Sustainable Feedstock Management for Charcoal Production in Kenya

Resources, Initiatives and Options

Working Brief

September 2012

Prepared for PISCES by Practical Action Consulting Eastern Africa

PISCES – Policy Innovation Systems for Clean Energy Security

Practical Action Consulting

Although this research is funded by DFID, the views expressed in this report are entirely those of the authors and do not necessarily represent DFID's own policies or views. Any discussion of their content should therefore be addressed to the authors and not to DFID.

Author:	Nellie Oduor
Contributors:	Mattia Vianello and Ewan Bloomfield (Practical Action Consulting UK), Tameezan wa Gathui and Hannah Wanjiru (Practical Action Consulting Eastern Africa)
Editors:	Katie Welford (Practical Action Consulting UK) and Colin Pritchard (University of Edinburgh)
Main image:	Tarchonanthus camphoratus (Leleshwa) in flower (Francis Gachathi, KEFRI)
Inset image:	Woman selling charcoal at local market (Practical Action/Georgina Cranston)
All images:	Practical Action (unless otherwise stated)

List Of Acronyms

ASAL	Arid and Semi-Arid Lands
CBO	Community Based Organisation
CARPA	Christian Agricultural and Related Professionals Association
CDF	Constituency Development Fund
CDSI	Centre for Sustainable Development Initiatives
ESDA	Energy for Sustainable Development Africa
FAO	Food and Agriculture Organisation
IUCN	International Union of Conservation of Nature
KEFRI	Kenya Forestry Research Institute
KFS	Kenya Forest Service
Ksh	Kenya Shillings
LPG	Liquefied Petroleum Gas
MSE	Micro and Small Enterprise
NEMA	National Environmental Management Authority
NGO	Non-governmental Organisation
RAFDIP	Rarieda Agro Forestry Development Initiative Programme
TC	Tissue Culture
YYAG	Youth to Youth Action Group

Executive Summary

Biomass, particularly fuel wood and charcoal, provides more than 14% of the world's total primary energy and plays a critical role in meeting the energy requirements of developing countries, particularly in Sub-Saharan Africa. In Kenya it is estimated that 90% of rural households use fuel wood or charcoal, with fuel wood meeting the energy needs of over 93% of rural households, and charcoal being the dominant fuel in urban households.

Biomass energy resources, in the form of trees, are derived from forests - closed forests, woodlands, bush lands, grasslands, farmlands and plantations as well as from agricultural and industrial residues. Currently there is a growing imbalance between biomass energy supply and demand, with a deficit of almost 60%. This imbalance exerts considerable pressure on forest and vegetation stocks and accelerates the processes of land degradation and desertification.

Charcoal production depends predominantly on woody biomass hence the rising demand for charcoal as a household fuel is associated with increasing levels of deforestation. To address this challenge, on-farm cultivation of fast maturing tree and shrub species which can produce high quality charcoal and adapt to a wide range of climatic conditions is crucial.

This publication discusses some of the trees and shrubs that are suitable for sustainable charcoal production, for example *Tarchonanthus camphoratusis* (Leleshwa), *Prosopis juliflora* (Mathenge), *Acacia drepanolobium* (Whistling thorn) and bamboo. The publication also discusses case studies on best practices in tree management from Sudan, Kenya and Uganda. For example in Siaya County (Kenya) communities have raised *Acacia polyacantha* and *A. xanthophloea* trees through an initiative that started in 2002. The group of 545 farmers have set aside 240 hectares and planted woodlots for charcoal production on land pieces ranging from 0.5 – 3 acres (0.21 - 1.25 hectares) with a 6-year harvesting cycle. In Kajiado County a private business known as Musaki Enterprises established a 2.5 acre (1.05 hectare) arboretum with a total of 24 tree species adapted to dry land. The initiative which started in 1996 focuses on innovative research on the production, management, and processing of wood and charcoal biomass resources. They also develop and produce new and original designs of energy efficient technologies that include charcoal and wood-burning cook stoves for households and small businesses.

Efforts towards sustainable tree production and management for fuel wood and charcoal production are affected by various barriers and constraints. Land tenure for private land, trust land or state owned land can affect the production system if any conflicts in land ownership occur during the tree growing cycle. Lack of proper management plans as provided for under the Forests Act of 2005 can affect sustainable feedstock management. The arid and semi-arid areas of Kenya where majority of charcoal is produced are water deficient environments that experience challenges in vegetation growth and tree regeneration. This highlights the need for proper agronomic planning.

In conclusion, since charcoal is an integral part of Kenya's economy and socio-cultural life it is important to intensify sustainable tree production. Strategies for achieving sustainable tree growing for charcoal production include:

- Ensuring successful charcoal production and marketing through implementation of existing charcoal policy guidelines and developing additional policies which encourage investments in improved charcoal processing technologies.

- Encouraging establishment of woodlots of high density trees, promoting species of low density that are appropriate for briquetting, such as bamboo, and encouraging utilisation of agricultural residues and industrial residues such as sawdust and bagasse for fuel.
- Promoting the use of improved charcoal kilns (with efficiency of more than 25%); currently majority of charcoal producers use the traditional earth kilns with 10-20% efficiency.
- Encouraging the use of dry wood during carbonisation and promoting appropriate technologies that are simple, affordable and easy to adopt.
- Promoting energy conservation through the use of improved cook stoves with higher efficiency levels.
- Streamlining the charcoal value chain through collaborative action among all players in the sector, including farmers.
- Enhancing implementation of land use regulations and guidelines, especially where changes in land use occur.

Contents

1.	**Introduction**	**6**
1.1	Forest Status in Kenya	6
1.2	Energy Resource Status	7
2.	**Potential feedstock**	**8**
2.1	Tarchonanthus camphoratus	8
2.1.1	Products from Tarchonanthus camphoratus	8
2.1.2	Services from Tarchonanthus camphoratus	9
2.1.3	Fuel wood yield from Tarchonanthus camphoratus	9
2.2	Prosopis juliflora	10
2.2.1	Products of Prosopis	10
2.2.2	Services from Prosopis	11
2.2.3	Fuel wood yield from Prosopis	11
2.3	Acacia drepanolobium	12
2.4	Bamboo	13
2.4.1	Bamboo Yield	14
2.4.2	Agroforestry/intercropping practices with bamboo	14
2.4.3	Basic Economics for charcoal production from bamboo	15
2.4.4	Bamboo as sustainable biomass energy: a suitable alternative for firewood and charcoal production in Ethiopia and Ghana	15
3.	**Species preference for charcoal producers**	**15**
4.	**Case studies on tree management practices**	**17**
4.1	The charcoal industry in Sudan	17
4.1.2	The Sudan Charcoal Producers Association	17
4.1.3	Charcoal processing in Sudan	17
4.1.4	Charcoal export in Sudan	18
4.1.5	Lessons learnt from Sudan	18
4.2	The charcoal industry in Kenya	19
4.3	The charcoal industry in Uganda	19
5.	**Community based initiatives on tree management for charcoal production**	**20**
5.1	Afforestation project in Rarieda, Siaya County	20
5.2	Musaki Enterprises in Kitengela, Kajiado County	24
5.3	Opportunities in commercial charcoal production	25
5.4	Recommendations for tree management practice for small scale farmers for on-farm charcoal production	26
6.	**Research on feedstock regeneration**	**27**
6.1	Bamboo	27
6.2	Eucalyptus species	28
7.	**Barriers and constraints in current feedstock management practices**	**31**
8.	**Conclusions**	**33**
9.	**References**	**34**

1. Introduction

Wood is by far the most important biomass type, with total global annual wood utilisation at 3.3 billion m3, more than half of which is used for energy (FAO, 2007). Fuel wood is the main energy supply for over 2 billion people, particularly for rural households in developing countries (FAO, 2010). Biomass, in particular fuel wood and charcoal, currently provides more than 14% of the world's total primary energy (FAO, 2010), demonstrating the critical importance wood plays in meeting the energy requirements of developing countries, particularly in Sub-Saharan Africa.

In Kenya its estimated that about 90% of rural households use fuel wood biomass, either as fuel wood or charcoal (Ministry of Energy, 2002), with the former (fuel wood) meeting the energy needs of over 93% of rural households, and the latter being the dominant fuel in urban households (Theuri, 2002). Fuel wood is also an important energy source for small-scale rural industries such as tobacco curing, tea drying, brick making, fish smoking, and bakeries, amongst others. A comprehensive biomass study undertaken in 2000 revealed that the principal sources of fuel wood were agro-forestry (84%), biomass in trust lands (8%) and (8%) in gazetted forests. (State of Environment Report, 2004).

1.1 Forest Status in Kenya

Kenya is a relatively dry country, with approximately 80% of total land area defined as arid and semi-arid. The current status of much dry land forest resources is the direct result of unsustainable practices and degradation, as a result of overgrazing, overexploitation of trees for the acquisition of fuel wood, and charcoal, particularly in the close vicinity of towns and refugee camps.

The Food and Agricultural Organisation (FAO) defines forests as follows:

— Tree crown cover of between 10 – 30%
— Tree height of 2 metres and above
— Land area of more than 0.1 Ha.

Following these parametric limits, Kenya has itself defined forests to constitute land area where tree crown cover is 30% or more, trees grow to 2 metres and above and a minimum land area of 0.1 Ha (Kenya Forest Service, 2009).

Kenya has 3.47 million ha of forest cover which is equivalent to 5.9% of land area. From this, 1.42 million ha or 2.4% of total land area comprises of indigenous closed canopy forests, mangroves and plantations in both public and private lands. Kenya has 10.39 million ha with trees on farmlands. It is estimated that the farmlands have wood stocking of about 9.7 m3/ha. Bushlands which are open stands of bushes and climbers, usually between 3 and 7 meters tall with a canopy cover of 40% or more (Matiru, V., 1999) cover 24.51 million ha. Together with the woodlands, which are open stands of trees, at least 8 meters tall, with a canopy cover of 40% or more with the field layer usually dominated by grasses (Matiru, V., 1999) these are major sources of wood biomass in Kenya.

1.2 Energy Resource Status

Biomass energy resources, in the form of trees, are derived from forests - closed forests, woodlands, bush lands, grasslands, farmlands and plantations as well as from agricultural and industrial residues. In 2000 the biomass demand stood at 34.3 million tonnes, as compared to an estimated sustainable supply of 15 million, thereby indicating a deficit of over 56%; while the deficit is estimated by others to be nearer 60% (Status of Environment report, 2004). Population growth and lack of access to energy substitutes are some of the principal drivers of biomass energy demand. Biomass energy supply and demand imbalance is exerting considerable pressure on the remaining forest and vegetation stocks, thereby accelerating the processes of land degradation and desertification. In addition, the production of biomass energy poses a threat to competing land use systems such as agriculture, forestry and human settlements.

Among the components of the biomass energy system, charcoal is growing in importance as a household fuel, particularly for urban dwellers. Since charcoal production depends predominantly on woody biomass, its rising demand is associated with increasing levels of deforestation. In areas adjacent to major urban centres, charcoal trade is active, and the ineffective regulation of the charcoal industry remains a key challenge facing the government.

The charcoal industry employs over 700,000 people who support over two million dependants (ESDA, 2005). Table 1 summarises the annual fuel wood and charcoal consumption demand from households and by cottage industries, with the highest consumption being restaurants. Despite charcoal being an important energy source, its production and transportation still faces numerous challenges, with its true value not being adequately captured in the national economic statistics. The industry has continued to have a low profile, and this has made it difficult to access funds for investing in product development, a crucial first step towards commercialisation.

Industry	Quantity of fuel wood in tonnes/year	Quantity of charcoal in tonnes/year
Brick making	55,772	–
Tobacco	78,365	–
Milk processing	4,900	540
Fishing and fish smoking	17,960	–
Jaggeries	180,000	–
Bakeries	20,665	622
Restaurants/kiosks	1,276,155	428,025
Tea Industry	155,000	–
Total	**1,788,817**	**429,187**

Table 1.1: Annual fuel wood and charcoal consumption by cottage industries Source: Republic of Kenya, 2002

Increased charcoal demand has led to increased destruction of trees in the landscape. Use of traditional charcoal kiln even accelerates the destruction due to low efficiency. There is need therefore, to look at trees that are suitable for on-farm/community level sustainable charcoal production in the country and to have appropriate technologies to improve efficiency.

2. Potential feedstock

Charcoal is a predominant cooking fuel in most African countries, for which demand from a burgeoning human population has sometimes outstripped the supply of wood from forests and woodland. Therefore, there is need to explore the potential of trees and shrubs for sustainable charcoal production.

2.1 Tarchonanthus camphoratus

(Common names: Leleshwa, Camphor tree, Camphor bush, Camphor wood)

Tarchonanthus camphoratus an evergreen shrub or small tree up to 9m tall, usually much-branched with a narrow crown; trunk diameter up to 40 cm (Orwa et al.2009). It is a tropical and subtropical plant that grows in semi-arid lands in Africa, such as savannah, dry forest margins, secondary deciduous bushland, woodland and wooded grassland, often dominant or co-dominant and commonly associated with Acacia spp. and *Adansonia digitata (Baobab).*

2.1.1 Products from Tarchonanthus camphoratus

- The leaves have different uses; to prepare a beverage, smoked as tobacco and inhaled as snuff.
- The shoot and leaves are browsed by cattle.
- Milled mature branches (of 1.25 cm in diameter) of *Tarchonanthus camphoratus* and Grewia flava could be used as cattle fattening feed.
- The wood is termite resistant and thus its timber is used for hut-building, making of general utensils and hunting weaponry, e.g. bows and fishing rods. Rungus or knobkerries are made from the rootstock. The wood also provides high quality fuel wood.
- The leaves contain essential oil which when extracted is an effective natural product for protection from mosquitoes and many other insects.
- Several African tribes use this plant as a treatment for bronchitis and chest ailments, for chilblains, tired legs and sore feet. A beverage made of the crushed leaf is a drink infused in one cup of boiling water to tackle stomach ailments, asthma, over-anxiety and heartburn. Tarchonanthus essential oil has also been found to have excellent cosmetic and dermatological properties, especially as soothing, anti-irritation, decongestant remedy for sensitive skins, dermatitis, sunburn, bedsores, etc.
- Maasai community from Kenya and Tanzania use the plant as a deodorant.

Figure 2.1: Tarchonanthus camphoratus (Leleshwa) in flower (Francis Gachathi, KEFRI)

2.1.2 Services from Tarchonanthus camphoratus

The shrub/tree protects against soil erosion from wind and water, and the slow decomposition of leaves improve soil fertility. It also offers shade or shelter and can act as a windbreak for low winds. Its resistance to fire is remarkable: little mortality is seen in *Tarchonanthus camphoratus* even after three burnings, making it ideal for firebreaks. The Leleshwa is drought and fire resistant hence very useful in reclaiming dry lands. It is also a popular indigenous ornamental in South Africa especially suited for bonsai because of its aggressive root system. The wood is used in fencing too.

2.1.3 Fuel wood yield from Tarchonanthus camphoratus

*Tarchonanthus camphorat*us has a high regenerative capacity after being cut or burnt, which indicates its high potential for sustainable management. The maximum rate of re-growth occurs between 5 and 8 years after coppicing. Studies have shown that the woody biomass increases with age at a rate of between 124 and 335 kg of fresh wood per ha per month over a 10 year time course after a single coppicing event (Royal Botanic Gardens Kew, 1999).

A study by Young & Francombe (1991) shows that the growth of Leleshwa is the result of the age of the stand, rainfall, individual plant history and competitive interactions among and within other Leleshwa plants. Although Leleshwa clumps produce new shoots throughout their lives (after the rains), larger shoots continually and increasingly suppress the success (growth and survival) of these shoots, a phenomenon common in coppicing plants, with age the plant become more dominant. Table 2.1 shows fuel wood uses for different diameter sizes of Leleshwa.

Wood size (Diameter) (cm)	Use
0-1	Fuel for kiln, kiln spacers
1-2	Fuel for kiln, kiln spacers, (firewood)
2-3	Kiln spacers, marginal (poor) charcoal, firewood
3-4	Fair charcoal, firewood
4-5	Good charcoal, firewood
>5	Excellent charcoal, (firewood)

Table 2.1: Fuel wood uses for different diameter sizes of Leleshwa

Source: Young, T.P and C.Francombe (1991)

To obtain maximum productivity, a management strategy involving a rotation age of 8-10 years between coppicing is recommended. Kiruki and Njung'e, (2006) recommended a management and utilisation schedule based on distinct stands of permanent sample plots of natural stands of Leleshwa. This will facilitate assessment of productivity of Leleshwa woodland so that harvestable volumes can be effectively determined. Kiruki and Njung'e, (2006) also recommended that an elaborate mapping and delineation of selected areas based on the identified stand types is done. This will enable the development of management guidelines and harvesting schedules for Leleshwa.

At the African Gallmann Conservancy situated in Laikipia, Kenya, the Leleshwa grows rampantly and charcoal is being produced using these species in efficient kilns (the retort). The proprietors have ventured into producing a line of cosmetics called Africa Botanica using the oil extracted from the Leleshwa leaves.

2.2 Prosopis juliflora

(Common names: Mathenge (Kenya), Mesquite and honey mesquite (English-USA), algarrobo (Spanish-Latin America), vilayati babool (Hindi)

Prosopis juliflora is an evergreen tree native to South America, Central America and the Caribbean. It is fast growing, nitrogen-fixing and tolerant to arid conditions and saline soils.

Concern about deforestation, desertification and fuel wood shortages in the late 1970s and early 1980s prompted a wave of projects that introduced Prosopis and other hardy tree species to new environments across the world. The tree has survived where other tree species have failed and in many cases it became a major nuisance. Prosopis has invaded, and continues to invade, millions of hectares of rangeland in South Africa, East Africa, Australia and coastal Asia (Pasiecznik et al.,2001). Prosopis was introduced into Baringo District in Kenya through the efforts of the "Fuel wood/afforestation extension in Baringo" project, a joint FAO/Government of Kenya initiative.

More than thirty years after the introduction of Prosopis into the dry lands of Kenya, there is now increasing concern and debate about the negative impacts of the species on the lives and livelihoods of communities where this species is found, the ecological integrity, as well as the possibilities for its control and perhaps total eradication. The communities in these areas are mainly pastoralists. Prosopis has affected them negatively because the tree has become established in the dry season grazing reserves (wetlands), croplands and along river courses. Concerns have been voiced on the impacts of the tree on the biodiversity of native species and on water resource dynamics in dry land streams. The species now features on the IUCN list of 100 world's worst invasive alien species (Mwangi E. & B. Swallow, 2005).

The species has been declared a noxious weed in many countries, including Kenya by the National Environmental and Management Authority (NEMA). However, the debate is still on-going, with many citing the need to factor its useful attributes, such as its potential for meeting the country's fuel wood and timber requirements. In India, also suffering from the species' colonisation of what was once the best grazing and pasturelands in the whole of South-east Asia, the species is used by 70% of the rural population living in the vast arid and semiarid lands of the country for fuel wood (Jama B. and A. Zeila, 2005). During a preliminary survey, the Kenya Forestry Research Institute and the Forestry Department found the value of Prosopis-based income in 2002 to be Ksh 154,882 per household per year (Choge et al, 2002).

2.2.1 Products of Prosopis

Under the right conditions, Prosopis can produce a variety of valuable goods and services; this species is a multipurpose tree.

- Prosopis produces good quality fuel of high quality calorific value, which burns well even when freshly cut
- It also produces high quality charcoal using efficient kilns
- Supplies animal feed and forage for grazing animals

Figure 2.2: A sample of floor parquet made from Prosopis juliflora timber (Nellie Oduor, KEFRI)

- The branches are widely used as fencing posts
- Its timber is used in construction and for furniture making
- The pods are valuable sources of carbohydrates, protein and sugars and are important for livestock and human populations
- Industrial processing of pods can produce seed gums for use in the food industry, dietary fibre, and ethanol as a biofuel
- The tree is important for bee forage promoting honey production

2.2.2 Services from Prosopis

The Prosopis juliflora fits very well into dry land agroforestry systems by controlling soil erosion, stabilising sand dunes, improving soil fertility and reducing soil salinity. Prosopis can successfully establish and colonise wastelands and other similar habitats. The species offers shade in hot, arid climates where few other trees are found. The trees are also recognised as boundary markers. They provide shelter from the wind and reduce the movement of soil and sand, with material that is slowed and caught by the tree which eventually grows around the base. Soil and sand are, in addition, fixed by roots giving Prosopis an important role in erosion control. When planted in rows, Prosopis can serve as windbreaks and, if managed as a hedge, can protect dwellings and agricultural land from grazing livestock. This role is enhanced by the profusion of thorns on the species (Pasiecznik et al, 2001).

2.2.3 Fuel wood yield from Prosopis

Prosopis is fast growing, drought and salt-resistant and has remarkable coppicing characteristics, the plant has succeeded in inhabiting large swathes of dry lands in Kenya. The species mainly reproduces via seeds, producing one main crop annually. Each seed pod generally carries between 5 and 20 seeds, with potentially hundreds of thousands of seeds produced per mature plant. Animals consume the nutritious seed pods and excrete viable seeds in their droppings, helping to spread mesquite over shorter distances. By chewing the seeds, as long as they are not damaged, the process of digestion actually helps germination, especially since the expelled seeds are deposited in moist, nutrient-rich dung. Seed pods are also spread by flooding (CRC Weed Management, 2003).

An evaluation of the comparative performance of Prosopis against other tree species such as *Albizia lebbeck, Azadirachta indica, Dalbergia sissoo, Morus indica, Populus deltoids, Syzigium cuminii* and *Syzigium fructicosu m* found that Prosopis seedlings had the highest survival rate, height gain, girth growth and the highest primary biomass production (CDSI, 2008).

The importance of Prosopis as a dry land resource is illustrated in India where it is considered a valuable tree species of the desert ecosystem, particularly in the arid zone of the north-western Gujarat state. There, it constitutes a large percentage of vegetative cover, producing about 25 to 30 tons of biomass/ha/year at a short rotation age of 4 to 5 years (CDSI, 2008). In Kenya, the Ministry of Livestock Development have undertaken some interim mapping, where results show that the Prosopis coverage is now approximately 2% of the land cover (between 1 and 1.2 million ha). The rate of spread for the period between 2000 and 2010 is 36% for woodlands and 7.7% for wetlands. The total for these two is 44.7% for 10 years, making it about 4.5% spread per year on average. (Choge, S. Pers. Comm. 2011).

Prosopis can be used to produce excellent charcoal, but its use as biomass remains largely unexploited in Kenya. Studies carried out in Salabani sublocation in Baringo District/County have shown that four people can make an average of over 1,000 kg of charcoal per week or 4,000 kg a month using the Casamance kiln, an efficient earth kiln with earnings of over Ksh 27,000 per month with a bag selling at a farm gate price of Ksh 300 (in 2008, when the study was carried out) (Choge S., 2010). These are above average levels of income that can transform livelihoods of community members significantly while reducing the population of the invasive trees (Choge S., 2010).

2.3 Acacia drepanolobium

(Common name: Whistling thorn)

A study for evaluating the suitability of *Acacia drepanolobium* for sustained charcoal production was carried out by Okello B. et al (2001). The study looked at the growth, biomass estimates, and charcoal production of *Acacia drepanolobium* in Laikipia, Kenya. *Acacia drepanolobium* is a tree that grows to a height of 7.5m - but with maximum height averaging 3-5 m over much of its range. The species is browsed on by a large number of herbivores including giraffe, eland, elephant, Jackson's hartebeest, Grants gazelle and goats. However, its utilisation by herbivores is hampered by the presence of ants that live in its galls. Along with the trees' thorns, the ants are believed to ward off herbivores due to their stings and bites. The wood of the Whistling Thorn, although usually small in diameter, is hard and resistant to termites. The branches are also used for kindling and the resin has good quality adhesives. The ability to coppice after cutting makes the Whistling Thorn a potential sustainable source for firewood and charcoal. Conversely, Whistling Thorn has also been considered a weed of rangelands, and a bush encroachment species.

Acacia drepanolobium is an ideal candidate for sustained charcoal production because:

(a) It occurs in almost mono-specific stands in high densities over vast areas,
(b) It coppices readily when harvested or top killed by fire,
(c) Its hard wood is appropriate for good quality charcoal,
(d) Incomes from its charcoal are an attractive source of supplemental revenue.

Figure 2.3: Acacia drepanolobium tree growing in the wild

(Francis Gachathi KEFRI)

The study found that the total harvestable dry woody biomass was 18.97 metric tons Ha-1 for a 14-year-old stand. Given the coppicing rates of the Whistling thorn, the study suggested a minimum of 12-14 year harvest cycle. Being a relatively small tree, *Acacia drepanolobium* is ideal for sustainable charcoal production since no expensive machinery is needed for harvesting (machetes and axes suffice) and it does not have any special handling needs.

2.4 Bamboo

A plant species receiving increasing interest for charcoal production is bamboo. Charcoal made from bamboo has properties similar to wood and other ligno-cellulosic material in terms of high carbon content and calorific value. FAO Forestry Paper 63, (1985) provides the characteristics for a good quality charcoal as having the following properties:

— Moisture Content: 5 – 15%
— Volatile Matter: 5 – 40%
— Ash Content:3%
— Fixed Carbon: 50 – 95%

Studies carried out at KEFRI have shown bamboo charcoal to have the following properties:

— Carbon: 80–85%
— Ash Content: 4.5–6.5%
— Moisture Content: 6–9%
— Calorific value: 6.9– 7 Kcal/g

The moisture content, volatile matter, ash content, fixed carbon and calorific value of charcoal are indicators of charcoal quality. The calorific value or heat of combustion is the amount of heat energy released per unit mass when combustion is complete and the products have cooled to the initial temperature. Generally the range of variation of calorific values between species is rather small, where the calorific values for wood range from 3.5 - 5 kJ/g and that for charcoal ranges between 5 - 9 kJ/g.

The only Kenyan bamboo species which is indigenous is *Yushania alpina*. Over the last twenty years, research on species selection and investigations on their growth has been carried out by the Kenya Forestry Research Institute (KEFRI) in collaboration with several Asian research and development institutions. This research work introduced over twenty Asian bamboo species into the country. Half of these are successfully growing in the field under various ecological conditions. Thus bamboo is becoming abundant and commonly available in the country.

Characteristics of bamboo that make it suitable for charcoal production include:

— It is fast growing
— It is a highly renewable resource; unlike timber, it can be harvested every year
— Bamboo can produce products such as activated carbon

The recommended maturity age for bamboo is 4–5-year old this ensures that maximum bio-mass have been attained and moisture and starch levels lowered.

To get the best yield of charcoal (25% recovery rate); the moisture content of bamboo should be around 20 – 25 %. In many applications, the upper and lower portions of bamboo culms are not used, and are often thrown away. These can be used in charcoal-making as fillers in the stack to ensure a ‘tightly packed’ stack. Lops and tops of bamboo culms and thicker branches can be used too.

2.4.1 Bamboo Yield

Bamboo is widely used as a source of bioenergy in Asia, but in Kenya transformation of bamboo into bioenergy is not yet widespread. Bamboo is suitable for charcoal and briquette production, as well as a source of energy for large tea estates. The transformation of bamboo into energy can represent a significant value addition to industries that need to comply with increasingly strict environmental regulations in Kenya. There are tea estates interested in using bamboo as an alternative to Eucalyptus as a source of bioenergy for their tea production process: these are Unilever Tea, James Finlay and Williamson Tea (KEFRI, 2008). Tea estates in Kenya are under increasing pressure to adhere to the environmental legislation and policies, especially with regard to preventing environmental degradation and safeguarding catchment areas.

The use of bamboo as a fast growing source of biomass with relatively low water uptake represents an important sector that needs to be promoted and developed in Kenya. New culms emerge during the rainy season from rhizomes produced the previous year. For the most part, the tropical clumping bamboos will reach 80% of their potential height within a couple of months (Benton, A. et al 2011). The remaining 20% of growth can take a few more months to complete. The height and diameter of culms in a clump increases with age over a period of up to 7–8 years, depending on the propagation method employed and growing conditions, up to a species-determined maximum (Benton, A. et.al. 2011). Culms can be harvested year-round, except during the shooting season when harvesting may cause damage to emerging and young shoots. Branching occurs from buds at the nodes, usually once extension growth has been completed, and lasts a few months. Culms of older plants often do not have buds at the lower nodes, resulting in clear culms for many metres and a clearly defined canopy layer above.

Bamboo species	Yield	Approximate planting density
Dendrocalamus asper	20 t shoots/ha	5–6(10) × 5–6(10) m
Dendrocalamus giganteus	200 culms per ha	10 × 10 m
Thyrsostachys siamensis	9–15 t/ha	4 × 4 m

Table 2.2 : Yield examples of three bamboo species

Source: Benton, A. et al. 2011

2.4.2 Agroforestry/intercropping practices with bamboo

Bamboo intercropping can be done with a wide range of annual crops during the early years of establishing a bamboo plantation in which the annual crops can provide cash income while the bamboo is maturing sufficiently to be harvested. Practices of intercropping mature plantations with timber species exist (Benton, A. et al. 2011). Bamboo can be intercropped with shallow-rooted food or cash crops. Plantations of sympodial (clumping) bamboos can be intercropped with rhizomatous crops such as ginger or turmeric up to around 3 years of age.

2.4.3 Basic Economics for charcoal production from bamboo

Kilns for charcoal production from bamboo should be located where bamboo is available in plentiful supply. The strength of the bamboo is not important; the determining properties are moisture content and bulk density. Ideally, a battery of at least 4 to 5 kilns should be installed to maintain continuous production. A battery of 5 kilns can be operated by two workers (National Mission on Bamboo Applications, 2005). While bamboo charcoal is light and burns quickly, making briquettes from bamboo charcoal would be more economical since they burn slowly and have a higher calorific value (e.g. honeycomb briquettes have calorific value of 26-29 MJ/kg)

2.4.4 Bamboo as sustainable biomass energy: a suitable alternative for firewood and charcoal production in Ethiopia and Ghana

This is an initiative funded by the European Commission from 2009-2013 to promote bamboo firewood and charcoal as alternatives to timber charcoal in Ethiopia and Ghana. The programme is working in Benishangul-Gumuz State, Amhara National Regional State and Southern Nations Nationalities and Peoples Regional State in Ethiopia, and Western region, Ghana, to develop at least 1,000 enterprises producing bamboo charcoal, and 30,000 households using it. The main objective is to increase the use of bamboo as a source of energy for the poor in the two countries in a sustainable, environmentally friendly and economical way. The project aims to increase the range of useable bamboos available in each country and establish bamboo charcoal Micro and Small Enterprises (MSEs), The experiences from the programme will be applicable throughout the bamboo-growing regions of Africa. The project aims to train over 6,000 people in bamboo cultivation, best bamboo firewood practices and bamboo charcoal production, set up three bamboo charcoal technology centres, and develop marketing strategies for bamboo charcoal

3. Species preference for charcoal producers

Generally, all species of wood can be carbonised to produce charcoal. However, the quality of charcoal varies from species to species and depending on the method of carbonisation. Hines & Eckman (1993) gave characteristics of tree species suitable for woodfuel. These species should:

- Grow quickly, yield a high volume of wood quickly, and require minimum management time
- coppice or sprout well from shoots
- have dense wood with a low moisture content
- produce little and nontoxic smoke
- produce wood that splits easily and can easily be transported
- yield other products or services that are demanded by the household
- Produce wood that does not spit or spark when burning.

The species that have been reported to produce high quality charcoal include *Casuarina equisetifolia, Acacia mearnsii, Acacia polyacantha*, and *Acacia xanthophloea*, and other acacia and combretum species (Mugo, F. and C. Ong, 2006). These species are preferred mostly because of their heavy densities; the charcoal produced is heavy in weight, burns for a long time in the cook stoves and thus is economical to the user (KEFRI, 2005). Other tree species that have been cultivated for charcoal in short rotations are *Eucalyptus camaldulensis, Leuceana leucocephala, Tectona grandis, Acacia spectabilis* and *Sesbania sesban* (Mugo, F. and C. Ong, 2006). Studies in India, for example have shown that Eucalyptus species and Acacia nilotica can be cultivated in short rotations for charcoal (Mugo, F. and C. Ong, 2006). Table 4 lists suitable species for woodfuel in Kenya.

Acacia brevispica	*Afzelia quanzensis*	*Commiphora schimperi*
Acacia bussei	*Albizia amara*	*Croton dichogamus*
Acacia drepanolobium	*Albizia anthelmintica*	*Dalbergia melanoxylon*
Acacia gerardii	*Balanites aegyptiaca*	*Euclea divinorum*
Acacia hockii	*Barleria spinisepala*	*Grewia bicolor*
Acacia lahai	*Bauhinia taitensis*	*Grewia plagiophylla*
Acacia mellifera	*Boscia angustifolia*	*Grewia similis*
Acacia nilotica	*Combretum apiculata*	*Grewia vilosa*
Acacia nubica	*Combretum brownii*	*Maytenus spp*
Acacia reficiens	*Combretum constrictum*	*Olea europaeavar. africana*
Acacia senegal	*Combretum hereroensii*	*Tarchonanthus camphoratus*
Acacia seyal	*Combretum molle*	*Terminalia brownii*
Acacia tortilis	*Commiphora africana*	
Acacia xanthophloea	*Terminalia spinosa*	

Table 3.1: Suitable Woody Species for Wood fuel in Kenya

Source: National Arrangements and Capacity to Collect Wood Energy Information and Statistics: The Kenyan Scenario.

By Kareko KK and J. Githiomi (2000)

An addition to this list, the Prosopis is now being promoted by the Kenya Forest Service as a source of woodfuel in order to manage the spread of the invasive species.

Figure 3.1: Resprout of Acacia polycantha after coppicing (Nellie Oduor, KEFRI)

4. Case studies on tree management practices

4.1 The charcoal industry in Sudan

In Sudan 71% of energy derives from woodfuel with the remaining 29% from petroleum and electricity. From all the wood harvested, 88% is used for woodfuel and the remaining 12% for poles, posts and timber. The Forest National Corporation is a government agency responsible for planning and organising charcoal production from natural and planted forests. Natural forests in Sudan represent 68% of the total forested area, while plantations account for the remaining 32%. The corporation adopted a management plan for natural forests where forest land is initially leased to farmers for five years. At the beginning, charcoal producers are contracted to clear the land for crop production and use the wood to make charcoal. The land is then cultivated for five years, after which it's left to regenerate for 14-20 years. For planted forests, the department sets aside land and funds to plant and manage over 100,000 ha of trees a year. The species planted for charcoal are mainly *Acacia seyal, Acacia nilotica, Acacia melifera, Eucalyptus microtheca* and *Prosopis chilensis*. The trees take about 14-17 years to mature for harvesting. The government now recognises the charcoal producers to whom it sells the trees by tender at officially set prices.

Most of the charcoal is produced by large-scale contractors with the Sudan Charcoal Producers Association although small scale individual's producers play a role. The charcoal is sold to merchants who transport to wholesalers in urban centres for distribution to retailers and users. Overall, production costs are about 41% of the retail price. Transportation accounts for 37% and service fees (royalties, taxes, duty) 22% (Mugo, F. and C. Ong, 2006).

4.1.2 The Sudan Charcoal Producers Association

The Sudan Charcoal Producers Association was founded to negotiate with the government on behalf of traders. Grouping producers, transporters and traders, the association has set up its own rules in addition to those laid down by the government. For instance, the Association expels members who fail to pay taxes or engage in corruption. The expulsion means one can no longer trade in charcoal.

The Association has been successful, with some members producing between 2,000-5,000 bags of charcoal and earning up to US$50,000 a season. However, some internal issues have been raised for instance members complain of high taxes, unclear boundaries and conflicts due to animal routes through contracted land.

4.1.3 Charcoal processing in Sudan

Charcoal in Sudan is produced in earth kilns of up to 120 cubic metres. The unit of production and trade is a 40kg bag. One cubic metre of wood produces three bags of charcoal. The country produces 1.2–1.6 million tonnes of charcoal a year from 7.8–12.3 million cubic metres of wood. On average, 7.7 cubic metres of wood produces one tonne of charcoal.

Khristova P. and A.W. Khalifa conducted studies for four wood species i.e indigenous *Acacia seyal* (talh), exotic fast-growing *Conocarpus lancifolius* (damas), *Eucalyptus microtheca* (kafur) and *Prosopis chilensis* (mesquite), were assessed and compared as raw materials for charcoal making. The species were carbonised separately using an improved metal kiln and the traditional earth mound kiln. The metal kiln produced higher yields (33%) than the traditional earth mound (27%), although the difference in energy transformation yields was found to be insignificant both between appliances and species. The study also showed that charcoal produced by the earth mound had a slightly higher density and was more resistant to shatter, but no significant differences were recorded with respect to the water boiling test or the gross heat value. The exotic species studied gave equal or better charcoal, in terms of yield and quality, compared with the traditionally preferred talh.

4.1.4 Charcoal export in Sudan

Sudan banned the export of charcoal in 1960 due to deforestation. However, the ban was lifted in 1995 to help eradicate *Prosopis chilensis*, an invasive species. Charcoal export is restricted to specific places and the Forest National Corporation sets the minimum price. Export of high quality charcoal, mainly Acacia, is limited to 5,000 tonnes a year. However, exports could rise since the government is promoting private investment in charcoal production for foreign markets. Private forest owners are also allowed to export their charcoal, and many companies are now coming in to exploit the opportunity. Under this arrangement, investors meet the cost of establishing and maintaining the forests. The government is also encouraging farmers to plant trees under the agroforestry land management system.

In 1998, consumption of charcoal was found to be 45% higher than the sustainable supply. The government then adopted policies to reduce consumption and increase the supply. One of the strategies was to promote the use of LPG by increasing the price of charcoal up to three times that of gas. However, this has not reduced the demand for charcoal, suggesting that gas is not a direct substitute for charcoal.

4.1.5 Lessons learnt from Sudan

The following lessons can be drawn from Sudan experiences:

- Charcoal is recognised as a key source of energy.
- There is a specific governmental institution, to implement wood energy policies.
- Production of charcoal from plantations and natural woodlands is sensibly planned.
- Resources are allocated yearly for establishment of plantations.
- There is strong public and private sector participation.
- Charcoal is a formal and lucrative industry.
- There are clear trading arrangements and rules.
- Traders are organised into a formal association recognised by the government.
- The government receives royalties and taxes, which are reinvested in establishing plantations.

Other countries in eastern and southern Africa should use some of these lessons to establish dynamic charcoal industries of their own.

4.2 The charcoal industry in Kenya

There are initiatives in Kenya for large scale charcoal production. One of them is based at the Kakuzi Ltd in Muranga County, Kenya. Kakuzi for many years had been associated with agricultural products and cattle farming. In 1992, the Company expanded into tree farming to mark boundaries on its large farm, to put areas with poor soils to good use, and to diversify its product line. The company has a total of 3,068 acreage covered by *Eucalyptus grandis, Eucalyptus saligna* and *Eucalyptus camaldulensis*. This initiative gained momentum in 1995/96 when much larger areas of forestry were planted. Currently 50 to 75 acres are planted per year on commercially high yielding sites. Kakuzi Ltd has developed a wood-processing yard where timber and poles are treated. Timber is milled, pallets manufactured, “eco-friendly” charcoal produced efficiently using half orange brick kilns from waste off-cuts and smaller gauge logs left over from the forestry’s division’s main line of business – production of industrial timber and poles.

The cost of producing a bag of charcoal at Kakuzi has been estimated at Ksh 159 (60% of the retail price). This bag is sold at Ksh 260, with net revenue of Ksh 101 which is 40% of the retail price (COMPETE, 2009). Charcoal produced from Kakuzi is sold in the open market. Kakuzi has been able to establish exotic plantations for the production of timber, poles and charcoal. The company has installed charcoal kilns – half- orange brick kilns that are more efficient in producing charcoal than the traditionally used earth kiln.

Until recently, the lack of a clear policy on charcoal in Kenya presented a constraint to Kakuzi customers, who are often harassed by government officials when transporting charcoal from the company. The fact that there is no certification system, to differentiate charcoal that is sustainably produced from that being produced from government reserves, or from communally owned, or from the fragile dry-land areas of Kenya, have led Kakuzi to withdraw from transporting its charcoal to markets closer to the consumers (Matiru, V. 2002). Buyers themselves now transport the charcoal from the company. The market distortions caused from charcoal produced from stolen trees from government Forest Reserves or from the communal trust land areas, have reduced Kakuzi profit margins.

4.3 The charcoal industry in Uganda

Bukaleba Charcoal project is an initiative by Green Resources based in Jinja. These private forests product Norwegian company established in 1995 has 60 shareholders operating in Mozambique, Sudan, Tanzania and Uganda. It employs more than 3,000 people and has invested USD 55 million in its African operations since its inception. Green Resources manage Bukaleba forest, which covers 2,500 ha mainly consisting of *Pinus caribaea* (72%) and *Eucalyptus grandis* (23%). The pines are grown for saw logs on 20-year rotations and the eucalyptus for utility poles on 10-12 year rotations (harvesting began in 2007). The total area that will be planted by 2016 is around 5,750ha.

The project aims to collect waste biomass from the Bukaleba Forest and Jinja Pole Treatment Plant, and pyrolysis this into charcoal, thus avoiding methane emissions that would have resulted from the anaerobic decay of the biomass. The main charcoal briquetting operations of the project will be in Jinja, adjacent to the pole treatment plant that is also owned and operated by Busoga Forest Company. The Katugo kilns, in groups of four, are located in a handful of places around the project boundary, mostly in and immediately around Bukaleba forest, close to the raw material. Some of them are located alongside the briquetting plant in Jinja, to use the waste from the pole treatment plant. The Katugo kiln is capable of producing two to three tons of charcoal every six days and has a conversion efficiency of 35% on dry weight basis (Kawanguzi A. C. and P.Merrikim, 1987).

5. Community based initiatives on tree management for charcoal production

5.1 Afforestation project in Rarieda, Siaya County

There is a successful afforestation project based in Rarieda District in Siaya County. The project, which focuses on growing acacia trees for charcoal, was initiated by Youth to Youth Action Group (YYAG) – now known as Rarieda Agro Forestry Development Initiative Programme (RAFDIP) – and Thuiya Enterprises Ltd. in September 2002. RAFDIP is an umbrella organisation comprised of four major sub groups namely: RAID (Rachar Agricultural Initiative Development) Self Help Group, Chamluchi Women group, Masanga Self Help Group, Kobra Women group, and another 20 small groups.

This project was motivated by:

— Poverty levels estimated at 56% in 2002 and unemployment rate of 45%, in Rarieda District
— food insecurity in the District
— high demand for charcoal in urban areas of Kisumu; and
— high yield potential of intercropping of Acacia with groundnuts/beans.

The youth group sensitised and mobilised farmers interested in planting trees for charcoal production on a commercial basis, while Thuiya Enterprises Ltd. provided funding. The YYAG raised *Acacia polyacantha* and *Acacia xanthophloea* tree seedlings. The farmers were given between 500-2000 seedlings on loan (equivalent of Ksh. 2,500 –10,000), at zero interest rate, to plant as woodlots for charcoal. This was to be recovered from the tree/charcoal revenue at the end of six years when Thuiya Enterprises Ltd. purchases wood/ charcoal from the group.

Figure 4.2: Wood arranged tightly inside a half orange kiln (Fridah Mugo)

The current estimated area of land under acacia is 240 hectares, with an estimated yield of 100 tons of round wood or 30 tons of charcoal per hectare under six years rotation. The number of farmers who have set aside land sizes ranging from 0.5 – 3 acres (0.21 – 1.25 Ha) for wood lots, now stands at 545.

During the implementation of the project the farmers were also given 40kg of groundnuts/beans per hectare for intercropping with the acacia trees. To encourage more farmers to get into charcoal production, Thuiya Enterprises Ltd supported the construction of six half-orange kilns for the farmers to carbonise the wood into charcoal. The Kenya Forestry Research Institute (KEFRI) staff trained the farmers to use these and other efficient charcoal kilns. KEFRI and Moi University have been undertaking the necessary research to advice on:

— optimal tree spacing,
— wood yields,
— efficient production of charcoal, and
— optimal age for charcoaling.

Figure 4.3: Sealing the doorway of a half orange kiln (Nellie Oduor, KEFRI)

Other government agencies that have greatly contributed to the success of the project are the Ministries of Forestry and Wildlife, Agriculture, Livestock Development, Fisheries Development and Energy. NGO's like Practical Action have taken the policy issues at an implementation phase. Studies on the project recommended that an acacia 6-year growing cycle is adequate to produce good quality charcoal. During the tree growing cycle, farmers get revenue from short seasonal crops, honey from bee-keeping, poultry, and goat dairy.

Challenges

The organisation has faced several challenges:

— Prolonged droughts affecting the already planted Acacia woodlots.
— High cost of transportation due to the fact that the tree nursery site is about 23km from most of the farmers. Transporting the wood fuel to the kilns is also a challenge; tractors need to be hired in order to transport the wood to the kilns.
— Inefficient funds to enable the organisation to raise more acacia seedlings which are in great demand by farmers.
— Lack of technical knowledge by most of the members.
— Land ownership rights in communally owned lands and ranches are often a hindrance to drawing up sustainable charcoal production management plans and may require concerted efforts.
— There are some conflicts in implementation of the charcoal rules – need to harmonise the rules and sensitise the stakeholders (in the charcoal value chain).

Despite the challenges the project has produced some very positive livelihood outcomes which include:

Human capital

The farmers have gained knowledge and skills in tree nursery establishment, tree planting and harvesting and charcoal production using efficient kilns; bee-keeping and energy conservation technologies. They have harvested about 270 tonnes of grain for food or sold for income. They have gained a market for products and equable returns for individual actors. The knowledge and skills will remain within the community as a resource, while others can benefit from both the documented research outcomes and study tours. This added knowledge and skills will reduce vulnerability of the community

Natural capital

This has been gained by having 240 ha of Acacia trees planted over 7 years thus contributing towards the Country's Vision 2030 of attaining 10% tree cover and increasing the carbon sink capacity of the area. The two indigenous tree species are leguminous thus fix nitrogen in the soil improving the soil fertility of the land. The land has now a higher ecological value without depleting its biodiversity. The trees have made an impact on the micro-climate which is noticeable during the dry season.

Physical capital

This has been increased by the number of trees where they are used as collateral, e.g. one beehive is given for every 500 trees planted. The energy security has improved in villages and urban centres in that study area. The community has bought land for offices. They now own six charcoal processing kilns, accessible to all members. Farmers may choose to sell the wood to anyone; however, for wood harvesting for charcoal, they have to be certified by a Forest Service Officer. Seedlings for the three tree nursery sites (producing over two million seedlings) have been provided by the Ministry of Forestry and Wildlife and this has shown the good working relationship with the government.

Social capital

This has been enhanced through the growth of Community Based Organisations in the area.

- There is an increased interaction among members which has built internal trust and also toward outsiders.
- RAFDIP is now vertically linked to networks like the Embassy of Finland, CARPA, Practical Action Consulting, Kenya Forest Service and other potential supporters.
- The local network is improved also horizontally, with more participating groups.
- All group members have registered with the Ministry of Social Services.
- Leaders have improved their skills for their role.
- Farmers feel increased status, interacting with outsiders, building their own capacity and that of others. They have also negotiated with Constituency Development Fund (CDF) officials, to get support for building an office and attracting support for cotton production.

Financial capital

The 240 hectares will provide key factors with an income from:

—Charcoal of US$1,028,571 after six years
—Firewood savings through energy efficient stoves will save US$20,640 p.a.
—The fast-growing crops will bring in US$385,600 p.a.
—Transport services US$94,200 p.a.
—Wholesaling of charcoal US$214,500 and
—Retailing of charcoal US$321,400
—Honey will generate US$ 5,400 per year for the 60 hives. The number of hives is expected to rise to 1000 hives earning US$ 90,000 per year

The coordinating CBO, RAFDIP, receives an income of US$160 from the donor for raising seedlings for every hectare of trees planted. To date it has earned US$32,000 from tree seedlings. The total financial benefits for the entire key actors are about US$ 2,096,911 (charcoal included) in the six-year rotation period (Practical Action Consulting 2009).

Farmers receive revenue from short seasonal crops for the first and second year. In the third to sixth year, they receive income from honey, poultry and dairy goats. In the third year, farmers are loaned one beehive for every 500 Acacia trees planted, with an anticipated yield within three months, providing interim income. The farmer repays RAFDIP for the beehive with 2 kg (US $ 6) of honey from every harvest (US $ 24 per year) for three years. Goat dairy and poultry were introduced in 2009. The money paid to RAFDIP is used as a revolving fund for buying more beehives.

The Gender roles in this project

The youth benefit from raising tree seedlings, women from trading efficient cooking devices, beans and groundnuts, while men are mainly involved in tree planting, management and charcoal processing. In addition the women obtain firewood from treetops and smaller branches. Practical Action Consulting (2009).

Figure 5.1: Masanga Womens' Group tree nursery (Fridah Mugo)

Lessons from the Afforestation project in Bondo

The commercial tree growing for the charcoal project in Madiany Division highlighted the potential to improve the livelihoods of the rural poor, mainly as there is a wide local, regional, national and even international market for charcoal. The initiative does not require high capital investments and can easily be integrated with other enterprises to ensure sustainable access to food and income and other multiple benefits. The current initiative has not maximized its potential yet, as it is still in its pilot phase; and the enabling business environment is not sufficiently developed. If contractual business arrangements can be adopted, this will assure regular and predictable income to producers and also assure contractors of a steady supply of the product. Despite the presence of the large market, given the current corruption and harassment from the regulators, if farmers produce charcoal the enabling business environment is not conducive to selling it profitably; it would be very easy for the initiative to collapse. However, if the enabling environment improves, and sufficient investment is provided to reach the threshold level where the initiative expands naturally, then the project can be very successful. Since it is a business enterprise, whose every activity is valued, sustainability can be assured as long as there is a market.

5.2 Musaki Enterprises in Kitengela

The Musaki Enterprise is a private business run in Kitengela on the outskirts of Nairobi. The enterprise consists of a 2.5 acre arboretum with a total of 24 tree species adapted to dry land. It was started in 1996 with the aim of conducting research and developing a sustainable system for charcoal production in a semi-arid area. The initiative focuses on innovative research on the production, management, and processing of wood and charcoal biomass resources, along with development and production of new and original designs of energy efficient technologies, including charcoal and wood-burning cook stoves for households and small businesses in different parts of the country.

This enterprise is run as a self-sustaining business that grows and sells seeds of indigenous tree species, produces and sells fuel wood and Acacia charcoal, cook stoves and baking ovens, amongst other products. In addition, it offers training in charcoal production and woodlot establishment services to communities and other interested customers. The enterprise addresses the complete “seed to ash” cycle in a very innovative way.

The initiative has shown that small trees can also produce charcoal, and therefore that agro-forestry can be successfully practised on relatively small areas of land. The lessons learned include the encouragement of deliberate planting of indigenous tree species, the practice of pollarding - a silviculture practice where the tree stem is cut back at a certain height to allow dense new growth of many more shoots – indigenous Acacia trees can produce optimum biomass for charcoal production. In addition, removal of the tree canopy through pollarding allows for successful intercropping of short-term crops such as vegetables, sunflower and other species inside the forest. It demonstrates viable options for sustainable tree management and enhances the production cycle i.e. planting a seed or tree, harvesting the branches, without cutting down the tree.

The enterprise has also demonstrated that it is possible to combine tree planting, charcoal production and manufacture of improved stoves and demonstrates the concept of protecting the environment whilst using tree resources to produce charcoal for sale.

Lessons from the Musaki Enterprise

- Species selection: The initiative demonstrates that species such as *Acacia xanthophloea, Acacia kirki, Acacia polyacantha* and *Acacia nilotica* can be grown for sustainable production of charcoal and other products, e.g. carvings.
- Use of improved kilns: Improved kilns are very efficient (especially the drum kiln) and can be constructed by anyone. Charcoal production in this manner can be a good small scale income generating activity.
- Holistic approach: The combination of tree planting, charcoal production and manufacture of improved stoves has resulted in providing optimal results. This initiative, which was started by an individual, demonstrates that communities should focus on making efficient use of existing resources and expand their charcoal production and marketing enterprises gradually as they access more resources. The holistic approach has turned the two and a half acre plot into "an equatorial forest in a desert".
- Application of win-win concept: The Musaki Enterprise initiative demonstrates a win-win situation in which the environment is protected while tree resources are simultaneously used to produce charcoal for sale.

Figure 5.2: Drum kiln being tightly packed with branches of Acacia

5.3 Opportunities in commercial charcoal production

- The publication of the Forests (charcoal) Regulations 2009 - legal notice 186, is a major step towards streamlining the charcoal industry. This has been enabled through;
  - Formation of Charcoal Producer Associations, and
  - Registration of Community Forest Associations eligible to engage in charcoal production.
- There are already examples of successful commercial charcoal production enterprises (some of which have already been reviewed in the document).
- There is need for a charcoal national certification to enhance a structured charcoal production value chain.
- If charcoal were to be produced from commercially grown wood Mugo & Ong (2006) state that:
  - There is potential to produce 18 tonnes of charcoal from one hectare.
  - About 298,000 ha of fast-maturing tree species would be required every year to meet the annual demand of about 2.4 million tonnes of charcoal.
  - 496,000 jobs would be created at the rate of two jobs for each hectare of wood.
  - Making of efficient stoves and charcoal processing kilns would generate jobs both in rural and urban areas.
- Thus poverty reduction through biomass energy use – already the charcoal industry employs 700,000 people & supporting a population of 2.8 million people (ESDA 2005).

5.4 Recommendations for tree management practice for small scale farmers for on-farm charcoal production

The general recommendations regarding the establishment of a sustainable charcoal industry will need to take into considerations the following.

- The new policy and legislation on charcoal should reflect the evidence that in order to create a sustainable on-farm produced charcoal supply there must be incentives for the farmers to plant and manage trees for charcoal and disincentives for unsustainable production.
- A proper in-depth assessment of which tree species should be promoted for sustainable charcoal production on ASAL farms, and should take into account both technical and socio-economic implications of the selected tree species.
- While yield is important for the sustainability of charcoal production, farmers want to maximise profits; hence any processing techniques and practices that are to be disseminated must combine higher yield and quality of charcoal with higher profits for the producer.
- Specific recommendations on promotion of tree species and processing techniques in ASAL areas in order to establish a sustainable charcoal industry.
- Fast-growing tree species with multiple uses should be promoted when local conditions allow it.
- Charcoal characteristics of various tree species should be further researched by taking into account the species selection and also charcoal production is being carried out efficiently.
- The drying of raw material before processing should be promoted as a way of increasing yield and decreasing production time.

6. Research on feedstock regeneration

6.1 Bamboo

Bamboos can be propagated by seeds, via rhizome, culm cuttings or branch cuttings, via clump division or offset planting or via marcotting or layering. Some bamboos can be propagated only through one of these methods, while other species can be propagated through different methods. But the efficiency of these classical propagation methods varies greatly. Due to its increasing demand, the only indigenous bamboo (*Yushania alpina* formerly known as *Arundinaria alpina*) has been over-exploited from its natural habitat, leading to a ban on bamboo harvesting being imposed in 1986. This species, which is commonly known as alpine bamboo, occurs naturally on the main mountains and highland ranges of Kenya and Eastern Africa at altitudes ranging from 2400 to 3400 meters above sea level). The species is currently estimated to cover about 150,000 ha. KEFRI initiated a program to investigate the potential of bamboo and to develop strategies for its cultivation and utilisation in Kenya. Therefore the Institute introduced various bamboo species in the late 1980s from various parts of Asia.

The introduced species are:

— Bambusa bambos
— Bambusa laka
— Bambusa nutans
— Bambusa tulda
— Bambusa vulgaris (B. vulgaris var. Vitatta)
— Cephalostachyum pergracile
— Dendrocalamus asper(Giant bamboo)
— Dendrocalamus brandisii (Giant bamboo)
— Dendrocalamus giganteus (Giant Bamboo)
— Dendrocalamus hamiltonii
— Dendrocalamus membranaceus
— Dendrocalamus strlctus semi-solid / drought resistant bamboo)
— Oxytenanthera abyssinica (semi-solid / drought resistant bamboo)
— Phyllostachys nigra var. Henonis
— Phyllostachy pubescens
— Shibataea kumasaka
— Thyrsostachys siamensis

Trial Plantations

In 1988 KEFRI began establishing trial plantations of the above species at the following sites:

— Kakamega and Siaya in the Lake Region
— Muguga and Penon in the Highlands, and
— Gede and Jilore in the coastal region.

The trial plantations were established between 1988 and 1992 and an initial study showing the results of the trials was published by KEFRI in 1995. This study provided details of the characteristics of the planting sites, the form (i.e. seeds, rhizomes, offsets, or cuttings) and provenance of the germ plasma, the species planted in each site, as well as success or failure, and growth performance of the species by sites.

Tissue culture studies

In 2004 KEFRI launched a program to investigate the possibility of producing planting materials of bamboo by means of micro-propagation or tissue culture (TC) in its laboratory at Muguga. Attempts to micro propagate species such as *Yushania alpina, Bambusa tulda* and *Dendrocalamus giganteus* have had limited success. Some positive results in generating shoots have however been obtained for *Bambusa tulda* and *Dendrocalamus giganteus*. Bamboo is not an easy plant to micro-propagate and different protocols are required for each species. Success in shoot development is certainly an achievement, but the real challenge is the successful development of roots in sterile media.

Research on tissue culture (TC) of local bamboo at KEFRI is on-going. Research is focused on *Yushania alpina* and *Oxytenanthera abyssinica*. Research and development on bamboo TC in other countries have shown that this method is a very promising alternative source of bamboo planting stock. TC can greatly enhance the production of species that are difficult to propagate by other methods. Presently, only a few commercial tissue culture laboratories around the world produce bamboo. A very important step prior to TC is the selection of elite mother plants with desired characteristics. When bamboos are micro-propagated from the tissue of a mature plant, the result will be a clone of the mother plant. Bamboo produced by TC may be widely used to develop large scale industrial plantations for timber, biomass, or pulp and paper. Cloning bamboo plants with superior traits opens opportunities for achieving a better quality crop, either in culms or in high quality edible shoots. It is important that farmers be on the lookout for the development of this technique locally (Kigomo B. N., 2007).

6.2 Eucalyptus species

Forest plantations play an important role in socio-economic development in Kenya. These plantations are a major source of construction wood, timber, pulpwood, transmission poles, commercial and domestic fuel wood and non-wood products. The area under forest plantations is estimated at 120,000 ha. However, the resource is no longer able to meet the national demand for industrial and domestic wood products. This has therefore necessitated increased productivity of plantations on the available land. Eucalyptus species are grown in plantation by small and large scale farmers. These farmers are growing *E. grandis, E. camaldulensis, E. saligna* and *E. urophylla*. They also grow hybrid clones of *E. grandis* and *E. camaldulensis* (know as GC) sourced from the Tree Biotechnology Project of the Kenya Forest Service. The mean annual increment of these clones is up to 5m per year.

KEFRI in collaboration with the Kenya Forest Service (KFS) has implemented a tree improvement programme of *Eucalyptus grandis* (among other tree species). KEFRI has established seed orchards of E. grandis (8 ha) and have maintained an annual supply of improved seeds of 150 kg to KFS. This programme has seen a mean annual wood volume production from unimproved material 35 m^3ha-1yr-1 compared with improved which is producing 60 m^3ha-1yr-1.

The Tree Biotechnology Project Kenya: A Biotechnology Transfer Project between South Africa and Kenya

The Tree Biotechnology Project was started in 1997 in an attempt to increase the area of forest and the supply of forestry products and services in Kenya, where land clearance for agriculture and increasing demand for wood, particularly fuel wood, was causing widespread deforestation and forest degradation. Tree planting efforts have been severely constrained by lack of good quality seed and by slow, inefficient traditional propagation methods. The project brought together the Kenya Forestry Research Institute (KEFRI), the Forest Department (now Kenya Forest Service) of Kenya's Ministry of Environment and Natural Resources (now Ministry of Forestry and Wildlife) and Mondi Forests, a division of Mondi Ltd of South Africa. The latter is a large private company, which has over 20 years of experience in tissue culture and clonal techniques of tree propagation. The use of biotechnology makes propagation faster and more efficient, producing disease-free trees that grow faster than conventionally produced tree seedlings. Clones provided by Mondi were multiplied through tissue culture and used to establish a central clonal nursery at Karura Forest, near Nairobi. The nursery is currently producing 3 million seedlings annually. Hedge propagation ensures these tissue culture Eucalyptus seedlings are fast growing, resistant to pests and diseases, and provide a uniform product, while maintaining clonal desirable characteristics. Plants that are vegetatively propagated grow quickly due to the selection techniques utilised in the breeding and clonal programmes. These clones are less susceptible to pests and diseases, whilst producing a very uniform crop. Experience in South Africa has shown that clonal forestry is more profitable than traditional methods, provided the clones are matched to suitable sites. This has proved to be true in Kenya, as long as the clones are planted in suitable sites.

Cost-benefit analysis comparing the economics of growing feedstock for charcoal versus other uses including fuel wood generation

The annual fuel wood and charcoal consumption by cottage industries in 2002 showed that the consumption of fuel wood was over four times the consumption of charcoal at 1,788,817 and 429,187 tonnes per year respectively (Republic of Kenya, 2002). This study also indicated that the consumption of fuel wood is highest in the rural areas (over 90%) and charcoal is mainly an urban fuel (83% of urban population). Other major consumers of fuel wood are institutions (schools/colleges and hospitals) and industries including tea, bakeries, brick making, sugar and tobacco.

With urbanisation, the charcoal sector has acquired considerable economic importance. The charcoal industry, which is mainly an informal sector, accounts for an annual turnover of an estimated US$ 400 million to the Kenyan economy (ESDA, 2005). This is comparable to that of cash crops. The sustainable production and use of charcoal through proper management and planning of supply sources, together with rational trade and marketing infrastructures and efficient use, can also have a significant positive impact by helping to conserve resources. This can be achieved through growing feedstock.

Charcoal however has some factors that influence its choice over firewood in urban areas. These include:

— Charcoal has a higher calorific value per unit weight than firewood (about 31.8 MJ/kg of completely carbonised charcoal with about 5% moisture content as compared

to about 16 MJ/ kg of firewood with about 15% moisture content on dry basis).
- It is therefore more economical to transport charcoal over longer distances as compared to firewood.
- Storage of charcoal takes less room as compared to firewood.
- Charcoal is not liable to deterioration by insects and fungi which attack firewood.
- Charcoal is almost smokeless and sulphur free, as such it is ideal fuel for towns and cities.
- In most cities it is cheaper than kerosene, LPG or electricity.
- The current prices of wood and charcoal favour the use of charcoal by urban consumers. In fact, in terms of useful energy, the charcoal calorie is cheaper than wood calorie.

Most charcoal produced comes from woodlands, although a small, insignificant amount also comes from plantations and trees outside the forests. The potential for woodland to produce charcoal mainly hinges on the ability of the woody species to regenerate and grow. Generally woodland cut for charcoal production would regenerate by coppicing. However, regeneration in areas previously cut usually revert to woodland if there are no other disturbances in the area, therefore increasing the potential of the area to supply charcoal over a much longer time period. However, this is not so easy to monitor and to maintain since there would be a need to prevent browsers. This has led to an initiative to promote growing feedstock for woodfuel supply.

The price of fuel wood varies greatly depending on the buyer and the intended market. Farm-gate prices paid by transporters to a farmer are about KSh.800 per stere (cubic metre). The tea factories buy a stere of fuel wood at Ksh 1,200 – 1,400 (Githiomi J. 2010). Studies carried out by Ndegwa (2010) observed that in Eldoret, Murang'a, Kangemi and Mombasa, vendors sell their wood in small bundles of two or three pieces (depending on the size of split wood), each retailing at Ksh. 50. Each stere gives about 50 such bundles. The vendor is able to sell each stere of wood at Ksh. 2,500. Vendors in the upper class estates of Nairobi such as Loresho sell their wood in small 30 centimetre long half-split logs with a radius of about 120 centimetres for Ksh. 5 per piece. They are able to obtain an income of up to Ksh. 8,000 a stere. These residents use the wood for warming their houses during the cold months and not for cooking.

Regarding charcoal, the transporters buy a bag of charcoal from the farmer/producer at Ksh 300-450 depending on the area and species. The vendors in Nairobi buy the charcoal from the transporters at a cost of between Ksh. 750 and 850 in the dry season and KSh.900 and 1000 in the wet season. They in turn sell the charcoal at a price between Ksh 900 and 1000 in the dry season and Ksh. 1000 and 1,200 in the wet season depending on the location of the estate.

Great steps have been made in the energy sector in the country regarding use of efficient stoves for both charcoal and fuel wood and efficient charcoal conversion kilns. However, the use of these efficient technologies has not taken up as anticipated due to various reasons. A case study carried out in Kiambu, Thika and Maragua by Githiomi J. (2010) showed that the adoption rate of using improved stoves was very low - 19%, 24.5% and 28% respectively. This was much lower than 47% reported in a study on Kenya's energy demand and supply for households by Ministry of Energy (MoE, 2002). A number of reasons were cited for not using the improved stoves, with the costs of purchasing/making improved stoves regarded as the main reason for its low take up. There is need for further sensitisation on the importance of using improved stoves. The cost of the improved stoves can be reduced through facilitation of their production at the local level. This has been successfully done in Western Kenya where women's groups have been taught how to make improved Upesi stoves (Githiomi J, 2010).

The advantages of energy saving kilns and stoves are:

— Minimise consumption of woodfuel.
— Reduce rates of deforestation
— Provide time for women for other development activities.
— Promotion of the utilisation of local resources.
— Enhancing environmental sanitation by utilising waste products such as sawdust and rice husks whose disposal is sometimes a problem.

It is not easy to compare the economics of growing feedstock for charcoal versus other uses including fuel wood generation as their uses are also specific. Since fuel wood has been the main fuel in rural areas, there is need to encourage and enforce adoption of wood saving stoves, outside the traditional three stones. This should be done continuously in the medium term to protect the environment. There is also need to encourage and enhance energy saving and efficient methods in charcoal production to protect the environment from degradation.

7. Barriers and constraints in current feedstock management practices

Kenya has been subject to ad hoc policies and presidential decrees banning the production and distribution of charcoal, while trade and consumption has been legally accepted (ESDA, 2005). This has contributed to the lack of long term support to the biomass sector and thus no interest by private investors to ensure sustained growth. However, there are now opportunities for feedstock management practices which have been given a boost by the enactment of enabling policies and legislation. For a long time, tree farming in Kenya has been under the docket of the Forest Department, and currently the Kenya Forest Service (KFS). However until recently with the formulation of the "The Agriculture (Farm forestry) rules, 2009", "The Forest (Charcoal) Regulations, 2009" and the "The Forest (Harvesting) rules, 2009", private farmers were not monitored by the KFS, and operated just like any other farming activity. Currently all farmers, regardless of their farming enterprise, have to maintain 10% of their farmland under trees and cannot harvest without the approval of a forest officer from KFS and issuance of a harvesting permit.

Barriers and constraints that would affect the current feedstock management practices are many and varied.

Land tenure

Trees harvested for charcoal typically originate from one of the three types of land tenure systems: private land, trust land and state owned land. On private land, charcoal is produced from naturally occurring woody vegetation, when newly opened or fallow land is opened for cultivation. Landowners may also harvest trees planted by them. In the trust land and state owned land where charcoal production would be associated with ranching or pastoral land management, trees are usually selectively harvested. Trees of specific species or size are chosen while others are left behind; these systems are subject to minimal silvicultural management and are left to regenerate naturally. Depending on the intensity and frequency of harvest as well as the occurrence of post-harvest practices such as burning or grazing, land cover may be restored over time. However, even in the absence of any land management, stand structure and species composition may be permanently altered. Thus, land management programmes must contend with the apparently dual ownership of the land: the pastoralists have de facto ownership of the land, putting it to their chosen land use of pastoralism; and the State's laws claim ownership.

Figure 7.1: Creating charcoal from a drum kiln (Nellie Oduor, KEFRI)

Lack of proper management plans

The Forests Act 2005 have made provisions (Part III Section 1 and 2) whereby each local authority shall, with the assistance of the Kenya Forest Service, be responsible for the protection and management of all forests and woodlands under its jurisdiction, and shall ensure that such forests are managed on a sustainable basis in accordance with an approved management plan. This also applies to the management of indigenous forests situated within the jurisdiction of a local authority. However, management plans for these areas are yet to be finalised due to a lack of data on forest/woodland extent, characteristics, growth and yield, especially where charcoal is produced.

Challenges in regeneration and re-vegetation of dry lands/woodlands

The dry lands where charcoal production is mainly carried out are usually water-stressed environments. The Forests Act 2005 (Republic of Kenya, (2005a) has made provision for re-vegetation where it requires the licensee to undertake compulsory re-vegetation immediately upon the completion of the activity. The re-vegetation shall be undertaken in consultation with the Kenya Forest Service, which shall determine the seeds and seedlings proposed to be used in such re-vegetation. What this means is that water harvesting, especially rainwater harvesting has to go hand-in-hand with re-vegetation activities. Natural regeneration should be allowed to go hand-in-hand with enrichment planting in areas of depleted woodlands. Regeneration can also be hampered by browsers. Charcoal producers are required to form Charcoal Producers' Associations. This provision has been provided in the Forests (Charcoal) Rules (Republic of Kenya, (2009). These associations will be required to implement reforestation and conservation plans.

8. Conclusions

It should be noted that one way of ensuring woodfuel is sustainable is through commercialising it, and that charcoal is an intricate part of socio-cultural life.

— For the success of commercial charcoal production and marketing, there is a need for clear charcoal policy guidelines which would encourage investments in improved charcoal processing technologies. Charcoal production should be like any other cash crop farming and should be taxed and reflected as a potential revenue earner for the government. The 2009 charcoal regulations rules which are meant to establish sustainable charcoal production, transportation and marketing need to be put into operation. The fuel substitution from wood energy to modern sources of energy (LPG, kerosene and electricity) as stated by the energy policy document (Republic of Kenya, (2005b) cannot be very effective due to high initial cost of the modern energy appliances (and electricity supply) and a subsidy is recommended for initial procurement of non-electrical appliances.
— Improved charcoal kilns (with efficiency of > 25%) should be promoted since almost all of the charcoal producers use the traditional earth kilns with 10-20% efficiency. Use of dry wood during carbonisation should also be encouraged. The technologies to be used should be simple, cheap and easily adopted by charcoal producers - like the improved earth kiln developed by KEFRI (Oduor,N. et al., 2006). Masonry kilns are recommended for charcoal conversion in areas where there is available fuel wood over a long time period, such as large-scale land clearing and fuel wood plantations. This would lead to a significant reduction in wood needed for charcoal making. This should go together with training of charcoal producers to widen their skills in technical and economic issues.
— The conservation of wood energy should be given a priority through promotion of improved stoves with higher efficiency. A study by Githiomi J. (2010) showed that over 70% of households still used 3 stone stoves which were inefficient. The improved stoves consider user needs such as cooking comfort, convenience, health and safety. The improved stoves should also be affordable, as it was noted in the study by Githiomi J. (2010) that low adoption of improved woodfuel cooking devices was a result of their high cost. Affordability can be achieved through subsidising the cost of making stoves by the government through the Ministry of Energy.
— Charcoal users prefer charcoal made from indigenous tree species with inherently high densities (Oduor and Githiomi, 2003). Perhaps there is need to promote low density charcoal from trees like Commiphora spp which are drought resistant, easily regenerated from cuttings, and are abundant in arid and semi-arid lands (Oduor and Githiomi, 2003)
— To streamline the charcoal value chain, there is need for collaborative action among all players in the charcoal sector which includes farmers (to come together and form associations to grow trees for charcoal production), charcoal producers, vendors, the government, civil society, consumers and the corporate sector among others.
— Promote production of briquettes made from charcoaled bamboo, since this has a low density and burns fast. The bamboo is crushed and briquetted thus making it dense/heavier to enable it to burn for longer. There are opportunities to briquette wastes such as bagasse and sawdust.
— Lastly there is a need to have enhanced regulations and guidance on land-use, especially where changes in land-use is taking place.

References

Benton, A., L. Thomson, P. Berg, and S. Ruskin. 2011(revised). Farm and Forestry Production and Marketing Profile for Bamboo (various species). In: Elevitch, C.R. (ed.). Specialty Crops for Pacific Island Agroforestry. Permanent Agriculture Resources (PAR), Holualoa, Hawai'i. http://agroforestry.net/scps

CDSI (2008).Baseline survey on Prosopis in 3 Districts of Kenya.Report of Centre for Sustainable Development Initiatives (CDSI).http://www.csdikenya.org/baselineprosopissurvey.htm

Choge S., (2010). A tree with multiple uses; Contrary to its bad reputation, Prosopis (Mathenge) can realise economic benefits. Miti Magazine October – December 2010, pg. 30-31.

Choge, S. K., Ngunjiri, F. D., Kuria, M. N., Busaka, E. A., Muthondeki, J. K. (2002). The status and impact of Prosopis spp. in Kenya. KEFRI, Nairobi

COMPETE (2009). Traditional, improved and modern bioenergy systems for semi-arid and arid Africa, SIXTH FRAMEWORK PROGRAMME FP6-2004-INCO-DEV-3 PRIORITY A.2.3.: Managing Arid and Semi-arid Ecosystems

CRC Weed Management. (2003). Weed management guide: mesquite – Prosopis species. Queensland, Australia

ESDA -Energy for Sustainable Development Africa. (2005). National Charcoal Survey: Exploring the potential for a sustainable charcoal industry in Kenya. A product of the Kenya Charcoal Working Group. June 2005. Pgs. 74

FAO Forestry Paper 63, (1985). Industrial Charcoal Making. Mechanical Wood Products Branch, Forest Industries Division. Food and Agriculture Organisation (FAO) Forestry Department. FAO UN Rome 1985.www.fao.org/docrep

FAO (2007): Forests and energy in developing countries, Forests and Energy Working Paper 2. FAO, Rome

FAO (2010).Criteria and indicators for sustainable fuel wood. FAO Forestry Paper 160. FAO, Rome

Githiomi J. (2010). Micro-level wood energy planning for Kiambu, Thika and Maragwa Districts: a case study for decentralised wood energy plan in Kenya. PhD thesis, School of Environmental Studies, Kenyatta University, Nairobi, Kenya

Green Resources, (2009). Jinja Charcoal Processing Carbon Project

Green Resources, (2010). Development of Clean Development Mechanism Projects in Tanzania – Lessons Learnt http://www.norway.go.tz/PageFiles/402978/LESSONS_LEARNT_by_GRAS_Presentation.pdf

Hines D.A. and K. Eckman, (1993). Indigenous Multipurpose trees of Tanzania: uses and economic benefits for people. ISBN 0-9697075-0-9

Jama, B., and A. Zeila, (2005). Agroforestry in the dry lands of eastern Africa: a call to action. ICRAF Working Paper no. 1, Nairobi: World Agroforestry Centre

Kareko KK and J. Githiomi (2000). National Arrangements and Capacity to Collect Wood Energy Information and Statistics: The Kenyan Scenario. Paper presented at FAO/UNEP Regional Workshop on Wood Energy Information in Africa, 23rd – 27th October, 2000 in Nairobi, Kenya.

Kawanguzi A. C. and P.Merrikim, (1987). New kiln offers more and better charcoal and employment. CERES No. 116 (Vol. 29, No. 2) - March-April 1987

KEFRI, (2008). Status of Bamboo Resources Development in Kenya. The Kenya Forestry Research Institute. 16 pgs.

Keita J.D.(1987) Small-scale forest enterprises- Wood or charcoal - which is better? Unasylva - No. 157-158

Kenya Forest Service, (2009.) Kenya Forest Service Strategic Plan 2009/10 – 2013/14

Khristova P. and A.W. Khalifa,(1993). Carbonization of some fast-growing species in Sudan, Applied Energy, Volume 45, Issue 4, 1993, Pages 347-354, ISSN 0306-2619, 10.1016/0306-2619(93)90006-B.(http://www.sciencedirect.com/science/article/pii/030626199390006B)

Kigomo B. N. ,(2007). Guidelines for Growing Bamboo. KEFRI. Guideline Series: No. 4. Kenya Forestry Research Institute; Nairobi, Kenya. Guideline Series: No. 4. Kenya Forestry Research Institute; Nairobi, Kenya

Kiruki, H. and J.Njung'e, (2006). Population density, structure and early growth characteristics of Tarchonanthus camphoratus in a woodland at Naivasha, Kenya. African Journal of Ecology, Afr. J. Ecol., 44, 1–10

Matiru, V. Revised by, (1999). Forest Cover and Forest Reserves in Kenya: Policy and Practice. . Published by IUCN-EARO. Pp. 68

Matiru, V. (2002). Forest Landscape Restoration; Kenya country report. Analysis of existing initiatives and policy and legal framework in Kenya. Compiled by IUCN-EARO and WWF-EARPO

Ministry of Energy (2002) Study on Kenya's energy demand, supply and policy strategy for households, small-scale industries ad service establishments. Report submitted by KAMFOR Company Limited. September 2002. Pgs. 133.

Mugo, F. and C. Ong, (2006). Lessons of eastern Africa's unsustainable charcoal trade. ICRAF Working Paper no. 20. Nairobi, Kenya. World Agroforestry Centre

Mwangi E. & B. Swallow, (2005). Invasion of Prosopis juliflora and local livelihoods: Case study from the lake Baringo area of Kenya. ICRAF Working Paper – No. 3. Nairobi: World Agroforestry Centre

National Mission on Bamboo Applications, (2005). Bamboo-based Charcoal Production. Info sheet IS 03 09/05

Ndegwa, G. (2010).Woodfuel value chains in Kenya and Rwanda; Economic analysis of the market oriented woodfuel sector. MSc. Thesis, Cologne University of Applied Sciences, Institute for Technology and Resources Management in the Tropics and Subtropics (ITT)

Ndegwa, J. (2011). Bioenergy Market System Development Comparing Participatory Approaches in Kenya and Sri Lanka. (Working Paper for PISCES by Practical Action Consulting)

Oduor, N. and Githiomi, J. (2003) Study on feasibility of charcoal production out of Commiphora species. Kenya Forestry Research Institute Report, Nairobi, Kenya.

Oduor, N., Githiomi, J. And Chikamai, B. (2006) Charcoal production using improved earth kiln, portable metal, and casamance kilns. Kenya Forestry Research Institute-Forest Products Research Centre, Karura, Nairobi.

Okello B.D, T.G. O'Connor, T.P. Young. (2001). Growth, biomass estimates, and charcoal production of Acacia drepanolobium in Laikipia, Kenya. Forest Ecology and Management 142 (2001) 143-153

Orwa C, A.Mutua, R.Kindt, R., Jamnadass and A. Simons (2009). Agroforestree Database: a tree reference and selection guide version 4.0 (http://www.worldagroforestry.org/af/treedb/)

Pasiecznik, N.M., Felker, P., Harris, P.J.C., Harsh, L.N., Cruz, G., Tewari, J.C., Cadoret, K. and Maldonado, L.J. (2001) The Prosopis juliflora - Prosopis pallida Complex: A Monograph. HDRA, Coventry, UK. pp.172.

Practical Action Consulting (2009). Small-Scale Bioenergy Initiatives: Brief description and preliminary lessons on livelihood impacts from case studies in Asia, Latin America and Africa. Prepared for PISCES and FAO by Practical Action Consulting, January 2009

Practical Action Consulting (2010). Promoting Sustainable Charcoal Production and Marketing in Kenya: A Comparative Analysis through Participatory Market Mapping, Prepared for PISCES by Practical Action Consulting Eastern Africa , March 2010

Republic of Kenya (2002). Study on Kenya's Energy Demand, Supply and Policy Strategy for Households, Small Scale Industries and Service Establishments. Ministry of Energy, Nairobi, Kenya

Republic of Kenya (2005a). The Forests Act of 2005. Government Printers, Nairobi, Kenya.

Republic of Kenya (2005b) Energy Act No. 12 of 2006. Government Printers, Nairobi, Kenya.

Republic of Kenya (2009). Forests (charcoal) Regulations. Government Printers, Nairobi.

Kenya Royal Botanic Gardens, Kew (1999). Survey of Economic Plants for Arid and Semi-Arid Lands (SEPASAL) database. Published on the Internet; http://apps.kew.org/sepasalweb/sepaweb [13th December 2011; 5pm]

State of Environment. 2004. State of Environment Report. National Environment Management Authority, Kenya. www.nema.go.ke

Theuri, K. (2002) Woodfuel Policy and Legislation in Kenya; A paper presented during the Regional Workshop on Woodfuel Policy and Legislation held at ICRAF, Nairobi, Kenya.

Young, T.P. and Francombe, C., 1991. Growth and yield estimates in natural stands of leleshwa (Tar conanthus camphoratus). For. Ecol. Manage., 41 : 309-321.

Policy Innovation Systems for Clean Energy Security (PISCES)

PISCES is a six-year research project funded by the Department for International Development of the United Kingdom (UK). Project implementation started in July 2007. Through action research the project is increasing available knowledge and understanding of policy relevant trade-offs between energy, food and water security for livelihoods in relation to bioenergy. PISCES is a Research Programme Consortium whose members include African Centre for Technology Studies (ACTS, lead) Kenya; Practical Action Consulting UK, Eastern Africa, and Sri Lanka; the University of Dar es Salaam, Tanzania; M.S. Swaminathan Research Foundation (MSSRF), India; and the University of Edinburgh, UK. **www.pisces.or.ke**

Kenya Forestry Research Institute (KEFRI)

A leader in forestry research, KEFRI is a public institution established under the Kenya Science and Technology Act, Cap 250 of the Laws of Kenya. KEFRI's mandate is to conduct research in forestry, co-operate with other research bodies within and outside Kenya carrying out similar research, liaise with other organisations and institutions of higher learning in training on matters of forestry research, and disseminate research findings. Its mission is to enhance the social and economic welfare of Kenyans through user-oriented research for sustainable development of forests and allied natural resources. **www.kefri.org**

Practical Action Consulting (PAC)

For over 40 years, PAC has provided development consultancy services as the consulting arm of the international NGO, Practical Action. PAC provides high quality, independent and professional advice to governments, NGOs, aid agencies and the private sector. We work worldwide from regional offices in the UK, Eastern and Southern Africa, South Asia and Latin America. Our vision is of a sustainable world free of poverty and injustice in which technology is used for the benefit of all.
www.practicalaction.org/consulting