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Charcoal production and strategies to enhance its sustainability in Kenya

Mary Njenga, Nancy Karanja, Cristel Munster, Miyuki Iiyama, Henry Neufeldt, Jacob Kithinji, and Ramni Jamnadass

In sub-Saharan Africa, 72 per cent of urban and 98 per cent of rural households use fuelwood for energy. In Kenya use of charcoal in urban areas has risen by 64 per cent in two decades. Despite the charcoal industry providing employment to 500,000 people and generating over US$427 million that benefits grassroots communities, it has been kept out of the formal economies of this country. This review presents the status of the charcoal industry in Kenya, highlighting its contribution to livelihoods, production, utilisation, and implications for the environment; policy issues; and stakeholders' involvement. The review also proposes strategies to improve the sustainability of this sector.

La production de charbon de bois au Kenya et des stratégies pour l'augmentation de sa durabilité
Dans l'Afrique subsaharienne 72 pour cent de ménages urbains et 98 pour cent de ménages ruraux se servent du bois combustible pour leur propre énergie. Au Kenya l'usage de charbon de bois dans les secteurs urbains a augmenté par 64 pour cent au cours de deux décennies. Malgré le fait qu'elle fournit un emploi à 500,000 personnes et qu'elle génère plus de US$427 million de bénéfice aux collectivités populaires, l'industrie du charbon de bois reste écartée des économies formelles de ce pays. Cet examen présente la situation de l'industrie du charbon de bois au Kenya, en soulignant sa contribution aux moyens d'existence, à la production, et à l'utilisation ainsi que les implications pour l'environnement ; des questions concernant la politique ; et l'implication des parties prenantes. L'examen propose également des stratégies pour l'amélioration de la durabilité de cette industrie.

Producción de carbón y estrategias para aumentar su sostenibilidad en Kenia
En el África subsahariana, 72% de los hogares urbanos y 98% de los hogares rurales utilizan la leña como fuente de energía. En las áreas urbanas de Kenia, el uso de carbón ha aumentado 64% en dos décadas. A pesar de que la industria de carbón crea empleo para 500 mil personas, generando US$427 millones en beneficios para las comunidades de base, se la ha marginado de las economías formales de este país. El presente artículo examina la situación de la industria de carbón en Kenia, analizando, por un lado, su contribución a los medios de vida, y por otro, su forma de producción y su utilización, así como sus implicaciones para temas de política ambiental, además de la participación de los actores en la misma. Asimismo, el artículo propone estrategias para mejorar la sostenibilidad del sector.

Produção de carvão e estratégia para aumentar sua sustentabilidade no Quênia
Na África Subsaariana, 72 por cento de famílias da zona urbana e 98 por cento de famílias da zona rural utilizam lenha como fonte de energia. No Quênia,o uso de carvão nas áreas urbanas cresceu 64 por cento em duas décadas. Apesar da indústria de carvão proporcionar emprego a 500.000 pessoas e gerar mais de US$427 milhões que beneficiam comunidades de base, ela tem sido deixada de fora das economias formais deste país. Esta revisão apresenta o status da indústria de carvão no Quênia, destacando sua contribuição para os meios de subsistência, produção, utilização e implicações para o meio ambiente; questões de políticas e envolvimento dos stakeholders. A revisão também propõe estratégias para melhorar a sustentabilidade deste setor.

KEY WORDS: Environment; Labour and livelihoods; Governance and public policy; Sub-Saharan Africa

Introduction

This paper presents a review of existing information on the status of the charcoal industry in Kenya, highlighting its contribution of Ksh32 billion (US$427m) to the country's economy, support to the livelihoods of two million people along the value chain, and demand by 82 per cent of urban households and 34 per cent of rural households. The paper also illustrates the main source of wood used in charcoal production as being from people's own farms and private land, contrary to the belief that most charcoal originates from protected forests. This review discusses the charcoal production techniques and their environmental implications, efficiency in the use of charcoal, policy issues, and stakeholders in the charcoal industry. We then propose strategies to address some of the limitations highlighted along the value chain, in order to make the sector sustainable.

Growing energy requirements is one of the major challenges facing the world today. The poor and middle income populations who are the majority of wood charcoal users cannot afford to use electricity and/or liquid petroleum gas (LPG) for cooking because of the high investments needed in fuel and cooking appliances (Mugo et al. 2007). As living standards rise and urban areas expand, households and small-scale industries in many developing countries, especially in sub-Saharan Africa, are using charcoal more and more for cooking, as other sources of energy such as electricity are expensive. In developing countries charcoal is mainly used in urban areas and its use is estimated to increase at six per cent a year, which incidentally is proportional to the rate of urbanisation. Charcoal production and trade contributes to the economy by providing incomes and employment for men, women, and children at the community level and saves foreign exchange that would otherwise be used to import cooking fuel. Compared to firewood, charcoal has several advantages. For example, Fuwape (1993) found five-year-old *Leucaena leucocephala* and *Tectona grandis* yielded charcoal with a calorific value of 24.15kJ/g and 26.4kJ/g respectively, compared to 13.45kJ/g and 13.96kJ/g from firewood. Charcoal is easy to transport as it has lower weight in respect to energy content, burns evenly for a long time, and is less smoky. Hence there is no doubt that the charcoal trade will expand in the foreseeable future. It will continue to be the main and, in some cases, the only source of energy for millions of people in the sub-Saharan Africa for a long time (Mugo et al. 2007).

However, charcoal has been kept out of the formal economies of many countries, partly due to lack of supportive data and information. Charcoal production is a big threat to biodiversity because it targets specific preferred species found in natural forests and woodlands, most of which are poorly managed, leading to unsustainable harvesting. In drier areas, where the

regenerative capacity is lower, unplanned and unmanaged charcoal production accelerates the processes that lead to desertification (Mugo et al. 2007). The absence of replanting practices accelerates desertification and land degradation (Mutimba and Barasa 2005). Most charcoal producers in the country use inefficient carbonisation processing, leading to wastage of wood and greenhouse gas emissions.

Livelihood and gender aspects of charcoal

In comparison to other sectors in Kenya, charcoal is ranked fourth after tourism, horticulture, and tea. It represents an estimated annual market value of over Ksh32 billion (US$427m), almost equal to the Ksh35 billion (US$467m) from the tea industry (Mutimba and Barasa 2005). It is a sector that supports communities at the grassroots, as all the cash generated from it benefits poor Kenyans and circulates within the Kenyan economy, while for example 50 per cent of that from tea goes to multinationals. The charcoal industry involves 200,000 people in production, of whom 84 per cent are male and 16 per cent female, creating employment opportunities especially for rural young men. The number of charcoal producers alone is comparable to the government's teaching work force of 234,800 (Mutimba and Barasa 2005). The cost of producing charcoal has been estimated at Ksh159 (US$2) and producers sell at Ksh260 (US$3), making a profit of 40 per cent at farm gate, which is too low compared to the consumer price of about Ksh1000 (US$13) per bag of approximately 90kg. There are 300,000 persons involved in transportation and vending (86 per cent male and 14 per cent female, and 43 per cent male and 57 per cent female, respectively). Selling of charcoal mainly takes place in the urban areas, providing highly needed income to low income women whose sales involve small quantities measured using tins, but to a large number of buyers. Producers earn an average monthly gross income of Ksh4,496 (US$60), vendors Ksh7,503 (US$100), and transporters Ksh11,298 (US$151) (Mutimba and Barasa 2005). Four per cent of those involved in this industry are children. The number of dependants supported by those involved in production, transportation, and vending is estimated at two million (Mutimba and Barasa 2005).

Current demand for charcoal as a fuel source – and future trends

Though still less relative to firewood in most of Asia, charcoal use is becoming a much larger part of the woodfuels total in Africa and South America. It is predicted that charcoal will replace the use of firewood in urban areas. As in other parts of the region, charcoal demand in Kenya is high among urban households as shown in Table 1. In sub-Saharan Africa, over 72 per cent of urban and 98 per cent of rural households use fuelwood for energy (Bailis, Ezzati, and Kammen 2005). In Kenya, between 1.6 and 2.4 million tonnes of charcoal are consumed annually, with a

Table 1: Charcoal consumption in the East and South African region

Country	Annual consumption (million tonnes)
Kenya	1.6-2.4*
Ethiopia	0.23+
Zambia	0.7$

Source: *Mutimba and Barasa 2005
+Yigard 2002
$Chidumayo et al. 2002

Table 2: Charcoal consumption in Kenya

Type of user	1980	2000
Per cent households at national level	8	47
Per cent urban households	50	82
Per cent rural households	37	34

Source: Mutimba and Barasa, 2005

per capita consumption of 156kg and 152kg for urban and rural areas, respectively (Mutimba and Barasa 2005) (Table 1).

As in other countries in the region, charcoal use in Kenya is mainly in urban areas and is on the increase (Table 2).

Out of the 1.6–2.4 million tonnes of charcoal consumed in Kenya annually, 10 per cent goes to the capital city, Nairobi. The situation is similar in Tanzania, where 80 per cent of charcoal produced is used by urban households (Ngeregeza 2003). In Ethiopia, 70 per cent of total production was found to be used in towns, supplying 97 per cent of household energy needs (Yigard 2002). Charcoal use in Zambia is reported to have increased by four per cent between 1990 and 2000 and 85 per cent of urban households use charcoal in the country (Chidumayo et al. 2002). Using substitutes for charcoal for cooking is not a viable option in the short and medium term because of the high cost of both electricity and LPG, and of cooking appliances. For example, in the year 2000, while the cost of cooking with charcoal was US$150 per household per year, the cost of cooking with electricity and LPG was estimated at US$740 and US$397 per household per year, respectively. Most hotels and restaurants also prefer charcoal for roasting meat.

Sources of charcoal

Estimates from two studies show that sourcing of wood for charcoal burning from people's own farms and private land has been on the increase, contrary to the belief that most charcoal originates from protected forests; this is shown in Table 3.

However, for fear of legal consequences and threats to their livelihoods, charcoal producers may be afraid to reveal the actual sources of the charcoal and such findings on sources of wood used for charcoal production therefore need to be treated with caution as they may misadvise efforts on natural resource management. Sourcing of charcoal from non-government land is common in the region. For example in Uganda, charcoal is generally produced on non-state land.

Charcoal production from people's own farms is carried out by landowners in high potential areas who grow trees for various purposes ranging from fruit production, crop shade, firewood,

Table 3: Sources of wood for charcoal production in Kenya

Source of wood	2003	2005
Own farm	40%	44%
Private land	40%	38%
Government or county council land	15%	13%
Communal land	5%	5%

Source: Mutimba and Barasa, 2005

fodder, live fencing, building, and construction. Prunings and stumps are mostly used for charcoal production at a small scale (Mutimba and Barasa 2005). In other cases, charcoal is a by-product of other activities such as land clearing for agricultural purposes, where for instance outsiders are invited to manually clear land and in return use the trees or shrubs to produce charcoal as a form of compensation. In this case production is often on a large scale and is common in wheat-producing areas where large tracts of land are cleared to make room for production of wheat and barley, as in Narok District (Mutimba and Barasa 2005). In marginal rainfall areas, communities clear and produce charcoal from the invasive *Mathenge (Prosopis juliflora)* to save pastures for their livestock. One large-scale private company, Kakuzi Ltd, produces charcoal from stumps of *Eucalyptus spp.* after the tree is cut for production of posts.

Illegal charcoal production from protected government lands takes place adjacent to forests, in such districts as those bordering Mt Kenya Forest, Mt Elgon Forest, Kakamega Forest, Mau Forest, and along some sections of the Mombasa Road, and this contributes 13 per cent of total charcoal production. With proper enforcement this could be reduced to less than five per cent (Mutimba and Barasa 2005).

Nearly all charcoal consumed in Kenya and elsewhere in sub-Saharan Africa is made from local tree species. Over 100 tree species are used in charcoal production in Kenya. *Acacia* species (*Acacia tortilis, A. nilotica, A senegal, A. mellifera, A. polyacantha*, and *A. xanthophloea*) are the most widely used (38 per cent) and preferred (45 per cent). Other popular species include Croton, Olea, Manilkara, Mangifera, Eucalyptus, and Euclea (Mutimba and Barasa 2005). Charcoal from hardwood is preferred because of its high density and calorific value (Mugo et al. 2007).

Kenya's deficit in biomass energy rose from 46 per cent in 1980 to 57 per cent in 2000. In Kenya it is estimated that commercially-grown trees can produce 18 tonnes of charcoal from one hectare. About 135,000ha of fast-maturing tree species will be required every year to meet the current demand of 2.4 million tonnes (Mugo et al. 2007). Other countries both in the developed and developing world are also promoting the production of charcoal briquettes from biomass waste to supplement charcoal.

Impacts of cutting trees to produce charcoal

To satisfy Kenyans' annual charcoal demand, about 22 million cubic metres of wood is carbonised, resulting in deforestation of both rangelands and forests. Biodiversity is the basis of ecosystem health and of the provision of ecosystem services, but 100 species per million are lost per year (Rockström et al. 2009). The total area under woodland in Kenya is estimated at 48.6 million hectares. Of these, 1.3 million are under natural forests, 0.17 million are forest plantations, and 9.5 million are farmlands. Arid and semi-arid lands, which are a major source of charcoal in Kenya, cover 80 per cent of the land and cattle production is one of the most important livelihoods. Deforestation and land degradation are some of the challenges Kenya needs to address to achieve Millennium Development Goal (MDG) 7, 'Ensure Environmental Sustainability'. In Kenya the annual deforestation rate for 1990–2005 was 12,000ha/year, while the total remaining forest stood at 3.5 million hectares. In Mau Forest, one of Kenya's water towers, one quarter or some 100,000 hectares has been destroyed since 2000. Sourcing charcoal from protected governmental land among other factors contributes to destruction of forests which are already threatened. Charcoal producers for example destroy the forests as they use traditional kilns which are poor in biomass conversion and cause fires which in most cases destroy the areas surrounding the charcoal production sites. Because this activity is done illegally, effective monitoring and control of the impacts of charcoal production on forests and biodiversity has been difficult to achieve.

Methods of charcoal production and environmental implications

The charcoal production process involves burying wood under a mound of earth and igniting it underneath so that there is a limited air supply; this is the traditional earth kiln. The wood is partially denied oxygen and in the burning process is converted to charcoal, carbon dioxide (CO_2), carbon monoxide (CO), methane (CH_4), and particulates (Pennise et al. 2001). Factors that affect charcoal production efficiency in this technique include: design of the kiln, tree species used, moisture content of wood, arrangement of wood in the kiln, and monitoring of carbonisation process, which explains the wide productivity range of 10–20 per cent obtained in earth kilns. Research showed that 99 per cent of charcoal producers in Kenya use traditional earth kilns, which are cheap as they require only labour to construct. On the other hand they have low efficiency of 10–20 per cent in converting wood to charcoal, compared to improved retort kilns with 45 per cent efficiency (Mutimba and Barasa 2005). KEFRI has developed a manual based on four charcoal processing technologies, and this indicates that improved earth kilns, a portable metal kiln, a drum kiln, and the Cassamance kiln could give yields ranging between 27–30 per cent. Improved production techniques require more labour and cost, but the quality of charcoal is better compared to earth kilns, as the newer methods have better control of the carbonisation process.

The impacts of poor carbonisation techniques include wastage of woody biomass, low incomes for charcoal producers, and high levels of pollution and greenhouse gas emissions (Mugo et al. 2007). A study on emissions of greenhouse gases and other airborne pollutants from charcoal production in Kenya and Brazil showed that emission factors, expressed as grams of pollutant per kilogram of charcoal produced, ranged from 543 to 3027 for CO_2 and 143–373 for CO. On average, wood carbon is approximately diverted as follows: 51 per cent to charcoal, 27 per cent to CO_2, and 13 per cent to products of incomplete combustion (PIC). Due to the higher global warming potentials (GWPs) of PIC relative to CO_2 on a carbon atom basis, such kilns may contribute to greenhouse gas emissions, even when the wood is harvested sustainably (Pennise et al. 2001). Furthermore, use of inefficient earth kilns contributes to at least 0.77–1.63kg of CO_2 per kilogram of charcoal produced. This amount of emissions can be reduced by up to 75 per cent when improved and more efficient retort kilns are used.

Efficiency in use of charcoal and its effects on climate change and public health

Combustion of charcoal and inefficiency in its use as a source of cooking and heating energy contributes to emission of greenhouse gases as well as substances that are harmful to health. Recent calculations by the Edinburgh Centre for Carbon Management showed that one tonne of charcoal produced and consumed generates nine tonnes of CO_2 emissions. This implies that out of the 1.6–2.4 million tonnes of charcoal produced and consumed in Kenya, 14.4 to 21.6 million tonnes of CO_2 are emitted into the atmosphere every year, contributing to climate change. Combustion of biomass emits pollutants that cause over 1.6 million annual deaths globally, which translates to one death every 20 seconds or 400,000 in sub-Saharan Africa per year (Bailus, Ezzati, and Kammen 2005). Most of these deaths are among children (56 per cent) and women.

In Kenya, about 85 per cent of households in urban areas use the improved Kenya Ceramic Jiko stove, which has an energy conversion efficiency of about 33–35 per cent compared to 10–15 per cent obtained in traditional stoves. Use of the Kenya Ceramic Jiko enables poor urban households to make financial savings of 26 per cent of annual household income. Another

type of stove that could contribute to a reduction in the quantity of charcoal used is the fireless insulation-based cooker. A fireless cooker completes cooking that is initiated by another stove such as the KCJ. Tests have shown that this cooker despite cooking food for a long time can reduce cooking energy consumption by 50 per cent. This suggests that a combination of ceramic stove and fireless cooker can reduce household charcoal consumption by 75 per cent (Mugo et al. 2007). Fireless cookers are made from a simple basket, insulated with local resources such as banana leaves or old clothes. Use of improved stoves could reduce the negative health effects of using of charcoal, where for example respiratory infections in children and women fell by 60 per cent and 65 per cent respectively when the KCJ was used.

Policy issues and stakeholders in the wood charcoal industry

Due to lack of an appropriate taxation system for charcoal, it is estimated that the Kenyan economy loses about Ksh5.1 billion annually, based on the 16 per cent value added tax (Mutimba and Barasa 2005). The only revenue to the government is collected through charcoal by-laws approved by the Ministry of Local Government and business permits (trade licenses). For this to be realised, the existing rules and regulations on charcoal production, processing, and movement currently available would work, and what needs to be done is sensitisation and awareness creation with relevant stakeholders, including enforcement agencies to make charcoal trade commercially acceptable.

The Ministry of Energy has the mandate to provide adequate energy sources in Kenya. However, no charcoal law exists although a Renewable Energy Policy and Bill are being developed. The Energy Act 2006, section 103, mentions charcoal as one of the forms of biomass energy that the Ministry of Energy is mandated to promote, particularly its development and use technologies. The Environmental Management and Coordination Act 1999, paragraph 49, specifies that the National Environmental Management Act promotes use of renewable energy sources, of which charcoal is one. This is suggested to be done through encouraging private farmers, institutions, and community groups to plant trees and woodlots. Currently two documents are used to control charcoal production and transport: a certificate of origin and a movement permit. Acquisition of the two documents is free of charge.

The Forests Act of 2005 legalised charcoal as a forest product and gave the Kenya Forest Service the mandate to enforce and regulate charcoal-making as one of the forest utilisation activities. The Ministry for Forestry and Wildlife, under section 59 of the Forests Act 2005, developed forest (charcoal) regulations. The regulations re-emphasise that commercial charcoal production and transportation will require a valid license or permit that will be issued by the Kenya Forest Service. Exportation and/or importation of charcoal or charcoal products will require possession of a permit issued under the forest (charcoal) regulations 2009. A lesson could be learnt on controlling charcoal export from the case of Sudan, where charcoal export in Sudan is currently restricted to specific places and the Forest National Corporation sets the minimum price, and export of high quality charcoal, mainly acacia, is limited to 5,000 tonnes a year (Mugo et al. 2007).

The Ministry of Energy has been conducting technical capacity building on agroforestry for fuelwood and energy conservation strategies such as use of appropriate kilns through ten energy centres located in different parts of the country. Technical capacity building has also been provided to communities by other Ministries such as those of Agriculture, Livestock, and Fisheries Development and Education, as well as Forestry and Wildlife, on tree planting, management of range vegetation, and efficient energy utilisation.

Research and development work in the charcoal industry has also been going on in the country. For instance the Kenya Forest Research Institute, Kenya Forest Products Research

Centre-Karura has developed a manual on improved charcoal-making technologies. The government has been commissioning studies around the charcoal industry, such as the one conducted by the Ministry of Energy in 2002, and another by Energy for Sustainable Development AFRICA in 2005 (Mutimba and Barasa 2005). Other organisations both public and private involved in charcoal-related research and development include the World Bank, Food and Agriculture Organization (FAO), Danish International Development Agency (DANIDA), Swedish International Development Cooperation Agency (SIDA), United Nations Development Program (UNDP) and Global Environmental Facility (GEF), Regional Land Management Unit (RELMA), World Agroforestry Centre (ICRAF), Universities in Kenya and outside, Practical Action, Thuiya Enterprises Ltd, and Policy Innovation System for Clean Energy Security (PISCES). The Green Belt Movement and Kakuzi Ltd have been instrumental in tree planting for fuelwood, while sugar factories, the Coffee Planters Cooperative Union (KPCU) and Chardust Ltd have been working on fuel briquette production through recycling organic waste and agricultural residues. Other important stakeholders in charcoal include producers, transporters, and vendors as discussed earlier under livelihood and gender aspects of charcoal.

Interventions that could turn charcoal production into a sustainable sector

This section of the paper presents proposals for interventions in carbonisation and utilisation techniques, agroforestry for charcoal production, recycling of charcoal dust and fines for production of energy fuel briquettes to complement charcoal, and policy aspects that would turn this important industry into a sustainable sector.

Efficient production and utilisation processes

Kenya's current charcoal production is a threat to the environment as over 99 per cent of it still uses inefficient carbonisation processes (Mutimba and Barasa 2005). In addition to minimising gas emissions, adoption of efficient charcoal production kilns would reduce consumption of wood. This could be achieved through building technical capacity of charcoal producers, who also need microfinancing systems to adopt appropriate technologies supported by effective governing systems. Designing mobile, efficient charcoal kilns would minimise transport costs, while kilns for small-sized wood and branches would be necessary for farmers who are able to source wood from neighbours. Training materials are available: for example the easy-to-use manual on improved kilns by KEFRI, although much more research is required to improve the efficiency of kilns as the highest efficiency reported in the country stands at 45 per cent. Kenya already has improved stoves on the market, such as the Kenya Ceramic Jiko. The government supports this strategy, as the energy strategies Sessional Paper No. 4 of 2004 proposes increased adoption of efficient charcoal stoves from 47 per cent to 80 per cent by 2010, and to 100 per cent by 2020 in urban areas. The targets are 40 per cent by 2010 and 60 per cent for rural areas. The same paper announces the target to increasing efficiency of charcoal stoves from 30–35 per cent to 45–50 per cent. Use of these efficient stoves has a potential to reduce demand for charcoal as well as to mitigate climate change and indoor air pollution. For example, retort kilns reduce greenhouse gas emissions by 75 per cent (Adam 2009).

A large number of charcoal producers could easily be reached for training on efficient carbonisation processes through working with community based groups producing charcoal. The existing ten energy centres through which farmers are trained by the Ministry of Energy

are important platforms that could be empowered for community technical capacity building. The country has a wide range of media celebrities such as those in music and drama, public gatherings such as in churches, and community meetings (*barazas*), all of which could serve as important channels for reaching consumers with messages on efficient use of charcoal.

Agroforestry systems for sustainable charcoal production

Many view the charcoal industry as a threat to natural resources and climate and their fear is real, as revealed by Mutimba and Barasa (2005), who found that over 75 per cent of charcoal in the country is produced unsustainably. Ironically, the charcoal industry could save the environment that it now threatens if communities and private practitioners grew trees for charcoal as well as harvested trees sustainably through proper management plans. There is potential to improve tree cover and produce charcoal, through adoption of short rotational agroforestry systems. The Kenya Forestry Research Institute (KEFRI), showed that a six-year-old *Acacia xanthophloea* tree produced charcoal with calorific value of 33kJ/g. The fixed carbon was 70 per cent, within the range of good quality charcoal, which is 50–95 per cent. *Terminalia orbicularis* and *Commiphora Africana*, which are drought resistant, abundant in the arid and semi-arid lands, and regenerate easily from cuttings, have a potential that could be exploited for charcoal production in these areas. Another study on suitability of *Acacis drepanolobium* for sustained charcoal yield in Laikipia, Kenya showed that over a 14-year cycle while the trees are allowed to coppice naturally, a minimum of 3 tonnes per hectare of charcoal could be produced using the traditional kiln. The tree is suitable for charcoal production in arid and semi-arid lands as it occurs in almost mono-specific stands in high densities over vast areas, coppices readily when harvested or top-killed by fire, and its hard wood makes good quality charcoal. On the other hand as most charcoal is consumed in urban areas, there is a need for the establishment of private agroforestry systems in peri-urban areas and opportunity cost studies on the use of peri-urban areas to be carried out. However, adoption of agroforestry systems for charcoal production will depend on availability of labour, land, and money, among other factors.

Through government technical extension services, research and development organisations' work could help advise farmers on appropriate tree and shrub species, optimal tree management and rotation periods, as recommended by stakeholders during a charcoal seminar held at the World Agroforesry Centre (ICRAF). Farmers could be encouraged to form or join Community Forest Associations (CFAs) that will coordinate sourcing of seeds and seedlings, planting, management, awareness creation, and monitoring of charcoal production as a cash crop. The CFAs would also provide socio-economic benefits to communities such as encouraging equity, conflict resolution, poverty reduction, and sustainable utilisation of forest and tree products. There are 347 CFAs in Kenya which are mainly located in the important forest regions. Membership in these CFAs varies between 30 to 3,000 as they are made up of different self-help groups. Ranches and private companies could improve sustainability in charcoal production through formulating tree management plans and being provided with tax incentives by the government to plant trees for charcoal production.

The other option for sustainable charcoal production would be support of the ongoing harvesting of the invasive *Prosopis juliflora* species as a strategy to restore pastureland in the affected areas. Global concern about deforestation caused by fuelwood shortages prompted the introduction of *Prosopis juliflora* to the Lake Baringo area in the early 1980s. *Prosopis juliflora* is in the World Conservation Union (IUCN)'s new list of 100 world's worst invasive alien species (Mwangi and Swallow 2005). Unlike some other parts of the world where it has been introduced, *Prosopis juliflora*'s potential benefits have not been captured and few people in the areas where it is found in the country realise net benefits from the widespread presence of the tree. *Prosopis*

juliflora produces high quality charcoal, although its production involves the challenges of harvesting the branches, as they have strong thorns that are hard to cut and wear down simple cutting tools (Mwangi and Swallow 2005). However, a project funded by the Ministry of Energy and supervised by KEFRI is supporting the community in Marigat, Baringo District to harvest *Prosopis juliflora* for charcoal production for sale locally and for export.

Large plantations in low population areas and under-used land are some examples of how agroforestry systems are being adopted for sustainable charcoal production in Brazil (Rosillo-Calle et al. 1996) and Sudan (Ibrahim 2003). In the Democratic Republic of Congo, about 8,000 hectares of *Acacia auriculiformis* were planted from 1987 to 1993, and in 1998 the Mampu plantation was divided into 25ha plots for 320 farming families. The agroforestry woodlots were based on improved fallows, drawing on traditional slash-and-burn farming. Total charcoal production from the plantation ranged from 8,000 to 12,000 tonnes per year in addition to 10,000 tonnes per year of cassava, 1,200 tonnes per year of maize, and six tonnes per year of honey. Gross annual revenue for the country from charcoal alone amounts to US$2.6 million, with owners of these agroforestry plots earning at least a quarter (Bisiaux, Peltier, and Muliele 2009). This helps cover a large share of urban needs for renewable energy while creating rural employment.

Recovery of charcoal dust/fines for energy fuel briquette production

Between 10–15 per cent of charcoal ends up as waste in the form of charcoal. This occurs during transporation and at wholesale and retail stalls. In Narobi for example, about 70 tonnes of charcoal dust are produced daily at the charcoal wholesale and retail stalls. The term waste refers to something that is useless or worthless and one way of recovering charcoal dust is through production of energy fuel briquettes. Production of energy fuel briquette involves collection of combustible materials and compressing them into a solid fuel product of any convenient shape, and this is then burnt like wood or charcoal. Another option in briquette-making is harvesting of tree prunings. One NGO producer in Coast Province set up an out-grower scheme in which twigs are harvested from fast-growing trees at the rate of regrowth to ensure sustainability. Farmers in the scheme then carbonize the twigs and sell to the NGO, who mix it with a binder to make briquettes. Fifty per cent of briquette-making enterprises in the country are community based organisations with about 25 members each, and most involve women and youth. Others involved in briquette production include NGOs and private companies. The main raw material used in energy fuel briquette production is charcoal dust, which is bound with either biodegradable paper or soil. About 82 per cent of briquette producers in the country use manual machine presses, 25 per cent use electricity, and 10 per cent use other means including bare hands. The briquettes are used in homes, food kiosks, hotels, institutions such as schools, chicken hatcheries, and bakeries.

Formalisation of charcoal industry

Legalisation and enforcement of the charcoal regulations should be aimed at offering an enabling legal framework that promotes commercial charcoal production and licensing for revenue, enterprise-based approaches for poverty reduction, smallholder/private tree-growing, woodfuel-energy conserving technologies, improved agricultural productivity, and ecological sustainability. In Malawi for example stagnant policies based on charcoal bans and fuel-substitution were not effective and it was learnt that polices need to be transformed into proactive and realistic ones acknowledging woodfuel dominance and its socio-economic importance (Zulu 2010). To protect the country's biodiversity the charcoal regulations prohibit production of charcoal from endangered, threatened, and protected plant species, and require

reforestation or conservation plans for the area where trees will be managed for charcoal production. The regulation system will also address the lack of standards to regulate quality, weight, and size of the charcoal bags entering the market, which has caused buyers and sellers to pay the same amounts for different sized bags. Community based organisations have been entry points for many research and development interventions in the country but this has been absent in the charcoal industry due to its informal set up; the groups can now take advantage of the legal status of the industry. Legalisation and regulation of this sector through the coordination of the government will ensure that the policy framework works effectively.

Areas for further research:

- There is little information on the **origin of the charcoal supply**. More precise and reliable data on **sources** of charcoal and **how it is produced** are needed so as to evaluate the **impacts** on agro-ecosytems and the environment.
- The charcoal industry is an important economic activity but there is need for more data to illustrate **the flow of charcoal and money**. These include gathering gender-disaggregated data on amounts transported from source to market; mode of transportation; players in the marketing chain and how they are organised; amounts traded and prices; cost-benefit analysis for pricing; and the challenges, constraints, and opportunities along the market value chain.
- **Production and utilisation methods** are inefficient and there is need for more data on their **cost-effectiveness and sustainability**. Data are also missing on **impacts** of charcoal production on forests and biodiversity.
- There is need for research on **alternative sources of bioenergy** so as to save threatened tree vegetation cover. The potential to produce energy fuel **briquettes** through compacting tree by-products such as charcoal dust, sawdust, and agricultural residues, all of which are plentiful in some ecological zones, needs to be evaluated.

Conclusions and recommendations

In sub-Saharan African countries, wood charcoal is the main source of cooking energy, with highest consumption being in urban areas. This trend is likely to persist due to its affordability and high urbanisation rates. The charcoal industry supports livelihoods of men, women, and children at the grassroots level. Government involvement through development of supportive policies and regulations such as provision of tax incentives to private companies to grow trees for charcoal and establishment of forests specifically for charcoal is an important option that offers a great opportunity for sustainable charcoal production. Similar incentives would encourage farmers to engage in establishment of woodlots and on-farm forestry, using appropriate tree and shrub species for charcoal production, and following improved technologies. Options should also be evaluated with farmers to understand their priorities in using charcoal dust either for soil amelioration or in making fuel briquettes to meet their cooking energy needs.

The government, development practitioners, and partners need to carry out further action research and disseminate information to charcoal producers and users on appropriate production and utilisation processes. These include technologies with high biomass conversion rates and low gas emissions, such as improved kilns and cooking stoves. The waste generated in the charcoal value chain, which otherwise degrades the environment, has a potential to address the increasing cooking and heating energy demand through processing into fuel briquettes. In order to achieve inclusive development there is a need for the application of gender-responsive situation analysis, designing, and planning, as well as implementation and impact monitoring

and evaluation methods along the charcoal value chain. Awareness-raising and training among law enforcement bodies and other stakeholders on charcoal regulations, to combat the misconception that its production and transportation are illegal will also be vital.

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