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Woodlands and the charcoal trade: the case of Dar es Salaam City

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1 Introduction

Tanzania has a total area of about 94.5 million ha out of which 88.6 million ha is covered by landmass and the rest is inland water. Forests and woodlands in Tanzania cover about 34 million hectares making about 40% of land. Gazetted forestland is about 13 million hectares, predominantly managed by the Central Government. Only 600 000 hectares of the gazetted forest land are under the ownership and management of Local Governments. Game reserves and national parks constitute about 2 000 000 ha. Non gazetted forests in public lands cover about 19 million hectares and this is where forests are facing serious conversion to competing land uses. Non gazetted forests are also known as general land forests which are essentially open access. Deforestation in Tanzania, which is estimated at between 130 000 to 500 000 hectares per annum occurs mostly in the general land forests as well as degradation (loss of biomass) over much of the total forest area.

Establishment of village forest reserves under Participatory Forest Management (PFM) which started in 1990s was found to retard deforestation in unreserved forestland. To date more than 3 million ha are under PFM (MNRT 2006) which is about 11% of total forest area. This reduces the open access forest area in the general land from 19 million ha to about 16 million, which is 47% of the entire forested land (Table 1).

Table 1. Tenure status of Tanzanian forests (MNRT 2006).

Forest Reserves			Game Reserves	General land forests	Total forest area
Central	Local Government	PFM			
12 400 000	600 000	3 000 000	2 000 000	16 000 000	34 000 000

Table 2. Major forest vegetation types in Tanzania (MNRT 2006).

Vegetation type	Area ha	% of total forest area
Woodlands	32 544 000	95.72
Plantations	200 000	0.59
Mangrove	115 000	0.34
Others (montane forests, tropical rain forests, coastal forests)	1 141 000	3.36
Total	34 000 000	95.72

Woodland is by far the most dominant vegetation type in Tanzania occupying 95% of the entire forest area (Table 2). It is therefore logical to link the high rate of deforestation and degradation to be impacted on the woodlands because of its wide distribution in the country.

Reasons for deforestation and degradation are harvesting for woodfuel (charcoal and firewood) and timber, and land clearing for the expansion of agriculture. This paper looks into the potential of the woodland as main source of charcoal for Dar es Salaam city.

2 Charcoal production

Charcoal is a woodfuel produced in rural areas and consumed in cities and towns. Some of the factors influencing the choice of using charcoal instead of firewood in urban areas include (Kaale 2005):

- Charcoal has a higher calorific value per unit weight than firewood (about 31.8 MJ per kg of completely carbonized charcoal with about 5 percent moisture content as compared to about 16 MJ per kg of firewood with about 15 percent moisture content on dry basis).
- Due to its high calorific value per unit weight, it is more economic 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.

2.1 Major sources of charcoal for Dar es Salaam city

In Tanzania most of the charcoal is produced in dry woodlands. These range from the *Brachystegia – Julbernardia* (miombo) and *Acacia* to savanna woodlands. However observations in the Coast Region, Tanzania, revealed that farm land trees, mainly cashew nut and mango trees, and the mangroves are also used for charcoal production.

A recent study by WWF Tanzania (Malimbwi et al. 2007) showed that the amount of charcoal entering the city was 6 777 bags[1] of 56 kg each per day. Contrary to observations made by CHAPOSA (2002), the highest amount of charcoal is currently through Kilwa road, which accounts for the 50% of the total amount, followed by Morogoro road (24%). Formally the charcoal producing areas in the Kilwa route were limited to within 100 km. Since the completion of the Mkapa Bridge in early 2005 charcoal is coming from beyond that limit as far as Mtwara (565 km), Lindi (420 km) and Kilwa (210 km), almost doubling the amount of charcoal passing through Kilwa road since 2001. Other major charcoal entry routes to Dar es Salaam that were observed were Pugu/Nyerere, Bagamoyo and the Railway lines (Fig. 1).

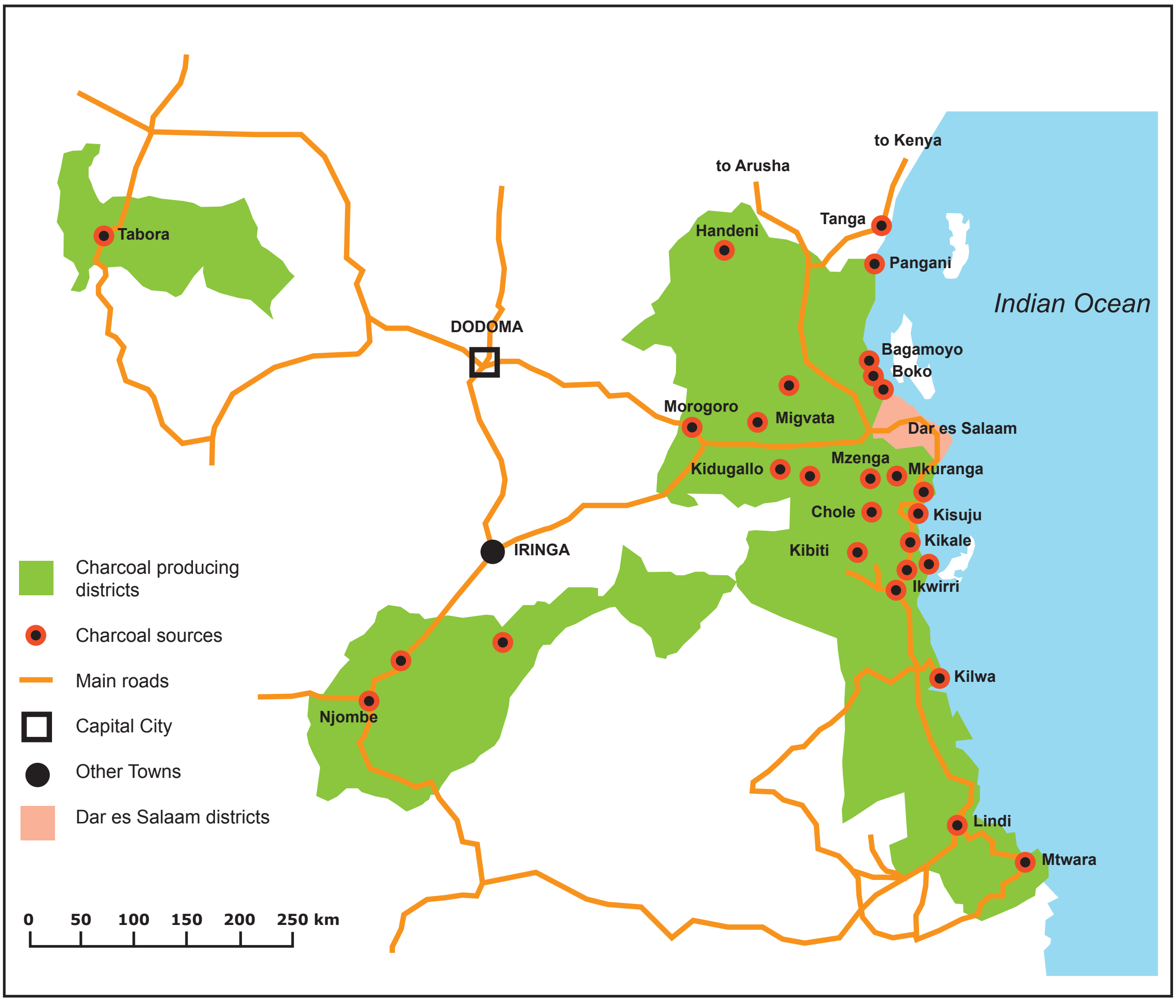

Figure 1. Charcoal sources for Dar es Salaam city.

[1]This is the amount recorded at check points. The actual amount of charcoal consumed per day in Dar es Salaam is more than 28 000 bags.

In the other routes charcoal comes from as far as Njombe in Iringa Region which is about 770 km, Handeni, 310 km (Tanga Region), and even some places of Tabora Region (1 050 km), using the railway. Previous studies indicated that charcoal production sites for Dar es Salaam city were located in Coast and Morogoro Regions and had changed from 50 km radius in 1970s' to about 200 km in the 1990s' (van Beukering et al. 2007). It is evident that the distance to charcoal sources is significantly increasing, signalling scarcity.

2.2 Charcoal producers

The economy of people in the charcoal producing areas largely depends on subsistence agriculture. There are three main charcoal producers in the charcoal market: full time, seasonal and occasional producers. Full time producers live within the forest areas and produce charcoal throughout the year, shifting to new areas when the sources become depleted. These are in most cases migrants to the charcoal producing areas. In one of the active charcoal making areas in eastern Tanzania (Gwata area in Morogoro Region) about 60% of charcoal makers are immigrants from other parts of the country (Zahabu 2001). Seasonal producers practice agriculture as their main occupation and produce charcoal only in off-farming period of the year. Occasional producers make charcoal to meet specific cash needs during the year (CHAPOSA 2002). This category includes those who make charcoal in the process of land clearing for agriculture.

In eastern Tanzania, annual household income of communities adjacent to the Morogoro – Dar es Salaam highway observed from 1992 to 2002 range from US$ 176–645 (Table 3). This indicates a growing dependence on charcoal for household income whereby about 75% of farmers in charcoal producing areas had charcoal as an important source of income.

Table 3. Household income from charcoal in Eastern Tanzania.

Year of study	Household income (US$ yr^{-1})	Source
1992	176	Monela et al. 1993
2000	445	Monela et al. 2000
2002	645	CHAPOSA 2002

This income from charcoal was also found to be above the minimum wage paid to most of the government and private sectors employees, hence attracting more people to engage in charcoal making. As already pointed out, migration to charcoal producing areas is a common phenomenon. Charcoal making requires neither formal education nor large capital investment although it is time consuming and labour intensive. In eastern Tanzania, 40% of the charcoal makers have no formal education (CHAPOSA 2002). The required labour is usually drawn from household members or other producers collaborating for specific tasks in the production process. While men carry out most of the masculine production activities such as tree felling, cross-cutting and kiln building, women participate in breaking the kiln after carbonization and in recovering and bagging the charcoal (CHAPOSA 2002). Manual tools such as axes, hoes and shovels are used. Given the low education level required, the income may be attractive for other people to join the business, and thus more deforestation to the woodlands.

2.3 Charcoal making process

Charcoal can be produced by a range of methods, from simple earth kilns to brick or metal kilns and retorts that capture condensable volatile compounds or combust them as gases, using the heat generated to drive the charcoal-making process. Charcoal is produced in kilns by a process called pyrolysis, i.e. breaking down the chemical structure of wood under high temperature in the absence of air. During the process, first the water is driven out from the wood (drying), and then the pyrolysis starts when the temperature in the kiln is high enough. When the pyrolysis is complete, the kiln gradually cools down, after which the charcoal can be removed from the kiln. Because some of the wood is burned to drive off the water, dry wood produces better charcoal at a higher efficiency. Typically, around two-third of the energy is lost in the process, but charcoal has advantages over firewood because of its higher efficiency and convenience in handling, storage and distribution (Hofstad 1995).

The oldest and still the most widely used method for charcoal production is the earth kiln. Two varieties exist, the earth pit kiln and the earth mound kiln. An earth pit kiln is constructed by first digging a small pit in the ground. Then the wood is placed in the pit and lit from the bottom, after which the pit is first covered with green leaves or metal sheets and then with earth to prevent complete burning of the wood. The earth mound kiln is built by covering arranged pile of wood on the ground with earth. The Tanzania Timber Harvesting Guidelines recommend charcoal producers to adopt the pit kiln, but generally the mound kiln is preferred over the pit where the soil is rocky, hard or shallow, or the water table is close to the surface. Also the mound requires less labour than the pit kiln. Mounds can also be built over a long period, by stacking gathered wood in position and allowing it to dry before covering and burning.

In most parts of Tanzania, charcoal is produced in earth mound kilns made by covering a pile of logs with earth, igniting the kiln and allowing carbonization under limited air supply (Monela et al. 1993, CHAPOSA 2002, Malimbwi et al. 2005). Typical earth mound kiln the dimensions differ depending on the amount of wood available around the kiln site (Fig. 2).

With this type of kiln, the process of charcoal making involves wood cutting, kiln construction, carbonization and finally unloading charcoal from the kiln. For a kiln with about 1.5 tons of charcoal, it takes an average of about 13, 10 and 14 days for woodcutting, kiln preparation and carbonization, respectively (Malimbwi et al. 2005). Unloading the charcoal takes an average of 4 days. During carbonization time the household may decide to prepare more kilns. As such a charcoal making household could have more than one kiln in a month. There are also some cases where a number of households may combine forces for the activities like wood cutting and kiln preparation. In such cases fewer days are spent and some more charcoal might be produced by a household.

There are no special months for charcoal making. However during the wet season, the seasonal charcoal makers devote most of their time in agriculture while the full time charcoal makers continue to make charcoal with easy availability of kiln construction materials, earth blocks and grass. During the wet season, earth blocks which are used to cover the kiln are more coherent and hence easy to handle and grass material becomes plenty and available. In the dry season, there is scarcity of grass material and the soil is too loose to produce the needed earth blocks.

Figure 2. Typical earth mound charcoal kiln under preparation at Gwata area, in Morogoro.

2.4 Suitable trees species for charcoal

As pointed earlier most of the charcoal is produced in dry woodlands that are in public lands with no or little harvesting control. This is because woodlands species produce heavier charcoal and with more concentrated fuel compared to fast growing softwood species and tropical rain forest species. However, not all woodland tree species are equally suitable for charcoal making. Tree species preference is based on the species property to produce charcoal with high recovery percent, high calorific value and which does not break easily during transportation (Monela et al. 1993, Nduwamungu 1996, Malimbwi et al. 2005).

In Eastern Tanzania most of the woodland species are preferred for charcoal making (Malimbwi et al. 2005) and they include; *Acacia* spp*, Julbernadia globiflora, Brachystegia* sp, *Lannea schimperi, Pseudolachnostylis maprouneifolia, Combretum* sp, *Mimusops kummel,* and *Tamarindus indica.* Few un-preferred tree species such as *Acacia polyacantha* sub. sp. *campylacantha, Sterculia africana* and *Adansonia digitata* are either with thorny stems making it difficult to handle or produce lighter charcoal of low calorific value. General observation, however, reveals that tree species selection for charcoal making is only done in areas with abundant trees. In areas where woodlands are already degraded and trees are in short supply, tree species selection for charcoaling is not done. This is also true during the opening up of new agricultural land where trees of all species found in the area are cut and made into charcoal. This constitutes a form of shifting cultivation that is widely spread in most of the woodland parts of Africa.

Whether there is species selection or not, valuable tree species for timber and carvings such as *Dalbergia melanoxylon, Pterocurpus angolensis* and *Afzelia quanzensis* are not exempted from charcoal making. These species are classified as 'reserved' trees which are theoretically nationally protected. In spite the fact that usually charcoal production is regarded as a secondary activity following harvesting for timber (Johnsen 1999), charcoal makers do not spare extraction of regenerating timber and carving species. This has the consequence of limiting availability of harvestable valuable timber species in charcoal production areas.

There is hardly any data on how much charcoal is collected from agroforestry home gardens in Tanzania. Observations in Coast region however indicates that farm land trees, mainly old cashew nut, mango and occasionally jack fruit trees are also used for charcoal production (Kaale 2005).

2.5 Kiln efficiencies

The Earth-Mound Kiln (EMK) is the most common method of making charcoal in sub-Saharan Africa with a conversion efficiency of 10–20% (Bailis 2003). Experience from CHAPOSA (2002) shows that kiln efficiencies in Tanzania ranged from 11 to 30%. In Zambia, the kiln efficiencies ranged from 20–28% while in Mozambique the range was 14–20%. These values are in line with those reported by Sawe and Meena (1994) and Hofstad (1995). In Tanzania, at an average of 19% kiln efficiency, 18 trees of 32 cm diameter at breast height (dbh) on average are used to produce 26 bags each weighing 56 kg of charcoal. That is 1 m^3 of wood yields 2.7 bags of about 56 kg of charcoal (CHAPOSA 2002).

According to Hofstad (1995) factors contributing to kiln efficiency variation are moisture content of wood involved in kiln preparation and its specific weight. Therefore tree species involved in kiln preparation contribute greatly to kiln efficiency variation. Lack of proper control during carbonization process is also reported to reduce efficiency due to some complete combustion of wood (Ishengoma and Nagoda 1991). It was noted from CHAPOSA (2002) that experienced specialized charcoal burners attain much more wood-charcoal production efficiency compared to seasonal burners.

There are currently two known improved kiln efficiency projects in Tanzania, the Half Orange Brick Kiln (Fig. 3) and the Improved Earth Mound Kiln (Fig. 4). The average carbonization efficiency of these improved technologies is estimated to be in between 27–35%.

The half orange brick kiln may not be the best option due to:
- high initial investment cost,
- the need to process the billets into specific sizes which is time consuming,
- the need to transport the billets to kiln site since the kiln is not moveable, and
- the need to continuously smear with mud on the outer surface to cover cracks; this may be a problem especially in most of the charcoal producing areas where water is not readily available.

Figure 3. Half Orange Kiln at Mazizi, Morogoro, Tanzania.

Figure 4. Improved Earth Mound Kiln at Ruvu Fuellwood Pilot Project, Coast Region, Tanzania.

Use of the Improved Earth Mound Kiln (IEMK) with better kiln management could be a better option. The IEMK is based on the traditional earth mound kiln modified by limiting air supply thereby controlling inlet air and limiting the exhaust air to a single chimney. With this type of kiln about 4 days are enough for the carbonization process to be completed which is an improvement from 10 days taken by the traditional earth kiln. The charcoal from these kilns are also said to be of high quality (Sago 2007, per. comm.).

2.6 Potential of the woodlands to produce charcoal

The potential for woodland to produce charcoal mainly hinges on the ability of the woody species to regenerate and grow.

Woodland regeneration

Woodland regeneration generally involves seed production, seedling development and vegetative regeneration. In absence of intense disturbance such as frequent late fires and overgrazing, the dominant trend in regenerating woodland is towards recovery to original state. Unless the trees have been thoroughly uprooted, most of the subsequent development of woodland will derive from re-growth of coppice from the surviving stems, stump/root sucker shoots and recruitment from old stunted seedlings already present in the grass layer at the time of tree cut, fall or death (Chidumayo 1993). Thus, one year after clearing a miombo woodland stand, the sapling population in re-growth may consist of one third coppiced stumps and two thirds seedlings recruited from the stunted seedling pool (Chidumayo 1997). Frost (1996) recognised four phases in regenerating woodland: (i) initial re-growth, just after sprouting and coppicing (most woody plants in the initial re-growth phase are less than 1 m tall), (ii) dense coppice, some two to five years after clear felling, (iii) tall sapling phase, starting from six to eight years after regeneration, and (iv) mature woodland.

Most seedlings and other tree regeneration (e.g. suckers and coppices) experience a prolonged period of successive annual die-back during their development phase. Their success to attain the canopy generally depends on their ability to survive fires and to exhibit rapid growth in years without grass fires. In general, fire and water-stress during the dry season are responsible for the annual shoot die-backs. This is probably why seedlings in miombo woodlands grow very slowly in height as they initially allocate more biomass to root growth. The underground parts of seedlings of many miombo trees grow faster than shoots during the establishment period (Chidumayo 1993). At least eight years may be needed for miombo woodland seedlings to reach the sapling phase.

After removal or death of the above ground parts of the trees, most woodland stumps produce many sucker shoots. However, during the establishment period the number of shoots would decrease as a result of inter-shoot competition and only dominant shoots contribute to the next generation of re-growth woodland. Sucker shoots grow relatively faster than shoots of stunted old seedlings. This is because stumps retain their well-developed root systems after tree cutting. However, stem height growth in re-growth woodland declines after 5–6 years and remains extremely slow thereafter (Chidumayo 1993, 1997).

Woodland productivity and charcoal yield

The stand density of woody plants in dry forests varies widely. For instance, in miombo woodland the stand density of woody species mostly ranges between 380 and 1400 stems ha^{-1} (Malaisse 1978, Nduwamungu 2001). In most miombo stands, the basal areas range from 7 to 25 $m^2\ ha^{-1}$ (Lowore et al. 1994, Nduwamungu 2001). Both stand basal area and mean biomass increase with increasing rainfall of a site (Frost 1996). Stand basal area is linearly related to both harvestable volume and aboveground woody biomass. In Tanzania, harvestable miombo woodland has the potential to produce 35 $m^3\ ha^{-1}$ (Malimbwi et al. 2005) whereas the mean harvestable volumes range between 14 $m^3\ ha^{-1}$ in dry miombo of Malawi (Lowore et al. 1994) and 117 $m^3\ ha^{-1}$ in Zambian wet miombo (Chidumayo 1988). Average aboveground biomass in old growth miombo woodland varies mostly from around 30 tons per ha to about 140 tons ha^{-1} (Malaisse 1978, Malimbwi et al. 1994) generally depending on the amount of annual rainfall and edaphic properties.

The annual increment of girth varies widely depending on species and site conditions. In an area protected from fire and human disturbances, the mean growth in girth range from 0.27 cm yr^{-1} (Grundy 1995) to 2.2 cm yr^{-1} (Chidumayo 1988). The mean annual volume increment (MAI) in mature miombo woodland ranges from 0.58 to 3 $m^3\ ha^{-1}yr^{-1}$ (Zahabu 2001, CHAPOSA 2002). The mean annual increment of biomass in coppice woodland range from 1.2 to 3.4 tons $ha^{-1}yr^{-1}$, which is about 4–7% of above ground biomass (Chidumayo 1993). In mature woodlands the mean annual biomass increment is estimated at 2–3% of the standing stock (CHAPOSA 2002).

2.7 Impact of charcoal production on forest resources

According to CHAPOSA (2002), charcoal production was responsible for degradation of 29 268 hectares (24.6%) of closed woodland and deforestation of 23 308 hectares (19.58%) of closed woodland and 92 761 hectares (50.8%) of open woodland in the catchment area to the west and north of Dar es Salaam that supplied charcoal to Dar es Salaam City. It has been noted that where there is bushland, most of it is regenerating from coppice, indicating that trees had been cut most probably for charcoal production.

A number of factors, however, play important role in influencing the trend of woodland development in the current and previous charcoal production areas. Woodland cut for charcoal production would normally regenerate by coppicing and recruitment from stunted saplings. Because of regeneration in areas previously cut, and if there is no further disturbance, such areas may revert to woodland, thus increasing the potential of the area to supply charcoal over a much longer time period. According to Hosier (1993) woodland appears to recover relatively well following harvesting for charcoal production. Human disturbances, such as grazing, frequent fires and extended cultivation periods may prolong the recovery period.

2.8 Management of the woodlands for sustainable charcoal production

For wood to be harvested sustainably from the woodlands, selective harvesting of trees with minimum dbh is recommended with careful attention paid to avoiding over-harvesting. Division of the forest into annual coupes will be necessary. Each year one annual coupe is selectively harvested thus allowing the remaining small trees to grow. By the time the last annual coupe is harvested the first coupe which was harvested in year one will have matured, ready for harvesting and hence the phenomenon repeats. The number of years passing before an annual coupe is revisited will depend on time required for the harvested annual coupe to re-mature, which will in turn determine the size of the annual coupe. Malimbwi et al. (2005) estimated the rotation period to be eight to 15 years for selective harvesting of trees with minimum dbh of 10 cm.

3 Charcoal trade

Charcoal is produced in rural areas and transported to urban areas by dealers/transporters who either buy charcoal from producers or hire labourers to produce their own charcoal. Usually trees used for charcoal production are obtained free of charge from the general land woodlands in charcoal producing areas. In urban areas, charcoal dealers sell their charcoal either to charcoal vendors or directly to consumers who buy charcoal in large quantities. Charcoal vendors who are spread all over the urban areas then sell the charcoal to final consumers usually in small quantities.

3.1 Charcoal transporters

Charcoal transporters are officially categorised at checkpoints mainly in two groups: the commercial dealers who include the cyclists and those who use vehicles to transport more than 10 bags; and non-commercial transporters who use vehicles to transport less than 10 bags for private uses. Of the estimated amount of 6 777 bags of charcoal entering Dar es Salaam City every day, 84% were transported by commercial vehicles, 11% by bicycles and only 5% by non-commercial vehicles (Table 4). Although vehicles transport most of the charcoal, transportation by bicycles employs the largest number of people (Table 4).

Table 4. Number of people engaged in charcoal transportation to Dar es Salaam city per day by vehicle type.

	Commercial Vehicles	Bicycles	Non-commercial	Total
Kilwa road	54	102	93	249
Morogoro road	22	54	40	116
Pugu road	14	125	3	142
Bagamoyo	2	33	4	39
Total	92	314	140	546
Percentage (%)	17	58	26	100

Truck transporters

These dealers use open trucks to transport their charcoal (Fig. 5). About 73% of respondents use lorries of more than 2 tons that carry 55 to 80 bags of 56 kgs Transportation of natural resources including charcoal is only allowed during day time between 6:00 am to 6:00 pm. Most of the charcoal passes through checkpoints very early in the morning between 6:00 to 6:59 am and late in the evening between 5:00 and 6:00 pm (Fig. 6). This is because most of the vehicles used are more than 10 years old (79%), and as such drivers tend to avoid traffic police.

To start the business as a charcoal dealer, one needs to apply for charcoal transportation license which costs TShs 55 000 including an application fees of TShs 5 000. The charcoal dealer then goes direct to the producer, enters into an agreement on the amount of charcoal required and pays in advance. Sometimes the transporters can also produce their own charcoal through hired labour.

Figure 5. Typical vehicles transporting charcoal to Dar es Salaam.

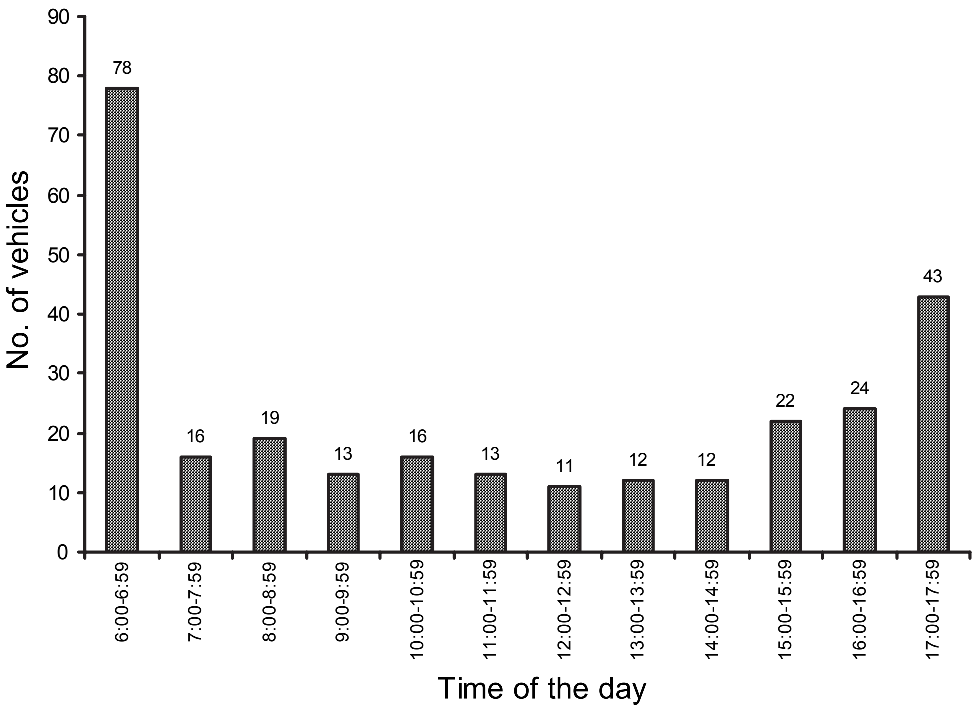

Figure 6. Current observed number of commercial vehicles passing through checkpoints at different times of the day.

Table 5. Average prices of charcoal at production sites for the past four years.

Year	Price per bag (Tshs)	
	Wet season	Dry season
2004	3000	2500
2005	4000	3500
2006	6000	4000
2007	8000	*

*Data not available as the study was carried out during rain season

For the past four years the average prices of charcoal at production sites have increased considerably (Table 5).

Other major costs in the charcoal transportation business are:
- tax paid to the Central Government (TShs 1 200 per bag of 56 kg),
- tax paid to the District Council (TShs 200 to 400 per bag),
- tax paid to the Village Government (TShs 100 to 400 per bag), and
- transporting the charcoal (TShs 4 000 to 6 000 per bag).

These costs in charcoal transportation differ depending on distances. There is no fixed tax charged for a bag of charcoal, therefore the taxes vary between District Councils and between Village Governments.

On average dealers using small lorries of less then 2 tons get a profit of about TShs 1 500 per bag while those who use lorries greater than 2 tons earn TShs 3 000 per bag. This is probably due to scale of economies when one uses a larger vehicle while the fixed costs are the same. It was also observed that there is increase in profit following the government ban of charcoal transportation in January 2006 (van Beukering 2007) which created shortage of charcoal in most of the urban areas and hence resulting in price increase.

Charcoal transporters encounter the following constraints:
- vehicle breakdown due to poor road conditions and use of old vehicles hence high maintenance costs,
- high taxes,
- corruption at traffic police checkpoints where the transporters claim to bribe up to TShs 30 000 per trip otherwise the truck is declared defective, and
- frequent changes in charcoal business regulations.

Bicycle transporters

Bicycle is also an important means of charcoal transportation into the city of Dar es Salaam. Although bicycles carry fewer bags than vehicles, they employ highest number of people (58%) (Table 4). This indicates that most charcoal transporters are low income class. They operate within a radius of up to 60 km from the city. Lack of alternative employment is the main drive for their engagement in charcoal transportation. Most of them (60%) are residents of production areas and the rest (40%) are from the city. Based on 2007 data, normally they buy charcoal from producers at a price range of TShs 9 000 to 13 000 per bicycle load and sell in the city at a price of between TShs 20 000 and 23 000.

The bicycle loads vary considerably in their weight, packing and size depending on the nature of the charcoal. For example, charcoal from Pugu and Morogoro roads is heavy (up to 140 kgs) compared to charcoal from other routes because it comes from natural woodlands. Cyclists in these routes have adopted a way of balancing the weight by putting two bags on opposite sides of the bicycle and a third on top of the two bags (Fig. 7a). Charcoal from Bagamoyo and Kilwa roads is usually lighter (up to 60 kgs) as it is made from cashew nuts and mango trees, therefore cyclists are able to carry large bags without a need of strategically balancing the weight while transporting (Fig. 7b and c).

(a) Pugu road

(b) Bagamoyo road

(c) Kilwa road

Figure 7. Charcoal bicycle loads captured at different routes.

Cyclists usually transport charcoal every other day during the morning and evening hours to avoid the hot sun during the day. They are required to pay tax of TShs 1 200 for a bag of 56 kg to the Central Government and TShs 400 to the District Council. As such the Pugu road cyclists pay a total of TShs 3 200 per bicycle load as it is considered as two bags while those of Bagamoyo, Kilwa and Morogoro are considered as a single bag. However, if actual weights were considered the Pugu bicycle load could have been considered as three bags while those of Bagamoyo, Kilwa and Morogoro roads as two bags. Cyclist who pass through checkpoints, strategically exceed the charcoal bag weights to evade tax otherwise most of them bypass the checkpoints. The profit realized range between TShs 3 000 to TShs 5 500 per bicycle load after paying for bicycle maintenance and all other running costs. Charcoal transporters who use bicycles claim that the business is difficult with high risk of road accidents. Also the distances to charcoal sources are ever increasing.

3.2 Charcoal vendors

Charcoal vendors are retailers who buy charcoal from transporters and sell it to end users. The average purchasing prices from the whole sellers over the last five years have increased with the highest rate of increase observed between 2006 and 2007 where the prices have almost doubled (Table 6). Similar observation was also made by van Beukering et al. (2007). This is because transportation of all forest products including charcoal was restricted following the government ban of January 2006. Although other costs associated with charcoal trading have also shot up, charcoal traders took advantage of the circumstances and retained higher prices even after the ban was lifted.

Table 6. Charcoal purchasing prices by vendors in Dar es Salaam city.

Year	Price range (TShs)	Average prices (TShs)	Change in price (TShs)
2007	19 000 to 25 000	22 000	9 000
2006	10 000 to 16 000	13 000	4 500
2005	8 000 to 9 000	8 500	3 000
2004	5 000 to 6 000	5 500	2 000
2003	3 000 to 4 000	3 500	

Charcoal vendors sell their charcoal in small measures of empty paint tins (kopo), buckets (sado) and small sacks (viroba). From a bag of charcoal they get 40 to 60 tins and 10 to 12 buckets. Based on 2007 prices, a tin is sold at about TShs 600 while a bucket is sold at TShs 1 750. On average charcoal vendors get about TShs 30 000 from a bag with a profit margins of about TShs 8 000 per bag. To increase profit margin the vendors normally manipulate, sizes and shapes of tins, buckets and bags while packing. Most of the tins and buckets used are deformed (Fig. 8). This manipulation is also done by producers and transporters of charcoal and the final burden goes to consumers. Large scale vendors have to pay for municipal permit, site construction, security and salaries for one to two employees while small scale charcoal vendors who sell charcoal at their home premises usually have less running cost.

Figure 8. Some measures used for charcoal vending.

3.3 Transportation of charcoal to Zanzibar

About 70% of charcoal used in Zanzibar comes from the Mainland. According to 2007 survey, the total amount of charcoal transported to Zanzibar daily is 10,500 bags out of which 7 500 bags enters the island illegally. Most important of the charcoal sources to Zanzibar are Tanga Region (Pangani District), Coast Region (Bagamoyo), Dar es Salaam (Mbweni, Bunju), Lindi and Mtwara. Charcoal from these sources is transported to Zanzibar through un-official ports that are out of reach of the taxation system making charcoal rather cheap. The distance to Zanzibar is only around 50 km from most of the unofficial ports, transporters charges are very low compared to road transportation to urban areas such as Dar es Salaam or Tanga. This is justified by the means of transport used i.e. by dhows which use no fuel. Charcoal dealers transport charcoal using dhows to Zanzibar because relatively small capital is needed compared to road transport to urban centres in the mainland where by one is also required to acquire the necessary permits.

3.4 Current charcoal consumption in Dar es Salaam

Low income households have a tendency of buying charcoal on retail scale (tin) on daily basis while those from high income tend to buy larger amounts (at least a bag) which stay longer (Malimbwi et al. 2007). On average a household uses a tin of about 1 kg of charcoal sold at TShs 600 to prepare one hot meal, 2 times a day. This is equivalent to a bag of charcoal per month since a bag has 40–60 tins. Therefore a household on average spends TShs 1 200 per day for charcoal alone. This makes an average of TShs 36 000 per month. On the other hand, the high income class also uses one bag of charcoal per month bought at about TShs 22 000. Households from high income levels who use charcoal as a major cooking energy therefore spend less money compared to those from low income class. This is contrary to what was reported by van Beukering et al. (2007), who argue that low income class buy charcoal more cheaply than the high income group. Various mechanisms have been deployed to reduce the quantity of charcoal consumed per day, these include:
- use of improved stoves
- combining charcoal with other types of energy
- cooking food that consumes less energy and
- improving kitchen management e.g. putting off charcoal after use.

It is estimated that charcoal is consumed by 94% of the households either alone or mixed with other fuels. Only 6% of the households do not use charcoal. About 78% of households in Dar es Salaam city use charcoal as their first choice energy source (Table 7).

Table 7. Household fuel preferences for 1991/92, 2000/01 and 2007.

Type of fuel	Percentage preference		
	1991/92	2000/01	2007
Charcoal	51	69	78
Kerosene	28	25	13
Electricity	15	4	5
Firewood	1	2	4

Source: CHAPOSA (2002) and field study done in 2007

There is energy declining shift for kerosene by 12% between 2001 and 2007. At the same period users of charcoal as a primary source of energy have increased from 69% to 78%. While the percentage of electricity users as a first choice source of energy has remained constant, users of firewood have increased from 2 to 4%. (Table 7). These energy shifts indicate an increase in biofuel consumption in the city of Dar es Salaam.

Assuming the current population of Dar es Salaam of 3 million people and average household size of 4.2, the total number of households is 714 286. The percentage of household using charcoal as their primary source of energy being 78%, the corresponding number of households using charcoal is therefore 521 429. Assuming also that two hot meals are prepared per day and that a bag of 56 kgs has 50 tins, 22 526 bags are consumed daily by households using charcoal as their primary source of energy in Dar es Salaam.

Apart from the households, charcoal is also the major source of energy for various organizations. Quantity of charcoal consumed per day depends on the number of persons served and the level of energy mix. Table 8 shows the amount of charcoal used by various organizations to prepare one hot meal.

Table 8. Amount of charcoal used by various organizations to prepare one hot meal.

Organization	Amount of charcoal used to prepare one hot meal
Hotels, bars and small scale food vendors	3 bags for 1 000 persons
Schools	1 bag for 150 students
Hospitals	1 bag for 200 patients
Army camps	2 bags for 1 000 army staff*

*Most army camps use firewood

However, there is high variation in terms of the total amount of charcoal consumed by these organizations, especially hotels, bars and small scale food vendors because most of them are informal/not registered and hence difficulty to track and quantify the amount they use. The charcoal consumed by organizations was therefore estimated having considering these limitations.

- Assuming that two persons from each household (714 286) get one hot meal from a hotel, bar and small scale food vendor a day and 3 bags of charcoal prepare one hot meal for 1 000 people, 4 200 bags of charcoal are consumed per day by these organizations in Dar es Salaam.
- The number of school going students in Dar es Salaam is about 300 000. These get one hot meal outside their homes prepared using a bag of charcoal for 150 students. The total amount of charcoal consumed by schools is therefore estimated to be 2 000 bags per day.
- The amount of charcoal consumed in hospitals is estimated to be only 25 bags per day. This was derived from the assumption that there are 5000 beds in hospitals in the Dar es Salaam city.
- Most of the army camps in the city use firewood for cooking. However, charcoal is sometimes used as an alternative energy source. The total amount estimated to be consumed is 8 bags per day.

Based on the above analysis, the current total daily charcoal consumption in Dar es Salaam is estimated at 28 759 bags of 56 kg (Table 9). CHAPOSA 2002 estimated 24 576 bags while van Beukering et al. (2007) estimated 24 951 bags which assume constant consumption since 2002. Due to population increase and the increase on the percentage of households using charcoal as the first choice fuel, the current estimates (Malimbwi et al. 2007) seem to be realistic despite the crude estimation especially of the consumption by organizations. A larger sample survey of households and organizations would probably give a more reliable estimate.

Table 9. Total amount of charcoal consumed in Dar es Salaam daily.

Organization	Amount of charcoal (bags of 56 kg/day)		
	This study (2007)	CHAPOSA (2002)	van Beukaring et al. (2007)*
Households	22 526	18 158	
Hotels, bars and food vendors	4 200	8 047	
Schools	2 000	8	
Hospitals	25	2	
Army	8		
Total	28 759	24 576	24 951

*Based on 2005 estimation of 17 million bags of 30 kg per year

The second major energy source for cooking in the city of Dar es Salaam is kerosene that 13% of the household use it as their first choice (Malimbwi et al. 2007). According to the respondents, preference to use kerosene is due to its efficiency compared to charcoal, which takes longer to lighten and sometimes one is forced to use kerosene to lighten it. When compared to previous studies, the general trend shows that percentage of households using kerosene is declining (Table 7) indicating a shift of energy use from kerosene to charcoal. The major reason for the reduction on the quantity of kerosene consumption is price increase for the past five years. Although the government removed Value Added Tax (VAT) on kerosene during the 2006/7 budget, the price of kerosene remained high and therefore failing to serve the purpose of encouraging more use of kerosene for charcoal (Table 10).

Table 10. Tanzania Kerosene tariffs (2000–2007).

Price + 28% VAT (Tshs)/Litre	Years							
	2000	2001	2002	2003	2004	2005	2006	2007
Minimum	470	480	489	498	583	828	830	880
Maximum	495	497	506	551	775	964	1100	1000
Average	482	489	498	524	679	896	965	940

Source: Mbwambo et al.(2005) and Malimbwi et al. (2007)

Electricity is another energy type used by 5% of households in the city of Dar es Salaam as a major source of cooking energy. The percentage of households using electricity has not increased since 2001 (Table 7). Reasons given by various households for not using electricity include: increased tariffs (Table 11) and unreliability of electricity due to power rationing in the dry seasons in the country.

Table 11. TANESCO electricity tariffs from year 2000–2007.

Tariff category	2000–2003		2004		2005		2006		2007	
	0–100 kWh	101–500 kWh	0–50 kWh	> 50 kWh	0-50 kWh	> 50 kWh	0-50 kWh	> 50 kWh	0–50 kWh	> 50 kWh
Low usage domestic (TShs)	24.00	-	30.00	-	38.00	-	38	-	40	-
High usage domestic (TShs)	-	38.75	-	115.00	-	115.00		121		126

Source: TANESCO HQ in Mbwambo et al. (2005), Malimbwi et al. (2007)

Most of the households (71%) combine more than one type of fuel such as charcoal, firewood, kerosene, electricity and gas (Malimbwi et al. 2007). Charcoal is the most combined fuel since 94% of the households use charcoal in one way or another.

According to CHAPOSA (2002) most of the households (88%) combine two or more types of fuels. There is therefore a decline in number of households that combine fuels compared to the 88% reported by CHAPOSA (2002). This suggests that there is more reliance on few energy sources mostly charcoal compared to other fuels.

Gas and other energy sources such as coal briquette are used at a very low rate in the city. Usually gas is combined with other energy sources such as electricity and charcoal. Only 3% of the households use gas. There is also emerging group of few households from medium income class that use oryx gas cookers. The low adoption of use of gas for cooking is attributed to:

- Low awareness: Users still have the mentality that gas is very risky and if not properly handled can explode. However, gas cookers have now been improved and explosion controlled.
- Price of appliance is also high for low income households forcing them not to opt for gas.

3.5 Supply and demand linkages

The demand for charcoal has increased due to increase in the number of households using charcoal as their first choice fuel from 69% observed in 2002 to 73% in 2007. The number of households who use charcoal is also very high (94%) indicating high demand for charcoal owing to the fact that population growth for Dar es Salaam city is estimated at about 6% (National Bureau of Statistics 2002). In 2006 the Ministry of Natural Resources and Tourism temporarily banned harvesting of forests for charcoal production. This reduced the amount of charcoal supply and hence increased demand and the price on the consumer side. At the supply side the price also rose since the producers were risking making charcoal illegally. When the ban was lifted the prices remained high because distances to charcoal sources as well as cost of transportation have increased. Forests that were previously found in the outskirts of the city have been depleted forcing traders to fetch charcoal far from Dar es Salaam.

The current total charcoal consumption in Dar es Salaam is about 28 759 bags of 56 kg of charcoal per day. This figure is about five times higher than that observed at the checkpoints meaning that only one fith of the charcoal that goes into the city is taxed. The same observation was also made by CHAPOSA (2002). This suggests that the incentive to evade check points is extremely strong, and that, in fact, most of the charcoal is unaccounted for in the check points. As a result the government loses more than 38 million shillings per day as shown in Table 12. The illegal charcoal usually passes the checkpoints at night or in closed vehicles. There is also a possibility of bypassing check points especially by cyclists. Laxity and probably corruption at the checkpoints may also be other reasons. Most of the check points have no space for inspection and storage of impounded products. Also they are in most cases not conspicuous making it difficult to be identified by new dealers. These problems could be minimized by

- strengthening the checkpoints including furnishing them with proper offices, signboards and communication facilities,
- strengthening patrol crews and providing them with reliable transport,
- install checkpoints in the railway system,
- certification of charcoal to ensure sustainable production at the sources, and
- effective accountability to ensure taxes are paid at all levels.

Table 12. Daily amount of tax collected against evaded at checkpoints.

Tax admin authority	Amount of tax per bag of charcoal	Expected total tax (TShs)	Amount of tax collected (TShs)	Evaded tax (TShs)
Central Government	1 200	34 510 800	8 132 400	26 378 400
District Councils	300	8 627 700	2 033 100	6 594 600
Village Governments	250	7 189 750	1 694 250	5 495 500
Total	1750	50 328 250	11 859 750	38 468 500

With a kiln conversion efficiency of 19%, about 3 million tons of wood are required annually to produce the 28 759 bags consumed every day in the city. This is equivalent to about 3.6 million m^3 of wood at a weight/volume ratio of 0.85 (Malimbwi et al. 1994). Ishengoma and Ngaga (2001) estimated the annual wood volume required to produce charcoal for Dar es Salaam to be 1.9 million m^3/year while CHAPOSA (2002) estimated 2.3 million m^3/year. The difference may be due to different assumptions of several parameters, but suggests that the order of magnitude is realistic and more volume for charcoal is needed for Dar es Salaam. At a mean annual increment of about 2.4 $m^3\ ha^{-1}yr^{-1}$ (Malimbwi et al. 2005) it would take the growth of 1.5 million hectares to produce the wood needed annually.

Considering that harvestable miombo woodland has the potential to produce 35 $m^3\ ha^{-1}$ (Malimbwi et al. 2005), it would require 104,000 ha of miombo to be harvested annually for the provision of charcoal to Dar es Salaam. The only other sources of charcoal for Dar es Salaam apart from miombo are the agroforestry systems around the city which supply 204 bags and the wattle plantations in Njombe (160 bags), making a total of 364 bags. These are equivalent to 39 159 tons or 46 069 m^3/yr, of which 25 819 m^3 are from cashew nut and mango trees. Assuming a large cashew nut or mango tree has 6 m^3 of wood, 4 303 trees would be cut annually for charcoal production. Obviously this has consequence on the environment and livelihood of the people as cutting the trees deprives them with regular income from sales of fruits. Non-the-less the charcoal from the wattle and agroforestry systems save 1 316 ha of miombo deforestation yearly so that only 102 684 ha would be cut annually. This indicates that agroforestry systems and plantations have a potential to reduce the rate of deforestation due to charcoal production.

3.6 Efficiency of charcoal stoves

Traditional charcoal stoves are made from un-insulated metal moulded and welded into a circular or rectangular shape. It has a perforated metal plate in the middle on which the charcoal is put and an ash collecting tray at the bottom. The thermal efficiency of these charcoal stoves in Tanzania is reported to range between 12% and 15% (MEM 1998), hence inefficient since most of the heat is lost throughout the surface of the stove. The improved stoves technology is built on these traditional stoves by adding an insulating clay lining inside the metal case in order to reduce the heat loss. As such improved stoves retain the heat much longer with relatively less charcoal used. Stoves which have double liner (clay and metal) enforcement attain up to 70% efficiency (TaTEDO 2007).

In Dar es Salaam city, the number of households using charcoal efficient stoves has increased from 49% (CHAPOSA 2002) to 72% in 2007 while only 20% of the organizations use efficient stoves (Malimbwi et al. 2007). Availability of these stoves has largely contributed to the increase in number of users.

However, most of the improved charcoal stoves currently in use have low durability. Some groups that manufacture these stoves also admitted making less durable stoves (12–18 months life span) purposely done in order to get regular customers. A well prepared efficient stove has a life span of 3 years at a cost of around TShs 4 000–50 000 depending on size and design whereas the traditional ones range between TShs 1 500–18 000.

3.7 The potential of Dar es Salaam charcoal efficiency production and use for carbon trading

From the above observations it is obvious that the demand for charcoal is increasing at the expence of the environment. An attempt was made to try to utilize the carbon trade opportunity to attract the adoption of efficiency technologies to reduce charcoal consumption.

Carbon credits are saleable certificates earned through the reduction of carbon dioxide emissions. It is possible to earn carbon credits through production and use of charcoal in a sustainable and efficient way. This is essentially from the reductions in carbon emissions resulting from the amount of wood that is reduced when charcoal is produced or used in efficient ways.

The current charcoal production attains a wood-charcoal efficiency of 19% and this can be improved through the use of improved kilns to about 27 to 35%. The amount of wood used to produce charcoal for Dar es Salaam at present is about 3 million tons just improving the efficiency to an average of 30% will reduce this amount of wood needed to produce the same amount of charcoal 1.9 million tons (Table 13). This reduction is equivalent to about 1 207 728 tons of CO_2. At the selling price of $ 5 per ton of CO_2, this is equivalent to about UD$ 6 million.

From the consumption side, the use of un-improved stoves attains only 15% efficiency. This can be improved up to 70% efficiency by the use of improved stoves. Taking an average of 40% efficiency will result to a reduction of the wood for the charcoal making from about 3.8 to 1.4 million tons (Table 14). This reduction is equivalent to the avoidance of carbon dioxide emission of 2.6 million tons CO_2 which is estimated to sell at about $ 13 million.

Table 13. Estimation of carbon trading potential of the improved charcoal production efficiency for Dar es Salaam city.

Bags per day	Kiln efficiency (%)	Equivalent green wood weight (tons/yr)	Equivalent green volume m^3	Biomass (0.5 green volume)	Carbon (tons/yr)	CO_2 emissions (tons/yr)
28759	19	3 051 481	3 589 978	1 794 989	897 494	3 293 805
28759	30	1 932 605	2 273 653	1 136 826	568 413	2 086 076

Table 14. Estimation of carbon trading potential of the improved charcoal consumption efficiency for the Dar es Salaam city.

Bags per day	Stove efficiency (%)	Equivalent green wood weight (tons/yr)	Equivalent green volume m^3	Biomass (1/2 green volume)	Carbon (tons/yr)	CO_2 emissions (tons/yr)
28759	15	3 865 210	4 547 305	2 273 653	1 136 826	4 172 153
28759	40	1 449 454	1 705 240	852 620	426 310	1 564 557

There is a much more potential for efficient charcoal projects for Dar es Salaam due to the growing market for CO_2. The $ 5 used here as selling price is a bit far less a price since as of June 2008 on the European Climate Exchange, the price of Certified Emissions Reductions (CERs) issued under the Kyoto Protocol's CDM was at € 20 (equivalent to $ 31) per tons of CO_2.

Recommendations

From the afore text recommendations can be made which aim to produce charcoal sustainably while reducing emissions:

- Implement sustainable harvesting for charcoal by introducing selective felling in annual coupes
- Promote agroforestry and plantations as sources of charcoal to reduce pressure in woodlands
- Promote adoption of efficiency projects and initiated a mechanism to explore the possibility of carbon trading from the efficiency projects.

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