energy source after fuelwood meeting about 21% of the energy needs of all households in the country. The proportional contribution to meeting household energy needs by other fuels is as follows: fuelwood 76%, electricity 2% and kerosene 1%.

Apart from being an important energy source and a provider of employment to a substantial number of people, charcoal is a major business commodity in the economy. In 1995, an estimated 17,500,000 bags of charcoal were traded. At June, 1995 Lusaka prices of K2,500 per bag, this charcoal was worth about K43.75 billion, the equivalent of US$48.61 million.

1.3 Charcoal Taxation, Pricing and Marketing

Charcoal attracts Four (4) types of levies: stumpage, conveyance, council and market fees. The stumpage fee is paid by producers for the raw material (wood). During 1995, this fee was K3,000 per cord (3m³). Since a cord weighs about 1,000kg (Banda, 1994), this wood can produce about 200 kg or 5 bags of charcoal. This translates into K600 per bag. The conveyance/removal fee is paid by traders and in 1995, it was K200 per charcoal bag. Both these fees are paid to the Forest Department. The council fee/levy is paid to local authorities from which charcoal is obtained. For Chibombo and Chongwe councils near Lusaka, these levies were, K400 and K200 respectively in 1995. The fourth levy on charcoal is the market fee. This is usually paid on a daily basis, to the market administration. In 1995 in Lusaka, this fee was about K100 per day for any quantity of charcoal being sold at designated places.

Road side selling is common in rural areas both as retail and wholesale business. In urban areas charcoal is traded from homesteads, municipal markets and by hawkers. An estimated 1.5% of urban households are engaged in charcoal trading from their homes. Approximately 50% of charcoal traders sell by the bag (40 kg) and the other half sell in smaller quantities. The former obtain their charcoal from the source at a producer's price while the latter purchase it from the municipal markets at a retail price and repack it in smaller quantities.

There is minimal storage of charcoal both in production and demand centres making its availability wholly dependent on smooth supply. Charcoal marketing is competitive and prices are determined by supply and
demand. This segment of the industry offers employment to at least 1,000 people making it the least labour intensive.

1.4 Opportunities for Charcoal Substitution in Households

As the bulk of the charcoal is used by households in urban areas, substitution of charcoal by other energy sources is targeted at this sector. The other urban household energy sources are: kerosene which is used for lighting, cooking and fire ignition; electricity for lighting, cooking, water & space heating and firewood for cooking, water & space heating. Whilst kerosene is widely used by urban households, it is not an ideal charcoal substitute due to its being an imported energy source. Its use is at a great cost to the nation in terms of foreign exchange. Electricity a good alternative. Not only is it an indigenous energy source, but also the installed capacity is sufficient to meet higher demand. To make this a reality however, household accessibility to electricity has to be enhanced. Furthermore it requires that appliances be made affordable to ensure that those who have access to it use it. In this way, the situation will be avoided where more than 40% of all electrified households do not use it for cooking (ESMAP, 1990) as they can not afford cooking stoves.

The majority of un-electrified households can not access electricity on account of high connection and internal house wiring costs. Unless feasible solutions to these problems are found charcoal will continue to dominate the urban household energy picture.

Efforts have been made by the National Council for Scientific Research (NCSR) to introduce coal to households. To make it environmentally safer, the coal is processed into briquettes. A market study that has been undertaken indicates that the briquettes are not competitive, on account of price in comparison to charcoal.
2 THE CHARCOAL PRODUCTION PROCESS

Charcoal is produced in the earth kiln by covering wood with earth, and then 'burning' it in a process called carbonization. A black solid residue called charcoal remains after the process. Several stages and activities are involved in the production process, and a variety of tools are used. The stages involved in charcoal production are:

(a) felling/cutting of trees and cross-cutting them into short logs or billets
(b) piling of the logs into a clamp
(c) covering of the clamp with dug up soil lumps
(d) applying fire to the kiln to initiate carbonization
(e) carbonization of wood into charcoal inside the kiln
(f) 'harvesting' of charcoal from the kiln and packing it into bags

While a variety of charcoal kilns exist, the most common are rectangular in shape, and vary in size from as small as 5 m$^3$ to as large as over 80 m$^3$ (Ranta & Makunka, 1986; Chidumayo and Chidumayo, 1984; World Bank ESMAP, 1990; Sawe, 1993). What determines the size of the kiln is the amount of wood and labour available to the producer. The kiln size should be such that the producer is able to work with (Boutette and Karch, 1984). Too large a kiln may be too difficult to cover and manage, especially for an inexperienced producer, while a small kiln has a lower thermal stability and may produce less charcoal and also of lower quality. The size of the wood available is another factor that determines the kiln size. A kiln of 5-10 m$^3$ for example, is too small for logs having an average diameter of 20cm (Ranta & Makunka, 1986). The amount of charcoal produced from a kiln depends on several factors which are related to the carbonization efficiency. This is outlined in Section 2.8. A kiln of 50 m$^3$ may produce 100 bags (Sawe, 1993)\(^1\).

2.1 Tools used in Charcoal Production

A variety of tools are used during the production of charcoal, depending on the stage at which the process is. Table 3.1 shows a list of tools commonly used and the stages during which they are used. The list however, is not exhaustive as other tools can be used depending on availability.

The axe is the major tool used for felling and cross cutting trees. Although power saws are sometimes used, this is infrequently done. In the Chisamba area near Lusaka and Misaka area near Kitwe, it was found during surveys that only 4-17% of producers used a power saw (World Bank, 1990). The main reason for the limited use of power saws is the high cost of either purchasing or hiring them. Hauling of logs is done mainly with crow bars which are used to roll the logs to the kiln sites. During the same survey, it

\(^1\) During field survey in October 1993, the authors found a kiln of 200 m$^3$ from which the producer expected to get about 500 bags of charcoal.
was found that about 85% of the producers used the crowbar for hauling and piling logs at the kiln sites while 4% of the producers used wheelbarrows. A hoe is most often used for digging soil lumps. Some producers however, use shovels which are also used during the recovery of charcoal from kilns. Rakes and forks are also used for charcoal harvesting and packaging.

### Table 2.1 Tools used at various stages of charcoal production

<table>
<thead>
<tr>
<th>Production stage</th>
<th>Tool</th>
</tr>
</thead>
<tbody>
<tr>
<td>Felling and cross cutting</td>
<td>Axe, power saw</td>
</tr>
<tr>
<td>Log haulage and piling</td>
<td>Wheel barrow, crow bar</td>
</tr>
<tr>
<td>Digging soil lumps</td>
<td>Hoe, shovel</td>
</tr>
<tr>
<td>Harvesting and bagging</td>
<td>Shovel, rake</td>
</tr>
</tbody>
</table>

(Modified after World bank/ESMAP, 1990)

### 2.2 Tree Felling and Cross-Cutting

Most of the charcoal produced in Zambia comes from Miombo woodlands which predominantly consist of Brachystegia, Isoberlinia and Julbernardia tree species. However, where these woodlands do not occur or have been depleted (mainly for agriculture) other indigenous tree species are used. In the Lusaka area, Acacia spp. are sometimes used. Exotic species, particularly Eucalyptus have also been used to produce charcoal in the copperbelt area though on experimental basis (Ranta & Makunka, 1986).

Mature trees which are highly lignified are known to produce good quality charcoal (Pagama, 1993). In the Miombo woodlands, some tree species are known to produce poor quality charcoal, others are too hard to cut, while it is illegal to cut fruit trees; other trees are left due to their value in producing good quality timber or wood (Appendix 1). These tree species are usually left uncut by charcoal producers. Most miombo trees however produce good quality charcoal (Appendix 2). The category of trees in Appendix 1 lead producers to cut selectively during charcoal production. The majority of trees left uncut are, with a girth (circumference) at breast height (GBH or 1.3 m high) of less than 20 cm. These are normally left for regeneration (World Bank, 1990).

Trees that are selected for charcoal production (some are shown in Appendix 2) are felled with an axe or a power saw at about 30 cm above ground. To aid coppicing, the cutting should be done in a slanting way. This ensures that no water collects on the stump leading to it rotting. The short logs into which trees are cross cut measure about 1 - 3 m (World Bank, 1990; Ranta & Makunka, 1986; Sawe, 1993). The whole tree, branches included, is cross cut in this way. It was observed, during a survey of two different locations that producers discarded twigs of less than 4 cm diameter. These were consid-
Discarded twigs are either just left on the ground or piled at the site of felling. In both circumstances they are later burnt up either intentionally or by wild fires.

2.3 Clamp Building

The logs are hauled to a pre-selected site where they are piled into a clamp. The site selected should be close to the wood source to minimise the haulage distance. It should be a reasonably level area which subsequently must be cleared using a hoe, and all material that can burn removed (Ranta & Makunka, 1986). The cleared area is much larger than the kiln size - about 3 m beyond the limit of the borders of the kiln to act as a safeguard against fire. A large cleared area is also necessary to give a clean surface on which to spread the charcoal during "harvesting" (Boutette & Karch, 1984). The method of hauling the logs depends on the particular producer, but in most cases logs are individually lifted on producers' shoulders to the kiln site, while large and heavy logs are rolled on the ground. A producer may enlist the help of others, and this is usually reciprocated. Sometimes payment for this help is made in kind.

Before piling begins, logs called stringers, which are several meters long are placed on the ground (World Bank, 1990; Ranta & Makunka, 1986). The stringers ensure good air circulation and efficient heat transfer in the kiln. The clamp logs are usually piled crosswise on the stringers. In some cases, the logs are placed lengthwise with the stringers crosswise in the general direction of the kiln (World Bank, 1990; Ranta & Makunka, 1986). The sequence of piling logs onto a kiln is as follows: medium logs are put first (at the bottom2), then the biggest logs available, other medium logs and finally small logs are placed at the top (FAO, 1987). The height of the completed clamp varies between 1.5 - 3 m (Sawe, 1993), but it should not be too high otherwise it would be difficult to cover.

The logs should be tightly packed. This enables the producer to pack more wood into a kiln without necessarily having to increase its size. It also lengthens the gas path through the kiln thus enhancing heat transfer, and breaks up favoured air channels which lead to wood in the favoured path being completely burnt while the rest of the charge remains un-carbonized (Boutette & Karch, 1984). Tight packing also minimises "caving in" of the insulating material (on top of kiln) which slows down and/or stops carbonization.

Small logs are used to fill up spaces in between big logs and are also piled on the clamp top in order to prevent the insulating material and soil "seeping" through the clamp. It is during this stage that the firing point (point where kiln is ignited) is determined. The producer should place small logs here and other kindling material in order to facilitate easy fire ignition. It is the usual practice to place the firing point in the direction from which the

2 The logs at the bottom are called cross members
prevailing wind blows. In other cases, the firing point is placed against or across the direction of the prevailing wind. Wood carbonization in relation to the prevailing wind is not a significant factor in terms of charcoal yield (Hibajene 1993).

2.4 Covering of the kiln

Soil lumps, usually referred to as guards are used to cover a piled clamp. The lumps are dug with a hoe or shovel up to a depth of 15 cm (Sawe, 1993), but if the soil is not too loose, digging deeper is recommended especially if the kiln is situated in an area to be used as a garden later on. If the kiln is large and digging is restricted to the top 15 cm, surface soil from a large area will be removed leaving it unsuitable for crop production. The disturbed area should be such as can be covered by soil and ash from the kiln after charcoal has been harvested.

The soil lumps are used to build the clamp wall. The top of the kiln is first covered with grass and/ or leafy material and then with soil lumps. Loose soil is also applied on top of the kiln. The thickness of the covering varies between 10-45 cm (Ranta & Makunka, 1986; World Bank, 1990; Sawe, 1993; Boutette & Karch, 1984) but the top soil cover should not be too thick (not more than 20-30 cm). The clamp is sealed completely to prevent uncontrolled air entry into the kiln which could lead to wood burning to ashes. The firing point is either left uncovered at this stage or made when the kiln is ready for firing. Sandy or loamy soils which do not shrink on drying are best suited for covering the clamp, while soils with a marked tendency to crack and shrink upon heating (e.g. vertisols) should be avoided (FAO, 1987).

2.5 Kiln firing

The kiln is ignited through the firing point that is left uncovered or is opened up after covering the kiln. Firing can be done in either of two ways (Boutette & Karch, 1984; FAO, 1987):

(i) the producer starts a fire in the firing point - this requires a certain amount of skill so that fire establishes in the kiln without burning a substantial amount of the wood; or

(ii) a shord of burning wood and/ or charcoal is pushed through the firing point. Fire may be established, depending on the conditions of the kindling material, in 10-20 minutes after lighting.

When the fire has established itself, dense white smoke billows from the kiln at which stage the firing point is then closed with soil. After closure of the firing point, the amount of smoke reduces, giving the impression that the kiln is 'dead'. In time however, it adjusts itself to the lower oxygen levels and loss of heat to the rest of the charge, and starts to pick up (Boutette & Karch, 1984).
2.6 Wood Carbonization

Wood is mainly a composite of three polymers, whose proportions in hardwood are as follows: Cellulose, 43%, Lignin, 22%, Hemicellulose, e.g Xylan, 34% (FAO, 1987). The remaining 1% consists of resin and mineral substances. The latter yield ash upon combustion. Also associated with wood is water adsorbed or held as molecules on the cellulose/lignin structure (FAO, 1987). Amounts of water associated with wood are variable, depending on whether it is fresh or "seasoned" (air dry). Wood carbonization is the process by which wood is transformed into charcoal. It occurs in the absence of air (oxygen), or when air intake is restricted. The process occurs in four distinct phases namely combustion, dehydration, exothermic reaction and cooling. All these phases occur at the same time in the kiln, but each log of wood has to pass through this four phase sequence (Boutette & Karch, 1984).

Combustion - After the kiln has been ignited, the kindling material and some of the wood burns. The oxygen supply is high and the temperature rises from ambient to over 500°C (Boutette & Karch, 1984). When the fire has established, and oxygen supply is reduced after the point of firing is closed, the kiln temperature drops to about 120°C.

Dehydration - This is the phase during which the free water in the wood is driven out. At the reduced temperature of about 100°C, the wood dries to zero moisture content and the kiln gives out thick, white and moist steam (FAO, 1987).

Exothermic reaction - When the wood has dried, the kiln temperature rises to about 280°C. The energy for the temperature rise is supplied by partial combustion of some of the wood (FAO, 1987). At this temperature, wood begins to spontaneously break down to produce charcoal, water vapour, methanol, acetic acid and other complex chemicals - mainly tars and condensible gases (hydrogen, carbon monoxide and carbon dioxide). Smoke at this stage is yellow, hot and oily, and one is able to hear snaps and cracks in the kiln resulting from wood shrinkage as it becomes charcoal and also the tars being driven off darkens the earth covering (Boutette & Karch, 1984). The spontaneous breakdown of wood above 280°C is an energy producing (exothermic) reaction. By touching the kiln, a producer may feel where the 'fire' is, and if uncertain of what a certain kiln part is undergoing, may open up that part to find out (Boutette & Karch, 1984). Although an exothermic reaction takes place, extra heat may be required to maintain adequate temperature in the kiln. This is achieved by introducing air into the kiln through vents/holes made in the kiln walls (Ranta & Makunka, 1986; FAO, 1987). As air is introduced into the kiln, part of the wood burns to produce the required heat. If however, carbonization stops completely at any part of a kiln, that section is re-lit.

In the event that external heat is not provided to a kiln, carbonization may stop and the resultant charcoal will contain large amounts of tar residue together with ash of the original wood. The ash content of such charcoal is
about 3-5%, tar residue about 30% by weight, the balance (65-75%) being fixed carbon (FAO, 1987). If further heating however, occurs, more of the tars are driven off and/or decomposed leading to an increase in the fixed carbon content and a reduction in the volatile substances. The effect of temperature on yield and wood composition is shown in Table 2.2. Table 2.2 shows that lower carbonization temperature gives higher yield but the poor quality charcoal. Such charcoal is corrosive due to its content of acidic tars and produces smoke when ignited (FAO, 1987). When such charcoal is soaked with water, the acids corrode the packaging material. Charcoal produced at higher temperature however, is friable. A temperature range of 450-500°C gives an optimum balance between high charcoal yield and a high content of fixed carbon (good quality charcoal).

Table 2.2 Effect of carbonization temperature on yield and composition of charcoal

<table>
<thead>
<tr>
<th>Carbonization temperature °C</th>
<th>Charcoal composition</th>
<th>Charcoal yield as % of oven dry wood*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>% fixed carbon</td>
<td>% volatile matter</td>
</tr>
<tr>
<td>300</td>
<td>68</td>
<td>31</td>
</tr>
<tr>
<td>500</td>
<td>86</td>
<td>13</td>
</tr>
<tr>
<td>700</td>
<td>92</td>
<td>7</td>
</tr>
</tbody>
</table>

* Yield indicated is not exclusively for earth kilns but includes other kiln types

Source: FAO, 1987

Cooling - When carbonization is complete, the kiln cools, and the charcoal can then be extracted from the kiln. Initially cooling takes place inside the kiln. When the temperature is approximately below 100°C, charcoal is dug out from the kiln, and thinly spread on the ground. It is then covered by loose soil to prevent it catching fire when it comes into contact with air, should any hot coal have been extracted.

The process of wood carbonization in the earth kiln is summarized in Table 2.3. Since the wood in the kiln does not carbonize at the same time, carbonization proceeds through the kiln section by section, each of which goes through all the phases stated earlier. During this time, the producer has to constantly check on the kiln to ensure that the process proceeds smoothly. Some management activities that the producer has to do are:

(a) Opening of vents/exhausts along the kiln walls to allow controlled air movement in and out of the kiln;

(b) Closing of openings where they occur following pre-mature collapse of the earth clamps;
(c) Closing of cracks that occur during the process;
(d) Harvest any part of the kiln that "ripens".

Management and monitoring of the process has a marked influence on the quality of the product (charcoal). When too much air (oxygen) is allowed through the kiln (e.g. when cracks that develop are not repaired), "heat spots" occur, and most of the wood will be burnt. During carbonization, a systematic collapse of the kiln occurs, and the kiln size drops to half of its original volume (World Bank, 1990; Ranta & Makunka, 1986). The completion of the combustion process can be determined from the reduced volume of a kiln section.

Table 2.3 Simplified summary of wood carbonization in an earth kiln.

<table>
<thead>
<tr>
<th>Carbonization stage</th>
<th>Smoke type</th>
<th>Kiln temperature</th>
<th>Kiln activity</th>
<th>Kiln product</th>
<th>Kiln management</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combustion</td>
<td>White &amp; dense</td>
<td>Ambient - 500 °C</td>
<td>Burning of wood/kindling mater</td>
<td>-</td>
<td>Close ignition point after fire establishes</td>
</tr>
<tr>
<td>Dehydration</td>
<td>White, thick &amp; moist</td>
<td>100 - 300 °C</td>
<td>Wood dries</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Exothermic reaction</td>
<td>Yellow, hot &amp; oily</td>
<td>100 - 300 °C</td>
<td>Wood breaks down; wood partially burns; heat production</td>
<td>Charcoal, water, vapour, acetic acid, methanol, complex chemicals</td>
<td>Controlled air admission through vents in kiln, kiln repair, may need external air provision</td>
</tr>
<tr>
<td>Cooling</td>
<td>-</td>
<td>700 - 100 °C</td>
<td>Inside kiln</td>
<td>Charcoal removed</td>
<td></td>
</tr>
</tbody>
</table>

Source: Boutette & Karch, 1984

2.7 Charcoal Recovery and Packaging

Charcoal can be recovered from one end of the kiln while carbonization is still proceeding in the rest of the kiln. Thus the kiln is harvested as it 'ripens'. How the producer does it depends on preference, experience or the availability of buyers. As the charcoal is recovered, it is spread on the ground and immediately covered with loose soil for cooling. The covered charcoal is monitored so that points where smoke appears are further covered; charcoal being cooled may be ready for bagging within a period of 48 hours.

After the charcoal has cooled, it is separated from the soil using a fork and piled aside. Un-carbonized wood, usually about 3.0% of original wood mass (Chidumayo, 1991), is also piled on its own, and depending on its amount, is used to build a smaller kiln, referred to as a "review kiln" (Hibajene, 1993). The charcoal is then packed in bags or other sellable units. Often the producer may wish to recover small pieces of charcoal called "rejects" (Hibajene, 1993), which are too small to be bagged for sale. These are usually
about 1% of original wood biomass (World Bank, 1990). The producer may use these for his domestic needs. Care should however, be taken that unpackaged (unsold) charcoal should not be exposed to moisture for too long especially in the rainy season. If this happens it becomes soft and crumbles when handled. It may thereafter not be sellable and the producer loses it all.

### 2.8 Efficiency of the Earth Kiln Method

The efficiency of a kiln is defined as the mass of charcoal that a producer obtains from a kiln expressed as percentage of the mass of wood the producer initially put into the kiln. Strictly speaking, this is the recovery efficiency. The conversion efficiency includes even the charcoal fines (rejects) that may not be packaged for sale due to their small size. The efficiency is calculated on fresh/air or oven dry basis, as follows:

\[
e_k = \frac{M_c}{M_w}
\]

where:
- \(E_k\) = Kiln Efficiency
- \(M_w\) = Mass of wood put into the kiln
- \(M_c\) = Mass of charcoal produced

When quoting efficiencies, one has to state on what basis the masses are indicated in relation to the moisture content of the wood, as shown below:

If a piece of wood weighing a hundred kilograms (100 kg) has 40 kg of free water associated with it, then the actual weight of wood is 60 kg. The moisture content (MC) of the piece of wood, on percentage basis, can be calculated as follows:

(i) Wet or dry air basis:

\[
MC = \frac{\text{Mass of water}}{\text{Mass of wet wood}} \times 100\% = \frac{40\ kg}{100\ kg} \times 100\% = 40\%
\]

(ii) Oven dry basis:

\[
MC = \frac{\text{Mass of water}}{\text{Mass of dry wood}} \times 100\% = \frac{40\ kg}{60\ kg} \times 100\% = 66.7\%
\]

Thus if the 100 kg of wood, when carbonized produced 15 kg of charcoal, the kiln conversion efficiency, \(E_{kc}\), is (on wet/air dry basis):

\[
E_{kc} = \frac{\text{Mass of charcoal}}{\text{Mass of wet wood}} \times 100\% = \frac{15\ kg}{100\ kg} \times 100\% = 15\%
\]
or on oven dry basis:

\[ E_{kc} = \frac{\text{Mass of charcoal} \times 100\%}{\text{Mass of dry wood}} = \frac{15 \text{ kg}}{60 \text{ kg}} \times 100\% = 25\% \]

It has been found through field tests that 3% of the charcoal produced is left at the kiln site as small pieces that cannot be packaged. In this example, 0.45 kg of the charcoal would be left at the kiln. The kiln recovery efficiency \( E_{kr} \), is calculated as follows:

On wet/air dry basis

\[ E_{kr} = \frac{5.0 \text{ kg} - 0.45 \text{ kg} \times 100\%}{100 \text{ kg}} = \frac{14.55 \text{ kg}}{100 \text{ kg}} \times 100\% = 14.6\% \]

Or on oven dry basis:

\[ E_{kr} = \frac{15.0 \text{ kg} - 0.45 \text{ kg} \times 100\%}{60 \text{ kg}} = \frac{14.55 \text{ kg}}{60 \text{ kg}} \times 100\% = 24.2\% \]

The earth kiln is generally described as "wasteful" and inefficient due to its low conversion efficiencies. Efficiencies as low as 5-12% (Commonwealth Science Council, undated) have been reported. However, recent reports by researchers have reported higher figures of 14-22% (Hibajene, 1993), 24.5% on oven dry basis (World Bank, 1990) and 17-33% on air dry basis (FAO, 1987). In comparative trials, 8 m³ of stacked wood with moisture content of 18% were used to obtain efficiencies of three types of kilns as shown in Table 2.4.

<table>
<thead>
<tr>
<th>Kiln type</th>
<th>Conversion efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Oven dry Basis</td>
</tr>
<tr>
<td>Earth clamp</td>
<td>25</td>
</tr>
<tr>
<td>Pit</td>
<td>15</td>
</tr>
<tr>
<td>Casamance</td>
<td>31</td>
</tr>
</tbody>
</table>

The results in Table 2.4 show that the earth kiln is not as bad as is generally thought, and given its low cost, in terms of investment, it compares favourably with other kiln types. Since woody biomass contains about 50% carbon by mass (Openshaw, 1985), an efficiency of about 25% is quite
Several factors are considered to influence the efficiency of a kiln. These are:
(a) the carbonization temperature
(b) the moisture content of the wood charged into the kiln
(c) the producer's skill and
(d) the condition of the wood charged into the kiln
Table 2.5 Theoretical reduction in charcoal yield from a kiln as a function of moisture content of wood charge

<table>
<thead>
<tr>
<th>Moisture content of wood charge</th>
<th>Reduction in charcoal yield (%)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry basis (%)</td>
<td>Wet basis (%)*</td>
</tr>
<tr>
<td>128</td>
<td>56.1</td>
</tr>
<tr>
<td>88</td>
<td>46.8</td>
</tr>
<tr>
<td>81</td>
<td>44.8</td>
</tr>
<tr>
<td>64</td>
<td>39.0</td>
</tr>
<tr>
<td>39</td>
<td>28.1</td>
</tr>
<tr>
<td>20</td>
<td>16.7</td>
</tr>
<tr>
<td>10</td>
<td>9.1</td>
</tr>
<tr>
<td>5</td>
<td>4.8</td>
</tr>
</tbody>
</table>

* Expressed as % of wood charge that has to be burned to remove moisture.
Source: Commonwealth Science Council, undated

2.8.1 Effect of carbonization temperature on charcoal yield and quality

The process of carbonization has been described in Section 2.6. The relationship between the carbonization temperature and charcoal yield is inverse; i.e., the higher the temperature, the lower the yield. Since it is often difficult to achieve and maintain high temperatures during carbonization in an earth kiln, charcoal is usually produced at relatively lower temperatures of 300-600°C (World Bank, 1990). Unfortunately, charcoal produced at such lower temperatures is of low quality having low fixed carbon and high proportions of volatile substances. Such charcoal has low calorific values, is corrosive due to its content of acidic tars and produces smoke when burnt (FAO, 1987).

Producing charcoal at much high temperature, however, may lead to it being friable, thus not being easy to handle and transport. Carbonization temperatures of 450-500°C give an optimum balance between friability and the desire for a high fixed carbon content (FAO, 1987). Table 2.5 and Diagram 1 give the relationships between carbonization temperature, charcoal yield and quality. Generally good quality charcoal has a fixed carbon content of about 75%.
2.8.2 Effect of moisture content on charcoal yield

The effect of moisture content of wood on charcoal yield is related to its effect on the heat budget inside the kiln. The higher the wood moisture content, the greater the pre-carbonization heat required to dry the wood (World Bank, 1990; Commonwealth Science Council, undated; FAO, 1987). Since the transformation of water to steam (during drying) requires heat which is produced by the burning of part of the wood charge, the higher the moisture content, the larger the amount of wood burnt. Charcoal yield is, therefore, reduced proportionally. This is so since more wood is burnt instead of being carbonized. The latent heat of evaporation of water is 2890 KJ/kg, while the calorific value of wood is 16,000 KJ/kg. If, for example, a wood charge of 50% moisture content (wet basis) is used, then 18% of the actual woody biomass (dry wood) will be sacrificed to drive out the moisture. Table 2.6 shows the theoretical reduction in charcoal yield associated with high moisture content.

Another aspect associated with wood of high moisture content is the cracking of wood during carbonization (FAO, 1987; Commonwealth Science Council, undated). During the drying of wood, the water within
its biological structure vaporises into steam, becomes pressurised and bursts the wood. Charcoal thus forms fines and has many cracks, and by the time it reaches the consumer the useful amount may have dropped significantly.

When wood moisture content is low, the wood carbonization time is proportionally reduced. Experimental trials have shown that when moisture content (wet basis) is reduced from 38.0% to 29.4%, there is a time reduction of 10 hours (Commonwealth Science Council, undated). Ranta & Makunka (1986) recommend a minimum drying time of 5 - 6 weeks after felling trees. Tree felling, log haulage and clamp building take quite some time to accomplish and sometimes three months can be spent on these activities particularly if the kiln is a large one.

2.8.3 Skill of the producer in relation to charcoal yield
The skill of the producer is crucial particularly during carbonization as the kiln has to be properly managed if a high yield of good quality charcoal is to be obtained (see illustrated part).

2.8.4 The nature of wood charged to the Kiln
The most important aspect considered here is the wood's lignin content. A high lignin content gives a high charcoal yield (FAO 1987; Commonwealth Science Council, undated; Pagama, 1993). Mature or old growth trees are highly lignified and are therefore better to use than young trees.

2.9 Economics of Charcoal Production.
The costs that a producer incurs in the process of making charcoal are related to labour, costs of tools and the fees paid to the Forest Department (World Bank, 1990). However, it is not in all cases that a producer incurs these costs. During field surveys in October 1993, in charcoal production areas around Lusaka, it was found that the charcoal is largely being produced from areas outside the forest reserves and hence no fees were being paid to the Forest Department. No instances were encountered where hired labour was engaged, payment was in kind, as for instance, giving part of the charcoal to the producer, provision of beer or meat. In some cases labour was paid for on a reciprocating basis. The cost of the packaging material (K200/ bag in October, 1993) is met by the charcoal traders from the city. The only monetary payment the producers had to make was in the purchase of tools.

An average bag of charcoal weighs about 40 kg (Chidumayo & Chidumayo, 1984; World Bank, 1990). In a survey in the Chisamba area, a producer's productivity for an average clamp was about 65 bags of charcoal.

Table 2.6 Total labour inputs per average charcoal clamp of 65 bags (2,600 kg)

<table>
<thead>
<tr>
<th>Operation</th>
<th>Duration</th>
</tr>
</thead>
</table>

17
The labour inputs were as shown in Table 2.7. Felling was done by axes. This data indicates that the labour input is about 0.49 work-days/bag of charcoal or about 82 kg of charcoal per work-day. The costs related to tools are shown in Table 2.8. The annual charcoal output per producer during 1988 was estimated at 16.9 tonnes or 1400 kg per month (World Bank, 1990). Assuming the same production rate for 1993 for example, the price of tools per 40 kg bag was therefore, K15.57. Although the producers surveyed did not pay for hired labour, the cost of labour have to be accounted for. In the World Bank study (1990), the cost of tools per bag were 4.2% of the total labour costs. Assuming the same labour cost ratio for 1993, the cost of labour per 40 kg bag was therefore K370.71. Hence the total costs for producing one bag of charcoal was K386.

Table 2.7 Mean costs and expected life of tools

<table>
<thead>
<tr>
<th>Type of tool</th>
<th>Tools per producer</th>
<th>Price per tool (K)</th>
<th>Life Expectancy (months)</th>
<th>Price per month (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Axe</td>
<td>2.0</td>
<td>2.000</td>
<td>20.1</td>
<td>100</td>
</tr>
<tr>
<td>Hoe</td>
<td>1.7</td>
<td>2.500</td>
<td>17.9</td>
<td>140</td>
</tr>
<tr>
<td>Shovel</td>
<td>1.9</td>
<td>3.990</td>
<td>26.8</td>
<td>150</td>
</tr>
<tr>
<td>Fork</td>
<td>0.9</td>
<td>5.400</td>
<td>48.7</td>
<td>110</td>
</tr>
<tr>
<td>Rake</td>
<td>0.2</td>
<td>1.900</td>
<td>41.4</td>
<td>45</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td>545</td>
</tr>
</tbody>
</table>

Source: World Bank, 1990 and Survey results for October, 1993 for prices

During 1993, the cost of a 40 kg bag of charcoal at the production site ranged between K450 - K700, the mean being K500. At this price, the profit margin to the producer was about 29%. If however, stumpage fees were paid to the Forest Department, the price per bag would have been higher than K500. It was found in the World Bank study (1990) that the cost of
wood was about 18.45% of the total production cost which in this case would have been K87.39, bringing the total production cost of one bag of charcoal to K473.67. If the price were to remain at K500 per bag, the producer would get a profit of 5.3% which would be unrealistic.
3 HEALTH ASPECTS OF CHARCOAL PRODUCTION

Charcoal production entails much strenuous work for the producer during felling, cross cutting, log haulage, kiln building and management. There are also risks associated with a carbonizing kiln particularly when repair work is being carried out. Accidents may occur which sometimes lead to death. Another health risk to the producer is the exposure to gases and smoke and also heat from the kiln. Of all the gases emitted, Carbon Monoxide (CO) is the major health risk. Table 3.1 shows the health risks associated with each stage of production.

Table 3.1 Health risks associated with charcoal production

<table>
<thead>
<tr>
<th>Production stage</th>
<th>Health risks/ possible complains</th>
</tr>
</thead>
<tbody>
<tr>
<td>Felling and cross cutting</td>
<td>Sore hands, backache, general exhaustion, chest pains</td>
</tr>
<tr>
<td>Log haulage/ clamp building</td>
<td>Backache, chest pains, general exhaustion</td>
</tr>
<tr>
<td>Kiln covering/ tendering</td>
<td>Cough, chest pains, heat, burns, exposure to smoke, gases, eye tearing</td>
</tr>
<tr>
<td>Kiln breaking</td>
<td>Heat, burns</td>
</tr>
</tbody>
</table>

Source: Ellegård, A., 1993

The Zambian woodlands usually provide dense, slow growing and highly lignified hardwood which produce good charcoal. However this type of wood makes cutting and hauling quite strenuous. Digging soil clumps to cover kilns is another task which requires much physical labour.

During carbonization (See section 2.6) water is driven from the wood in the form of steam. Thereafter, the wood structure breaks (during wood pyrolysis). Initially the cellulose, hemicellulose and lignin component of the charge break down to give volatiles which consist of Carbon Monoxide, hydrogen, pyrolysis oils, tars, acetic acid and methanol. At the same time products of the combustion process are emitted for instance Carbon Monoxide (CO), Carbon Dioxide (CO₂), Water (H₂O) and Hydrogen (H) (Commonwealth Science Council, undated). Some of the gases produced, namely carbon monoxide, as well as some oils and acids pose great risks to the producer. Ellegård (1993) in a survey among charcoal producers in the Chisamba area near Lusaka obtained an indication of the type of discomforts experienced by producers (Table 3.2). From this table, it is clear that backache is the most common complaint, which indicates that the greatest problem is the hard physical work. Cough on its own was not mentioned to be a problem, while in combination with heat, it was related to the time of
kiln breaking. Chest pains are a rather diffuse symptom which could mean anything from a strain to a serious heart condition.

**Table 3.2** Types of discomfort frequently mentioned by charcoal producers

<table>
<thead>
<tr>
<th>Type of discomfort</th>
<th>Frequency with other complaints (%)</th>
<th>Frequency of single complaints (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Backache</td>
<td>26</td>
<td>14</td>
</tr>
<tr>
<td>Heat</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Cough</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>Chest pains</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>Other</td>
<td>7</td>
<td>3</td>
</tr>
</tbody>
</table>

Source: Ellegård, 1993

The same study found that charcoal producers were exposed to an average of 1400 $\mu$gm$^{-3}$ for respirable suspended particulates, while for CO, the average concentration was 13 ppm during work at the active kiln. In the case of charcoal production, exposure is an occupational hazard. Comparison of these exposure levels with acceptable ranges elsewhere showed that they are in fact not very high. For an 8-hour shift in Sweden for example, the limit for organic respirable particulates from coal smoke and tars is 3000 $\mu$gm$^{-3}$. None of the producers would exceed this limit in 8 hours, while 2% would exceed it if the shift time were 4 hours, which was the average daily working time at the kilns during the time of investigation.

Using the Swedish example again, the occupational hygiene limit for CO is 35 ppm for an 8 hour shift. At this limit, it was found that 2% of the producers would risk exceeding the limit, while 9% would exceed it at a shift time of 4 hours.

Table 3.3 shows a comparison of indices of general health and breathing problems between producers and urban dwellers who use firewood, charcoal and electricity. The general health and respiratory problem indices are similar to those observed among woodfuel users. In fact these figures are less. Since two thirds of the producers involved were smokers, the low value with respect to respiratory problems is surprising since both work place exposure and own smoking would be expected to increase these problems. The great health risk among producers, therefore, seems to be associated with the hard labour in cutting, assembling logs, and also in covering the kiln. Not much can be done to offset this hardship as the use of chain saws, scooters or tractors is expensive. The use of protective clothing (boots, overalls, gloves, etc) would however, reduce the risk of accidents.
Table 3.3 Mean general health and breathing problems indices for charcoal producers and urban housewives using different fuels

<table>
<thead>
<tr>
<th></th>
<th>General health index</th>
<th>Breathing problem index</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean value</td>
<td>Standard error</td>
</tr>
<tr>
<td>Charcoal producers</td>
<td>6.39</td>
<td>0.536</td>
</tr>
<tr>
<td>Charcoal users</td>
<td>7.03</td>
<td>0.184</td>
</tr>
<tr>
<td>Wood users</td>
<td>6.58</td>
<td>0.254</td>
</tr>
<tr>
<td>Electricity users</td>
<td>6.50</td>
<td>0.373</td>
</tr>
</tbody>
</table>

Source: Ellegård, 1993
4 PHYSICO-CHEMICAL PROPERTIES OF CHARCOAL

The most important properties of charcoal are those that determine its quality. Charcoal quality is defined in terms of moisture content, volatile matter, fixed carbon and ash. These are termed as chemical properties. Physical properties relate to charcoal’s resistance to fracture.

4.1 Moisture Content of Charcoal
Charcoal straight from the kiln has very little moisture, usually less than 1% (FAO, 1987). Thereafter, it absorbs moisture of between 5 - 10% and when not properly stored, it may contain moisture of up to 15% due absorption of rain water (FAO, 1987). Moisture negatively affects the combustion properties of charcoal. It reduces its calorific value since the water in it has to be evaporated during burning. Therefore, the drier the charcoal, the better its combustion characteristics. To determine the moisture content of charcoal, a known mass of charcoal is heated at constant temperature (usually 105°C for 24 hours) and thereafter weighed. The mass difference is the mass of water which is expressed as a percentage of the original charcoal mass, either on air or oven dry basis. (See section 2.8).

4.2 Volatile Matter
Volatile matter includes all liquid and tarry residues not fully driven off during the process of carbonization. The longer the process of carbonization, coupled with higher temperatures, the lower the content of volatile matter. If carbonization time is short and temperature is low, the value of volatiles increases (see Section 2.8.1). Volatile matter approaches zero at high temperatures of about 1000°C (FAO, 1987).

Volatile matter in charcoal varies from less than 5% to about 40% and is measured by heating, in absence of air, a weighed amount of dry charcoal at 900°C to constant mass. The mass loss being the volatile matter content, while the remains is ash (see section 4.3).

Charcoal with high amounts of volatiles is easy to ignite, burns with a flame but most likely with much smoke and is more hygroscopic, less friable and thus producing less fines during transportation and handling. When volatiles are low, charcoal is difficult to ignite, but burns cleanly without a flame. Commercial charcoal has a volatile content of about 30% or less (FAO, 1987).

4.3 Fixed Carbon Content
Fixed carbon of charcoal ranges from a low of 50% to a high 95% (FAO, 1987). Charcoal, therefore, consist mainly of carbon. The fixed carbon content is the difference, in percent, from 100 of the other constituents (moisture, ash, volatiles).

4.4 Ash Content
The ash content of charcoal is determined by heating a weighed sample to red heat with excess air to burn away all combustible matter. The residue,
ash, which is mineral matter, occurs in the form of silica, calcium and magnesium oxides which are present in the original wood and also picked up as contamination from the earth during processing. The ash content depends on the species of wood, amount of bark included in the wood put into the kiln and the amount of earth and sand contamination. It varies from 0.5% to more than 5%. Good quality charcoal has about 3% ash content (FAO, 1987).

4.5 Physical Properties

Physical properties of charcoal relate to its strength or ability to resist fracturing during handling. Charcoal strength is determined by measuring the resistance of the charcoal to shattering or breakdown by allowing a sample to fall from a height onto a solid steel floor or tumbling a sample in a drum to determine size breakdown after a specified time (FAO, 1987). The result is then expressed as a percentage passing or retained on various sized screens. Table 4.1 shows properties of charcoal produced at Kamaila, about 50 km north of Lusaka. It is clear from the table that this charcoal has high ash content, probably due to contamination since this charcoal was produced during the rainy season.

Table 4.1 Properties of charcoal produced at Kamaila during October `92 - March `93 (in %)

<table>
<thead>
<tr>
<th>Moisture content</th>
<th>Volatile matter</th>
<th>Ash content</th>
<th>Fixed carbon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean value</td>
<td>7.5</td>
<td>15.7</td>
<td>7.8</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>2.3</td>
<td>4.0</td>
<td>2.6</td>
</tr>
</tbody>
</table>

Source: Hibajene, 1993
5 ENVIRONMENTAL IMPACTS OF CHARCOAL PRODUCTION

Until recently, very few studies had been undertaken to assess the ecological or environmental impacts associated with charcoal production. Studies curried out have focused on the effects of the charcoal production and use system in Central Zambia, particularly the effects of tree felling, brushwood burning, kiln covering, wood carbonization, road appearance and charcoal use (Serenje, et al 1993). The effects considered were on vegetation, wildlife, water, soil and air.

5.1 Tree Felling

During the process of tree felling for charcoal production, 90% of the basal area is removed representing about 95% of the above ground wood biomass. What remains are mainly small stems (see Section 2.2). About 20,000 hectares of Miombo woodland were cleared during 1990 in order to provide Charcoal in Central Zambia. When felling occurs in Miombo woodlands, the tree density of the first regrowth is 2-3 times higher than in the old growth woodland. Species density in regrowth Miombo is 20.55 per 0.1 ha compared to 17.13 in old growth (Chidumayo, 1987). Species diversity is, therefore, positively impacted. Grass production increases two years after felling and remains high until tree canopy is re-established in about 10-15 years.

Table 5.1 Soil moisture content (% dry weight) of felled and un-felled Miombo woodland plots in the Chakwenga area, 150 km east of Lusaka (figures are annual means).

<table>
<thead>
<tr>
<th>Site location</th>
<th>Year</th>
<th>Plot</th>
<th>Soil moisture content</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>0 - 10 cm</td>
</tr>
<tr>
<td>Hill</td>
<td>1991</td>
<td>OG</td>
<td>4.86</td>
</tr>
<tr>
<td></td>
<td></td>
<td>R1</td>
<td>5.19</td>
</tr>
<tr>
<td></td>
<td>1992</td>
<td>OG</td>
<td>4.81</td>
</tr>
<tr>
<td></td>
<td></td>
<td>R2</td>
<td>4.91</td>
</tr>
<tr>
<td>Interfluve</td>
<td>1991</td>
<td>OG</td>
<td>6.74</td>
</tr>
<tr>
<td></td>
<td></td>
<td>R1</td>
<td>7.86</td>
</tr>
<tr>
<td></td>
<td>1992</td>
<td>OG</td>
<td>4.64</td>
</tr>
<tr>
<td></td>
<td></td>
<td>R2</td>
<td>4.45</td>
</tr>
</tbody>
</table>

**OG** - Old growth - variable age; **R1** - 1st regrowth - approx 20 years old
**R2** - 2nd regrowth - approx 10 years old

Source: Serenje et al., 1993
Tree felling fragments wildlife habitats, but the current production areas have small populations of large mammals, so the effect is small. No quantitative data exists on the negative impacts of tree felling to wildlife species such as birds, reptiles and invertebrates. Nevertheless, woodland regeneration, though slow, would make such impacts temporal and short lived. Canopy cover in old-growth Miombo is estimated at 58%, which if removed is likely to lead to changes in the hydrological cycle. The combined effects of felling in Miombo woodland and subsistence cultivation, monitored by the National Council for Scientific Research (NCSR), revealed the run-off on experimental catchments increased by 10-18%.

The increase in water yield apparently comes from base flow as yearly woodland evapotranspiration is reduced as leaf area is reduced during felling. Therefore, tree felling increases the rate of aquifer recharge. The significance of these changes on climate, particularly on rainfall, is not known. Since total wooded area cleared during charcoal production in Central Zambia is only 2.5% compared to 19.3% by agriculture, the impact on water yield may be significant only at a small catchment level. Still such an impact would be temporal.

Table 5.2 Soil nutrient status of felled and un-felled Miombo woodland plots

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Soil depth</th>
<th>1991</th>
<th>1992</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Old Growth</td>
<td>1st Regrowth</td>
<td>Old Growth</td>
</tr>
<tr>
<td>Organic C (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 - 10 cm</td>
<td>2.42</td>
<td>2.12</td>
<td>2.10</td>
</tr>
<tr>
<td>11 - 30 cm</td>
<td>1.13</td>
<td>1.30</td>
<td>0.91</td>
</tr>
<tr>
<td>Total N (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 - 10 cm</td>
<td>0.21</td>
<td>0.23</td>
<td>0.07</td>
</tr>
<tr>
<td>11 - 30 cm</td>
<td>0.19</td>
<td>0.20</td>
<td>0.04</td>
</tr>
<tr>
<td>Available P (mg/kg)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 - 10 cm</td>
<td>20.08</td>
<td>19.0</td>
<td>22.4</td>
</tr>
<tr>
<td>11 - 30 cm</td>
<td>14.9</td>
<td>11.9</td>
<td>15.6</td>
</tr>
<tr>
<td>CEC (meq/100 g)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 - 10 cm</td>
<td>6.73</td>
<td>6.03</td>
<td>6.46</td>
</tr>
<tr>
<td>11 - 30 cm</td>
<td>3.71</td>
<td>4.23</td>
<td>4.28</td>
</tr>
</tbody>
</table>

Figure are annual means, vegetation age same as in Table 5.1
C = Carbon, N = Nitrogen and P =Phosphorous

Tree felling for charcoal production has very little effect on soil physical properties. On felled and un-felled equal Miombo plots, soil moisture content did not differ significantly up to a depth of 30 cm (Table 5.1). Tree leaf litter production estimated at 2.7 tonnes/ha/year in old growth Miombo sustains nutrient cycling upon decomposition together with dead herbaceous biomass. Although leaf litter input reduces upon felling, grass
litter production increases, thus the net litter loss is minimal, and is unlikely to have a significant effect on the soil nutrient pool and cycling (Table 5.2).

The effect of tree felling on air is insignificant. Annual old growth miombo woodland productivity is 4.2 t ha/yr of which about 60% is leaf, which represents a carbon fixation of about 1.9 t ha/yr (Chidumayo, 1990; Chidumayo, 1991a). A few years after felling this figure is 0.25 t ha/yr, and after six years it increases to 1.8 t ha/yr. Thus in the first 6 years after felling, less carbon is fixed in regrowth than old growth woodland which results in atmospheric carbon accumulation of about 1.6 t ha/yr. This figure is insignificant considering the small area felled for charcoal as compared to felling for agriculture.

**5.2 Brushwood Burning**

Standing woody biomass in old growth Miombo (Lusaka east) is estimated at 71.5% cord wood (logs), 25% twig/brush wood and 3.5% leaf biomass (Chidumayo & Kalumiana, 1991), while the total woody biomass in Central Zambia is estimated at 62.2 t/ha. This is the biomass that is felled for charcoal production. The brush wood and leaves are discarded and burnt (see Section 2.2.). In a survey it was found that charcoal spots covered about 4% of the felled area (Chidumayo, 1989). Brush wood burning kills grasses and some root stocks of woody plants, together with seedlings. Seedling density in old growth Miombo is estimated at 1.77 m², so that about 17,700 seedling ha⁻¹ may be killed by brush wood burning. Several years may be required before herbaceous plants colonise such burnt spots. For woody plants however, fire kills the above ground biomass of seedlings, while the underground part is not killed. Thus only temporal die-back is exhibited, and later resprouting occurs (Chidumayo, 1991b). A high species diversity has been found on chitemene (shifting cultivation) ash gardens ranging in age from 1 - 25 years (Stromgaard, 1986), which has been attributed to the survival of stumps and roots of the pre-felling woodland, which apparently were not killed by fire.

Although brush wood burning destroys habitats which may be provided by brush wood piles to small fauna like reptiles and invertebrates, it is not possible to quantify such impacts. Also given the small areas affected by brushwood burning, its impact on water is likely to be insignificant.

**Table 5.3 Carbon, nitrogen and sulphur concentration in miombo woodland biomass and estimated amount released by brush wood burning**

<table>
<thead>
<tr>
<th>Biomass type</th>
<th>Element content (%)</th>
<th>Burnt biomass t yr⁻¹</th>
<th>Element released (t)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C</td>
<td>N</td>
<td>S</td>
</tr>
</tbody>
</table>

27
Stromgaard (1984) found an increase in top soil nutrient concentration due to branch and brush wood burning on future chitemene plots, and this may also apply to charcoal production. However, such fires may also kill microorganisms that are involved in nutrient cycling. Additionally, the resultant darkened soil surfaces devoid of tree cover may raise top soil temperatures due to reduced albedo which leads to excessive drying of the soil. Nonetheless, since the affected areas are small, the impacts are minimal. Since current deforestation due to charcoal production in central Zambia is 20,000 ha/year, brushwood burning affects about 800 ha (i.e 4%). Given the concentration of carbon (C), Nitrogen (N) and Sulphur (S) in Miombo tree biomass (Table 5.3), brush wood burning generates the following amounts per year: Carbon 6,000 t (about 22,000 t CO2), Nitrogen 60 t (155 t NOx) and Sulphur 5 - 17 t (34 t SO2).

Source: Miombo Productivity Progress Report, 1992

In Central Zambia, non-cultivated vegetated area covers about 3.5 million ha, of which about 70% is burnt yearly by human made fires. If half of the tree leaf litter and all grass litter in burnt areas are burnt, about 3.68 million t of carbon (13.5 million t CO2), 59,400 t of nitrogen (161,24 t NOx) and 9,240 t of sulphur (18,480 t SO2) will be generated annually. The amounts of carbon, nitrogen and sulphur released in charcoal production areas is about 0.2% of that released from bush burning, which figures are quite small in relation to other sources. These figures are however meant to give the general picture and do not take into account the different emission patterns that would arise from the more highly intense brush wood fires and the low intensity of normal bush/ grassland fires.

**Table 5.4 Mean annual soil nutrient concentration in two old growth miombo woodland sites in the Chakwenga area, about 100 km east of Lusaka (kg/ha)**

<table>
<thead>
<tr>
<th>Top soil (0-10cm)</th>
<th>Sub soil (11-30cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium</td>
<td>1090</td>
</tr>
<tr>
<td>Magnesium</td>
<td>340</td>
</tr>
<tr>
<td>Potassium</td>
<td>410</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>1740</td>
</tr>
<tr>
<td>Mineral Phosphorous</td>
<td>27</td>
</tr>
<tr>
<td>Organic carbon</td>
<td>28530</td>
</tr>
</tbody>
</table>

Source: Chidumayo, 1993
5.3 Kiln Covering

Kiln covering destroys vegetation at the dug up site, and plant roots up to 15cm deep (see section 2.4). Surviving roots coppice within weeks, while herbaceous vegetation from seed may take several years to re-establish. The affected area, which is about 5.5% of the cut over area, is small and its impact on species diversity will be insignificant. The same applies to faunal habitats which may be destroyed in the process.

The uneven surfaces created by kiln covering may impede surface drainage and trap rain water, which in turn improves water infiltration and reduces the risk of soil erosion. These positive impacts are however, left at the micro-level and are therefore minimal.

There are more nutrients in the top soil of a miombo woodland than in sub-soil for a given volume (Table 5.4). When the top soil is removed in order to cover a kiln, site productivity of dug up areas will obviously be reduced, and such nutrients may take years to replace. With regards to air, dust is released into the air during kiln covering. However the quantities are small as dug up soil is bound in lumps by plant roots.

5.4 Wood Carbonization

During wood carbonization, a lot of heat is generated over several days due to the high temperatures attained (500-700°C). This heat destroys all plants at the kiln site. Herbaceous vegetation from seed dispersal may establish within a few years. Seeds of miombo trees which are dispersed by the exploding of wood pods are dispersed for short distances (10 - 20cm) as compared to wind dispersed seeds of herbs (28 - 103m) (Malaisse, 1978). Therefore, for large clear-cut areas, miombo trees will fail to colonise kiln sites. Also seedling development of the majority of miombo trees is very slow (Chidumayo, 1991 b). Hence the negative impact is long term although the affected area is small.

Table 5.5 Concentration of soil nutrients at a charcoal kiln, and an adjacent undisturbed area at Chitemalesa, east of Lusaka. Figures are mean values of duplicate samples which were collected on August 6th 1992

<table>
<thead>
<tr>
<th>Soil nutrient</th>
<th>Top Soil (0-10cm)</th>
<th>Sub soil (11-30)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Charcoal kiln</td>
<td>Adjacent area</td>
</tr>
<tr>
<td>pH CaC12 (ratio 1:2.5)</td>
<td>7.0</td>
<td>6.1</td>
</tr>
<tr>
<td>Potassium</td>
<td>2.37</td>
<td>1.45</td>
</tr>
<tr>
<td>Sodium</td>
<td>0.16</td>
<td>0.15</td>
</tr>
<tr>
<td>Calcium</td>
<td>6.25</td>
<td>4.78</td>
</tr>
<tr>
<td>Magnesium</td>
<td>1.88</td>
<td>1.61</td>
</tr>
<tr>
<td>CEC</td>
<td>10.66</td>
<td>7.99</td>
</tr>
</tbody>
</table>
Since the cord wood stacks' existence is temporal, numbers of fauna likely to be trapped in kilns and later killed during carbonization are small. As for water, although the kiln site dries up during carbonization, the disturbed loose soil is likely to have greater water absorptive capacity during the rainy season, thus enhancing infiltration of rain-water, and also reducing the risk of soil erosion. However, the loose soil on the kiln site may lose moisture fast during the dry season leading to desiccation and eventual mortality of seedlings that may establish on the charcoal site.

How the soil’s physical properties are affected by carbonization is not known, but the process may increase soil pH by up to 2 units, and mineral phosphorous may more than double, while other nutrients do not significantly change. (Table 5.5) Charcoal spots are good for growing crops, and those that are accessible are used for this purpose.

Since carbonization occurs in a confined space, the amount of emissions to the air are small, even for smoke which escapes through the earth walls and vents. And since high carbonization temperatures are rarely attained in earth kilns, the charcoal retains most of the volatile substances.

5.5 Road Appearance

Foot paths used by charcoal producers eventually become bush tracks after repeated use by motor vehicles. Road appearance impacts vegetation only as far as it destroys that which is on ruts. The air may be polluted by engine exhaust fumes, but only at a very small scale. Wildlife too is insignificantly affected. On the other hand soil in the tracks is compacted, thus increasing its bulk density, reducing plant root penetration and seedling establishment. Compacted soil has low infiltration rates and hence surface run-off concentrates on wheel ruts, and this may increase overland water yield and flash floods in downstream valley areas. When combined with tree felling, run-off may be increased substantially and a reduction in the quality of water from deforested catchments will result.

5.6 Charcoal Use

Most of the charcoal produced in Zambia is used in the traditional mbaula for domestic energy requirements in urban areas. Vegetation, wildlife and water are not directly affected by the use of charcoal for energy. The nutrient status of soil however, is increased at disposal sites.

Apart from Nitrogen, gas emissions from the traditional mbaula are quite high. In 1990, charcoal burning generated an estimated 452,600 t of carbon or 1,788,200 t of CO₂ while total annual CO₂ emissions in Zambia is estimated at 33.5 million tonnes. Hence the contribution of urban charcoal
burning to total carbon dioxide emissions is about 5%. Of this amount, 99% accumulates in the atmosphere since only 1% is fixed during photosynthesis in deforested areas. However, as reforestation occurs, the net CO$_2$ release declines. An estimated 200,000 t yr$^{-1}$ of SO$_2$ is released from industry, while from charcoal burning about 48 t was released in 1990 in Central Zambia, which represents 0.024% of the total SO$_2$ industrial output. This is quite clearly an insignificant amount.

5.7 Charcoal Production and Deforestation

Annual deforestation is estimated at 200,000 ha (Environmental Council of Zambia, 1994). Deforestation attributed to woodfuel alone is estimated to be 56,000 ha (Table 5.6), about 28% of the total annual deforestation rate estimated by the Environmental Council of Zambia (ECZ). Table 5.6 assumes clear felling during charcoal production. This is not usually the case, as producers selectively cut trees (section 2.2). Percentage contribution of deforestation arising out of charcoal production is therefore much lower. Besides, some of the charcoal is produced using wood in gardens being prepared for growing crops (Kalumiana et al., in press), and such deforestation should be attributed to agriculture.

It is quite difficult to determine the deforestation rate caused by charcoal production. It can however, be estimated from the amount of charcoal produced, based on amount of charcoal consumed. The following formula is used:

$$D_c = \frac{W_p}{S_r},$$

where

- $D_c$ is annual deforestation, in hectares, arising out of charcoal production,
- $W_p$ is the quantity of wood, in tonnes, used to produce charcoal in a year, and
- $S_r$ is the stocking rate, in tonnes/ha, in this case the amount of usable wood for charcoal production.

If, for example, we assume an area supplies 97,000 tonnes of charcoal to a nearby town per annum, and that the stocking rate of Miombo in that area is 76 t/ha, and we know that 3% of the charcoal produced is left as fines at the kiln site, by diving charcoal consumed by 0.97 (since only 97% of charcoal produced is packaged for sale), we find that the total charcoal produced is 100,000 tonnes per year. Suppose from section 2.8, calculations showed that the kiln conversion efficiency is 20%, then the total amount of wood used for producing the 100,000 tonnes of charcoal is therefore 500,000 tonnes per year (i.e dividing 100,000 by 0.2). Applying the above formula,
deforestation arising out of charcoal production in the supply area can therefore be calculated as follows:

\[ D_c = \frac{500,000 \text{ t}}{\text{annum}} = 6,600 \text{ ha per annum.} \]

\[ 76 \text{ t/ha} \]

This approach merely gives the order of magnitude of the contribution of charcoal production to deforestation and the result obtained should be regarded as an upper limit since producers do not clear fell the areas. Furthermore areas deforested during charcoal production are likely to be re-afforested if other factors (agriculture, fires, etc) do not hinder forest regeneration.

Table 5.6 Estimated deforestation from charcoal production in 1995

<table>
<thead>
<tr>
<th>Area</th>
<th>Wood for Charcoal Production (tonnes)</th>
<th>Charcoal Production (tonnes)</th>
<th>Miombo wood biomass (t/ha)</th>
<th>Estimated deforested area (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central Zambia</td>
<td>1,250,000</td>
<td>250,000</td>
<td>58</td>
<td>21,550</td>
</tr>
<tr>
<td>Copperbelt Province</td>
<td>1,433,000</td>
<td>287,000</td>
<td>76</td>
<td>18,850</td>
</tr>
<tr>
<td>Other areas</td>
<td>922,000</td>
<td>184,000</td>
<td>59</td>
<td>15,630</td>
</tr>
<tr>
<td>Total</td>
<td>4,290,000</td>
<td>721,000</td>
<td>-</td>
<td>56,030</td>
</tr>
</tbody>
</table>

Source: Banda et al., 1996

5.8 Charcoal and Green House Gas (GHG) Emissions

Table 5.7 gives estimated gas emissions arising out of the production and use of charcoal in Zambia in 1990. For Carbon Dioxide (CO₂) total fixation by above ground forest biomass was estimated at 123,196,000 tonnes per annum, for which natural regeneration accounted for 99% (MEWD/GTZ, 1995). When all the sources of CO₂ during 1990 were considered, it was found that forests still had capacity to fix an extra 63,527,000 tonnes. Even considering this excess capacity only, the current CO₂ emissions from charcoal production and use is only about 9% of this figure. Activities related to charcoal production do not therefore have a significant impact on GHG emissions. Besides the other gases are emitted in small quantities.
Table 5.7 Estimated Green House Gas Emissions from production and use of charcoal in 1990

<table>
<thead>
<tr>
<th>Type of gas</th>
<th>Charcoal Production</th>
<th>Burnt regrowth</th>
<th>Charcoal Use</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon Dioxide (CO₂)</td>
<td>3,834,550</td>
<td>142,690</td>
<td>1,788,240</td>
<td>5,765,480</td>
</tr>
<tr>
<td>Methane (CH₄)</td>
<td>16,730</td>
<td></td>
<td>7,800</td>
<td>27,530</td>
</tr>
<tr>
<td>Carbon Monoxide (CO)</td>
<td>244,010</td>
<td></td>
<td>113,800</td>
<td>357,810</td>
</tr>
<tr>
<td>Nitrogen Oxide (NO₂)</td>
<td>11,490</td>
<td></td>
<td>5,360</td>
<td>16,850</td>
</tr>
<tr>
<td>Nitrous Oxide (N₂)</td>
<td>270,790</td>
<td></td>
<td>126,290</td>
<td>397,080</td>
</tr>
</tbody>
</table>

Source: MEWD/GTZ, 1995
6 INSTITUTIONAL FRAMEWORK OF CHARCOAL PRODUCTION

The Ministries of Energy and Water Development (MEWD) and Environment and Natural Resources (MENR) are the major Government actors in the charcoal industry. In the MEWD, the Department of Energy (DOE) and the National Energy Council (NEC) deal with energy matters, the former being the most significant. The major actor in the MENR is the Forest Department (FD), while the Natural Resources Department (NRD) is involved to a lesser degree. These government agencies work in conjunction with quasi-government, NGO's and donor organisations in matters relating to charcoal. In addition to these, charcoal producers associations, prominent among which is the United Charcoal Organisation of Zambia, are also important actors.

6.1 The Department of Energy

The Department of Energy (DOE) was created in 1982, in the then Ministry of Power, Transport and Communications, but became operational at the end of 1983. Up to date, this Department is not backed by an act of parliament. It is the contact point for the Southern African Development Community (SADC) energy sector. In relation to woodfuel (firewood and charcoal) the Department has the following tasks:

(a) To advise government on woodfuel policy. Currently the Department of Energy is working on implementation plans for the recently launched woodfuel policy. This policy seeks to ensure the long term sustainability and effective management of the charcoal industry by promoting:

(i) proper management and sustainability of forest resources for woodfuel harvesting;
(ii) improving the technology of charcoal production and utilization;
(iii) promoting the stabilization of charcoal supply to urban areas; and
(iv) improving revenue collection from the woodfuel industry

(b) To formulate comprehensive energy plans for short, medium and long term woodfuel strategies; and

(c) To provide a comprehensive approach to the rural and urban household energy problem.

In order to achieve these objectives, the Department of Energy has undertaken studies, together with institutions like the University of Zambia (UNZA), National Council for Scientific Research (NCSR) and donor agencies, into the following areas:

- Evaluation and improvement of charcoal stoves
- Health aspects of charcoal production on producers
- Health aspects of charcoal and fuelwood use
- Testing emissions of household fuels
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- Responses of miombo woodlands to wood harvesting and management
- Environmental impact assessment of the charcoal system
- Improvement of the charcoal supply and distribution in Zambia
- The role of energy in the household economy
- Improvement of the traditional charcoal production method
- Charcoal supply stabilisation for urban areas
- Adoption of a new charcoal revenue collection system
- Low cost approaches to household electrification

6.2 The National Energy Council

The National Energy Council (NEC) was established by an Act of Parliament, in 1980, to advise the energy Minister on key issues of energy policy and planning. Its functions however, overlap with those of the Department of Energy. In 1995, the National Energy Council Act was repealed, setting into motion the abolishment of this institution.

6.3 The Forest Department

The Forest Department (FD) dates back to the colonial days, and is responsible for designated forest reserves, and maintains timber plantations under provincial forest officers. When in 1983 the Copperbelt Industrial plantations were transferred to the Zambia Forest and Forestry Industry Corporation (ZAFFICO), the Forest Department became more interested in social or community forestry. In the forest reserves, the Department carries out management practices such as early dry season burning. It is also responsible for collecting woodfuel fees administered as follows:

- The stumpage fee of K3,000/3m³ stacked wood (1995 rate) which is paid by the harvester before felling trees, and
- The charcoal removal fee of K200/bag (1995 rate) which is paid by the charcoal trader prior to delivery at the market.

In 1986, the mandate of the Forest Department was defined as follows:

a) To ensure management of indigenous and exotic forests for production and environment protection;
b) To expand its extension services to promote public participation in forest conservation and tree planting for their own benefit;
c) To expand the wood consumption study to incorporate socio-economic parameters;
d) To establish fuelwood plantations in fuel deficit areas; and
e) Silvicultural and utilization research on exotic and indigenous tree species.

The Forest Department has also promoted charcoal making from exotic tree species (Ranta & Makunka, 1986). By early 1996, it was in the process of absorbing the Natural Resources Department and its functions. Since July
1992, the Forest Department has been undertaking the Zambia Forest Action Programme (ZFAP), a strategy designed to re-organise the forest sector.

6.4 The Department of Natural Resources
Prior to its recent absorption into the Forest Department, this Department was responsible for all non-agricultural natural woodland (excluding forest reserves), and bushland with the exception of areas in National Parks. It was responsible for land conservation, monitoring and control of bush fires (outside forest reserves), and shifting cultivation (Chitemene). Its district officers were also involved in extension work. The Department of Natural Resources (DNR) had carried out research on productivity and sustained yield from natural woodlands, charcoal production and marketing systems, rural and urban household energy consumption, deforestation etc. It also maintained research plots where woodland regeneration was monitored. Its role of environment control and monitoring was, however taken over by the Environmental Council of Zambia. It is envisaged that the departmental staff will use these skills to carry out similar activities in the FD. The DNR was the contact point for United Nations Environment Programme and the Southern African Development Community (SADC) Land Conservation Programme.

6.5 Quasi-Government Actors and Donors
The University of Zambia (UNZA) has been involved in research concerning ecological aspects of charcoal production of the resource base, the miombo woodlands. It has also carried out biomass surveys and other studies involving charcoal producers and users; and has been involved in stove research. The National Council for Scientific Research (NCSR) has investigated emissions from charcoal using different stoves as well as quality of charcoal. These activities were carried out on behalf of the DOE. Prominent donors in the Zambian charcoal industry have been the World Bank/ESMAP, United Nations Development Programme (UNDP) and the Swedish International Development Agency (SIDA) through the Stockholm Environment Institute (SEI). The SEI has been working with DOE on various charcoal related projects since the late 1980's.

6.6 Charcoal Producers' Organisations
There exists a United Charcoal Organisation of Zambia whose headquarters is in Kitwe. The organisation is essentially a union of charcoal traders although membership is open to all individuals who legally produce charcoal. The objectives of the organisation are summarised as follows:
   a) to supervise the production and marketing of charcoal;
   b) to advance members' awareness of the benefits of trees and forests in relation to conservation of the natural environment and of the role of forestry in national development; and
   c) to create a favourable working relationship between the relevant government agencies and members of the organisation.
6.7 The Role of Local Communities

The involvement of local communities in charcoal production starts with the resource base (woodlands). Most charcoal production areas are outside forest reserves and hence not directly administered by the Forest Department. Those in Trust or Tribal land are administered by local chiefs or village headmen whose permission must be sought before a producer can start production.

Local communities have been involved in various tree planting activities aimed at increasing raw materials for charcoal production as well as for arresting deforestation (McCall, 1987). In the urban areas, local blacksmiths have been trained to make improved models of the traditional mbaula, while demonstrations involving women have been carried out to teach the best means of using the mbaula. The promotion of the improved mbaula has been undertaken by the Non Governmental Organisation Coordinating Committee (NGO-CC) charcoal stove project team.
PART II:
THE CHARCOAL MAKING PROCESS ILLUSTRATED
Figure 1 Selecting trees for felling

Most of the trees that are found in Zambia can be used to make charcoal, especially those that belong to the group called Miombo. However, there are some trees that do not make good charcoal. These are: Erythrophleum africanum, Albizia Antunesiana, Burkea Africana and Swartzia Madagascariensis. You should also know that trees like Pericopsis Angolensis are too hard to cut. You may be sick if you overwork yourself! It is illegal for you to cut fruit trees like Uapaca Kirkiana, Anisophyllea Boehmii, Parinari Curatellifolia and Strychnos spp. like Cocculoides. It is also not allowed to cut Pterocarpus Angolensis as it is a good timber tree. See also Table 8 and Table 9 on page 55.

Bigger trees give more and better charcoal. Therefore, do not cut trees that are less in size than the calf of your leg! Small trees should be left to regenerate. If you cut them you are destroying the land. Land that should have trees should not be left bare. Remember trees protect the land, including the soil. Remember that the lack of trees reduces rainfall which leads to famine!

Figure 2 Tree felling

The first stage in making charcoal is to cut suitable trees. The trees are cut with an axe, a hand or power saw, depending on what is available to you.
You should cut the trees to a height not exceeding 30 cm from the ground, about the length from your elbow to the end of your wrist. The lower the height at which the tree is cut the better, so as to ensure that not too much wood is left in the form of stumps. The cutting should be slanting to ensure that water does not collect on the remaining stumps. This aids coppicing (growing of new shoots).

Figure 3 Cross cutting

After you have felled the tree, cross-cut it into logs/billets of 1 - 2 m long. You should cross-cut the whole tree, main stem together with the branches, leaving only branches that are less than 12 cm in circumference or about the size of an average axe handle.

After you have cross-cut a tree, leave the logs lying around. You should only start collecting them after you have cut enough wood to make a kiln of your desired size. Remember that dry logs are lighter to carry compared to freshly cut ones. You also make more charcoal from dry wood than from fresh wood. So by the time you finish cutting most of your wood would have dried to some extent.
After completing cross-cutting and left your logs to dry for a period not less than 3 weeks, you can start hauling your logs to one place where you are going to build your kiln. If possible you can ask your friends, or fellow charcoal producers to help you.

Log haulage is achieved by physically lifting small logs to the kiln site or carrying large ones using a wheelbarrow. You do not need to have a commercial wheelbarrow as even a wooden one could do as shown in the picture. The bigger and heavier logs are normally transported by rolling them on the ground using a strong stick or anything suitable.

During this time ensure that you pile the logs according to their size. This will make it easy for you when it comes to building the kiln clamp as parking proceeds in stages according to the log sizes.

When all the wood has been brought to one place, you can plan when you will start packing. If you plan not to start packing right away, but want to wait until some other time, make sure you clear the area around the packed wood. Remember that it can easily be burnt by wild fires, especially if it is
during the dry season. Ensure that logs which may not have been put on a pile corresponding to their size are put on the right pile.

Ensure that the wood is kept for reasonably long time (at least 3 weeks after cutting) before it is used to make charcoal. However, it should not be left for too long as it may start to rot or be eaten by termites. Rotten wood does not make good charcoal.

Figure 6 Piling the twigs

When all your logs have been piled, go through the area you have cut to ensure that no twigs are piled on stumps. Remember that soon the twigs will dry and burn. Coppicing stumps are usually destroyed by fire, and this is worsened if the fire has more material to burn. Ensure that all stumps are free of twigs, leaves and grass so as to protect them from fire. You can pile such twigs, leaves and grass in spaces far from stumps and small trees. If you do not do this, you are destroying the forest from which you are getting you charcoal. In future you and your children will have no more trees left!

Figure 7 Kiln building - laying the stringers

Before you start piling the logs, ensure that the place where your kiln will be located is not likely to be flooded when it rains i.e. it should be a flat or even place and not low ground compared to the surrounding. It also should not be under shade otherwise your wood will not dry substantially. Clear the
ground around the kiln site so that you will have enough space to spread hot charcoal for cooling and to minimise the risk of the charcoal catching fire in case of delayed collection.

The first step of building a clamp involves laying medium sized logs, called stringers, lengthwise on the ground. Join them in rows according to your intended kiln length, the rows being about 1 m apart. The lengths of the stringers vary, but should not be less than 1.5 m. The stringers are intended to allow for easy air/fire movement at the bottom of the kiln.

![Kiln building - laying the cross members](image)

**Figure 8 Kiln building – laying the cross members**

The second stage of packing involves parking medium sized logs slightly larger than the stringers. These logs called cross-members are laid across the stringers, and are the first layer of wood intended for charcoal making. Their small size ensures that while the kiln is being built, there is still space below for air circulation and also for fire to spread through.

![Kiln building - laying the largest logs](image)

**Figure 9 Kiln building – laying the largest logs**

The next stage involves the laying of the largest logs available. These are placed as tightly as possible ensuring that as little space as possible is left between the logs. The fact that the logs were initially piled according to their sizes makes it easy to conduct the packing. If possible, the largest logs should be in the centre of the kiln, neither at the bottom nor at the top. This
is because the smaller logs surrounding them will then help the carbonization of the largest logs. The most important aspect of wood piling is that the wood should be as tightly packed as possible.

Figure 10 Kiln building – laying medium sized logs
After the largest logs have been packed, then lay the large logs, taking much care that the wood is packed as closely as possible. Of course the number of stages to be involved will depend on the different sizes of the wood available to you. With many different sizes, you will have more stages during packing. The most important aspect, however, is that the wood should be as tightly packed as possible.

Figure 11 Kiln building - laying small logs
The small logs will be the last to be packed. This should also be done neatly, on both the front and back of the clamp as well as on top.
Figure 12 Kiln building - filling the spaces

When the small logs have been parked, ensure that there are no spaces between the wood. Any sizeable spaces must carefully be closed using small logs, which may have to be cut into shorter logs to ensure they fit neatly. The final clamp should appear very tightly packed. This is a very important aspect of kiln building.

Figure 13 Crosswise packing

The style of parking described so far is called cross-wise packing. The stingers are laid lengthwise while the wood is parked cross-wise.
Figure 14 Length-wise packing

Another way of laying the logs is lengthwise packing. Here the stringers are parked cross-wise while the wood is packed lengthwise. In this case the wood used may be longer than the one in the crosswise loading but for the sake of allowing wood to dry as soon as possible, it is advisable to cut the wood into short lengths (1 - 2 m).

None of the two ways has an advantage over the other in terms of charcoal yield, so the adoption of either depends on the producers preference. The steps taken in building the kiln are the same in both cases. What matters is that the wood is tightly packed in the kiln.

Figure 15 Digging soil lumps

The kiln is now ready for covering with soil. To make the work easier, it is advisable to dig (with a shovel or hoe) the soil lumps in advance and leave them lying around. After enough lumps have been dug covering of the kiln can then start.
Ensure that the soil used is not the type that shrinks or cracks when heated or else you will have problems during carbonization as your kiln will develop a lot of cracks. This leads to the production of poor charcoal - sometimes the wood is burnt and you may get no charcoal at all. The kiln covering must be as airtight as possible.

Figure 16 Covering the kiln with soil lumps
Covering the clamp with soil involves a thick wall round the kiln. The wall should be built such that the lumps "stay" on the wood, the kiln walls being thicker at the bottom. All the clamp sides are covered in this way, and loose soil is also applied to make sure the clamp is tightly sealed with no spaces remaining uncovered. At this stage, the top of the clamp is left uncovered.

Figure 17 Charcoal making and your health
The steps described so far, are labour intensive and can cause you to be sick. Please do not overwork yourself! Remember you can do more if you are healthy. It is also not advisable for women to be too involved in these
Hibajene and Kalumiana

stages. If you are a woman, you could pay people to do the work for you. You could arrange to give them charcoal instead of money when the work is done.

![Figure 18: Covering the kiln with soil lumps](image)

**Figure 18 Covering the kiln with soil lumps**

The kiln top is covered with grass and/or green twigs and leaves. These are collected when this stage is reached. The grass, twigs and leaves are first put on top of the small logs. These will prevent loose soil seeping through the kiln and impeding carbonization. Any loose soil that seeps through will block the movement of air and fire through the kiln thus resulting in the wood around that area not being converted to charcoal.

After the underlying material (i.e. grass, twigs and leaves in combination or otherwise) has been neatly packed to cover the top, soil lumps and later loose soil are added on top to complete the sealing. The soil layer at the top should however, not be as thick as on side walls.

If the kiln is near a settlement, it may be necessary to put around it some twigs which will stop livestock and/or children trampling or destroying the kiln walls or compacting it unnecessarily leading to loose soil seeping through.
When finally your whole kiln is covered it should look something like this. You would by this time have done much of the work. The kiln is now ready to be fired, so that the process of carbonization can start.

It is normal practice that during the time of building the kiln walls, the place where the firing point will be would have been covered as well. Small dry wood and other kindling material would however, have been deliberately placed here so as to enable the charcoal producer easily light a fire.

The first step therefore will involve uncovering the firing point and then the producer lights a fire here or pushes in, with a shovel, a shord of burning charcoal/ wood so as to ignite the kindling material. The fire will have to establish first before the hole is closed. It is advisable to light the kiln in calm weather. After the fire has established, close the firing point. Immediately the amount of smoke will drop, but soon it peaks up again. The process of turning wood into charcoal has begun. For the next several days you have to constantly keep watch over the kiln.
Figure 21 Kiln management

You must ensure that all those parts where smoke comes out in excess are closed. If you do not close them, too much air goes into the kiln and the wood burns and then you lose charcoal. The kiln surface in most parts will be darkened by tars being released from the wood. Careful management of the kiln is important. It will give you good and plenty of charcoal from your kiln. During this time do not plan to travel away from your village. Do not even go to drink beer unless there is someone else looking after your kiln. It is important that you observe all the happenings at your kiln.

Figure 22 Monitoring progress

By feeling (with your hand) sections of the kiln, you will be able to tell how far the fire has gone. The section where the fire is will be hot.

In order to constantly revive the fire and enable it to move along, you will have to make small holes along the kiln length about 10-15 cm above the ground. These will allow limited quantities of air to get through and thus revive the fire, especially if it is about to go out. The kiln progressively collapses at those places where carbonization has taken place. In case you are not sure of what is happening at any part of the kiln, you can open it and check, but close is again. Sometimes, you may have to re-start the fire.
Hibajene and Kalumiana

You should however, be careful when climbing a kiln in progress - an accident could lead to your death.

Figure 23 Carbonization progress: A summary

The four small drawings summarise what happens to a kiln on fire. The first one shows a fire after it has been lit through the firing point/hole. On the second one the firing hole has been closed and carbonization commenced. The last two drawings show the kiln progressively collapsing as sections of it "ripen".

Figure 24 Starting charcoal harvesting

After some time the part of the kiln that has collapsed can be `harvested' while the rest of the kiln is still carbonizing. This part is opened and
charcoal is taken from it. The hot charcoal that is taken from the kiln is thinly spread on the ground to cool it. The ground should be devoid of any material that can burn.

Figure 25 Covering the charcoal with soil
As soon as the hot charcoal is spread on the ground, it is immediately covered with clean loose soil. It must however, be thinly spread. Any covered part that shows some smoke is re-covered. This is important otherwise the charcoal completely burns, and then you lose everything. The charcoal should therefore, be adequately covered so that any fire is extinguished.

Figure 26 Preparations for packaging
After the covered charcoal has cooled (this can be within 48 hours) you can then recover the charcoal using a fork and pile it aside. Do not pile hot charcoal otherwise it will all burn to ashes.
Those pieces of wood which have not adequately turned into charcoal are piled aside as well. If they are many, or if combined with others from nearby kilns, they can be built into another kiln, from which you will still
get more charcoal. You can collect the small charcoal fines, which are not suitable for sale, either for your own use or for igniting other kilns.

Figure 27 Bagged charcoal ready for sale

Your charcoal is now ready for packaging into bags for sale. You do not have to worry about bags where to pack the charcoal. Normally the charcoal buyers will bring with them their own bags. But if you want to sell the charcoal yourself, you can buy used maize "90 KG" bags and use them. You realise of course that the harvesting of the kiln is a somewhat continuous process. You can be selling charcoal while harvesting "ripening" sections of the kiln until everything is finished.

Figure 28 Keeping unsold charcoal

It is not good to make charcoal if you have no one to buy it, especially during the rainy season. Uncovered charcoal when constantly soaked with rainy becomes soft and easily crumbles. It cannot be sold later! You can avoid this loss by not firing your kiln until you are sure someone will buy the charcoal. Some people cut trees and leave them lying around without making charcoal. This is bad too. Remember trees protect the land. They should only be cut when necessary, and this should be done carefully.
As mentioned earlier, ensure that no twigs are left piled on stumps. You could even collect as many of the twigs as you can and pile them on the kiln spot—the place where charcoal was made. If however, you want to use that place as a garden, you do not have to do this as long as stumps and small trees/shrubs are free of any material that burns. Remember that your actions can destroy the forest. The Government and the chief will not be happy with you. Be a responsible and good charcoal producer!
**Table 8 Trees not usually cut for charcoal production**

<table>
<thead>
<tr>
<th>Scientific name</th>
<th>Bemba</th>
<th>Lozi</th>
<th>Tonga</th>
<th>Nyanja</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Erythrophleum africanum</em></td>
<td>Mukoso</td>
<td>Mubako</td>
<td>Mungansa</td>
<td></td>
</tr>
<tr>
<td><em>Albizia antunesiana</em></td>
<td>Musase</td>
<td>Munganyama</td>
<td>Kawizi</td>
<td>Mpefu, Buwa</td>
</tr>
<tr>
<td><em>Burkea africana</em></td>
<td>Mukoso, Museshe</td>
<td>Kaiwizi, Kapanga</td>
<td>Msase</td>
<td></td>
</tr>
<tr>
<td><em>Swartzia madagascariensis</em></td>
<td>Ndale</td>
<td>Mushakashela</td>
<td>Mulundu</td>
<td>Mchelekete</td>
</tr>
</tbody>
</table>

Some species are too hard to cut especially with an axe for example:

<table>
<thead>
<tr>
<th>Scientific name</th>
<th>Bemba</th>
<th>Lozi</th>
<th>Tonga</th>
<th>Nyanja</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Pericopsis angolensis</em></td>
<td>Mubanga</td>
<td>Mubanga</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Afzelia quanzensis</em></td>
<td>Mwande</td>
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</tr>
</tbody>
</table>

It is also illegal to cut fruit trees like:

<table>
<thead>
<tr>
<th>Scientific name</th>
<th>Bemba</th>
<th>Lozi</th>
<th>Tonga</th>
<th>Nyanja</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Uapaca kirkiana</em></td>
<td>Musuku</td>
<td>Musuku, Chilundu</td>
<td>Musuku</td>
<td>Musuku</td>
</tr>
<tr>
<td><em>Anisophyllea boehmii</em></td>
<td>Mufungo</td>
<td>Mufungo</td>
<td>Muhoto</td>
<td></td>
</tr>
<tr>
<td><em>Dialium Engleranum</em></td>
<td>Muhamani</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Parihari curatellifolia</em></td>
<td>Mupundu</td>
<td>Mubula</td>
<td>Mbulua</td>
<td>Mbula</td>
</tr>
<tr>
<td><em>Strychnos spp</em> e.g.</td>
<td>Kasongele</td>
<td>Muhulu</td>
<td>Muono</td>
<td>Mbula</td>
</tr>
</tbody>
</table>

Other trees are left due to their value in producing good quality timber or wood. The predominant type in this category are:

<table>
<thead>
<tr>
<th>Scientific name</th>
<th>Bemba</th>
<th>Lozi</th>
<th>Tonga</th>
<th>Nyanja</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Pterocarpus angolensis</em></td>
<td>Mulombwa</td>
<td>Mukwa</td>
<td>Mukula</td>
<td>Mulombwa</td>
</tr>
<tr>
<td><em>Baikiaea plurijuga</em></td>
<td>Mulombe</td>
<td>Mukushi</td>
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</tbody>
</table>

**Table 9 Trees that make good charcoal**

<table>
<thead>
<tr>
<th>Scientific name</th>
<th>Bemba</th>
<th>Lozi</th>
<th>Tonga</th>
<th>Nyanja</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Brachystegia boehmi</em></td>
<td>Mutobo</td>
<td>Mubombo</td>
<td>Mubombo</td>
<td>Mufendaluzi</td>
</tr>
<tr>
<td><em>Brachystegia allenii</em></td>
<td>Maumba</td>
<td>Musumbu</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Brachystegia bussei</em></td>
<td>Munkulungu</td>
<td></td>
<td>Mkongolo, Msase</td>
<td></td>
</tr>
<tr>
<td><em>Brachystegia manga</em></td>
<td>Musompa</td>
<td></td>
<td>Musumbu</td>
<td></td>
</tr>
<tr>
<td><em>Brachystegia spiciformis</em></td>
<td>Mutuya</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Brachystegia taxifolia</em></td>
<td>Ngalati</td>
<td>Mukube</td>
<td>Lukwe</td>
<td></td>
</tr>
<tr>
<td><em>Isoberlinia angolensis</em></td>
<td>Mutobo</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Julbernardia golbiflora</em></td>
<td>Katondomumba</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Julbernardia paniculata</em></td>
<td>Mutondo</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Monotes africanus</em></td>
<td>Chimppampa</td>
<td>Mutembo</td>
<td>Mutembo</td>
<td>Chipampa, Mzaza</td>
</tr>
</tbody>
</table>
REFERENCES


