Transforming Tanzania's Charcoal Sector

Life Cycle Assessment Component

Prepared for: **SDC**

Prepared by: **Quantis**

Simon Gmünder

Rainer Zah

Jürgen Rainhard

François Charron-Doucet

February 10, 2014

Quantis is a leading life cycle assessment (LCA) consulting firm specialized in supporting companies to measure, understand and manage the environmental impacts of their products, services and operations. Quantis is a global company with offices in the United States, Canada, Switzerland and France and employs close to 70 people, amongst which several are internationally renowned experts in the LCA field.

Quantis offers cutting-edge services in environmental footprinting (multiple indicators including carbon and water), eco design, sustainable supply chains and environmental communication. Quantis also provides innovative LCA software, Quantis SUITE 2.0, which enables organizations to evaluate, analyze and manage their environmental footprint with ease. Fuelled by its close ties with the scientific community and its strategic research collaborations, Quantis has a strong track record in applying its knowledge and expertise to accompany clients in transforming LCA results into decisions and action plans. More information can be found at www.quantis-intl.com.

This report has been prepared by the Zurich office of Quantis. Please direct all questions regarding this report to Quantis Zurich.

Quantis Switzerland/Germany

glaTec Technology Center

Überlandstrasse 129

8600 Dübendorf (Switzerland)

+41 445 52 08 39

info.schweiz@quantis-intl.com

www.quantis-intl.com

PROJECT INFORMATION	
Project title	Transforming Tanzania's Charcoal Sector - Life Cycle Assessment Component
Contracting organization	SDC
Liability statement	Information contained in this report has been compiled from and/or computed from sources believed to be credible. Application of the data is strictly at the discretion and the responsibility of the reader. Quantis is not liable for any loss or damage arising from the use of the information in this document.
Version	[Preliminary/**Draft**/Final] report
Project team	Simon Gmünder, Quantis (simon.gmuender@quantis-intl.com) Rainer Zah, Quantis (rainer.zah@quantis-intl.com) Jürgen Reinhard, Quantis (juergen.reinhard@quantis-intl.com) François Charron-Doucet, Quantis (francois.charron@quantis-intl.com)
Client contacts	Ueli Mauderli, SDC (ueli.mauderli@eda.admin.ch) Joel Aram Kalagho, SDC (joel.kalagho@eda.admin.ch)
External reviewer	Not reviewed externally

Executive Summary

TABLE OF CONTENT

Abbreviations and Acronyms (DRAFT)

AGB	Above Ground Biomass
AF	Allocation Factor
BGB	Below Ground Biomass
BEST	Biomass Energy Strategy Tanzania
CO_2	Carbon Dioxide
CDE	Centre for Development and Environment
CF	Characterization Factor
CDM	Clean development mechanism
DSM	Dar es Salaam
DOM	Dead Organic Matter
DFHC	District Forest Harvesting Committee
DFO	District Forest Office
DNRO	District Natural Resource Office
DoE	Division of Environment
eq	Equivalents
GWP	Global Warming Potential
GOT	Government Organization of Tanzania
GHG	Greenhouse gas
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LCIA	Life Cycle Impact Assessment
LCI	Life Cycle Inventory
LAFR	Local Authority Forest Reserves
MEM	Ministry of Energy and Mining
MFEA	Ministry of Finance and Economic Affairs
MLHSD	Ministry of Lands and Human Settlements Development (MLHSD)
MNRT	Ministry of Natural Resources and Tourism
MJUMITA	Mtandao wa Jamii wa Usimamizi wa Misitu Tanzania
NFR	National Forest Reserves
NLUPC	National Land Use Planning Commission
Pt	Point
PMO-RALG	Prime Minister's Office – Regional Administration and Local Government
REDD	Reducing Emissions from Deforestation and Degradation
RES	Renewable Energy Section (of MEM)
SOC	Soil Organic Carbon
SOM	Soil Organic Matter
SCP	Sustainable Charcoal Project
SDC	Swiss Agency for Development and Cooperation
TFCG	Tanzania Forest Conservation Group

TRA	Tanzania Revenue Authority
TaTEDO	Tanzania Traditional Energy Development Organization
TFF	Tanzanian Forest Fund
TFS	Tanzanian Forest Service
TTCS	Transforming Tanzania's Charcoal Sector
UNFCCC	United Nations Framework Convention on Climate Change
VPO-DoE	Vice President's Office, Division of Environment
VA	Village Assembly
VC	Village Council
VEO	Village Executive Officer
VLFR	Village land forest reserves
VLUMC	Village Land Use Planning Committee
VNRC	Village Natural Resource Committee
y	Year

PART I – INTRODUCTION

1 Introduction

1.1 Background and problem statement

Charcoal is the main energy source for the urban population in Tanzania. In 2009 about 1 million ton of charcoal is consumed every year (World Bank 2009). The energy source is perceived as reliable, inexpensive and accessible compared to alternative energy sources. Given the lack of affordability of other fuel types and the convenience of using charcoal, domestic consumers are increasingly switching to charcoal, especially in urban areas. Given the high urbanization rates in Tanzania, the consumption of charcoal will even increase in near future.

The charcoal business is characterized by low capital costs, little knowledge and experience requirements to enter business and by relatively high financial returns compared to other rural economic activities. The charcoal market works efficiently and the value of the entire Tanzania charcoal sector is valued at US$650 million. Consequently, the charcoal sector contributes significantly to rural employment and income generation.

The production of charcoal dominated by the “informal sector” in which small scale producers use traditional technologies to produce charcoal. In Tanzania mainly traditional earth kilns are used to produce charcoal from wood. The wood itself is extracted from natural forests, rather than from plantations, and the wood is very often illegally harvested. Even though wood is a renewable resource, the unregulated utilization of natural forest causes at least a temporal deforestation. If the land is used for agriculture after the clear-cutting, the land use is permanently changed, which causes severe environmental impacts.

Charcoal and commercial wood have become major sources of rural income and livelihoods, however, on the cost of the environment. Almost all stakeholders along the charcoal value chain agree that the current depletion of natural resources and environmental degradation is not sustainable and cannot be maintained forever. There are various approaches available to improve the sustainability of charcoal value chains, ranging from the sustainable forest management, improved charcoal kilns to efficient stoves. Currently, a wide range of measures towards a sustainable energy supply are tested as pilot projects. However, the socio-economic and environmental impacts of a more sustainable charcoal value chain are currently not fully understood.

1.2 SDC project: Transforming Tanzania's Charcoal Sector

The "Transforming Tanzania's Charcoal Sector (TTCS)" project - initiated and funded by the Swiss Agency for Development and Cooperation (SDC) – aims to "*deliver improved climate change adaptation and mitigation, enhanced environmental sustainability and leveraged returns on biomass resources, delivering sustainable development to Tanzania and its people. This will be achieved by supporting improvements in raising the efficiency and environmental sustainability of the charcoal industry and by launching a research-based knowledge management, communications and advocacy strategy to develop credible new policy and governance measures designed to enhance the role of biomass energy enterprise in poverty reduction and national development.*

The proposed project lifetime is six years with a budget of USD 7,101,782, comprising a two year inception and design phase and a four year period of expanded implementation."

The sustainable charcoal initiative is managed by Tanzania Forest Conservation Group (TFCG), in conjunction with Tanzania Community Forest Conservation Network (MJUMITA).

TFCG is a national non-governmental organization whose mission is to conserve and restore the biodiversity of globally important forests in Tanzania. Through TFCG's five programs: advocacy, participatory forest management, environmental education, community development and research, TFCG has succeeded in rolling out innovative and high-impact solutions to the challenges facing Tanzania's forests and the people that depend on them. www.tfcg.org

MJUMITA[1] is a national network of community groups involved in Participatory Forest Management (PFM) in Tanzania. The network provides a forum for capacity building, advocacy and communication for these groups. MJUMITA has operated since 2000 with support from TFCG but was officially registered as an independent NGO in 2007. www.mjumita.org

TFCG will co-opt expertise from Tanzania Traditional Energy Development Organization (TaTEDO) for the introduction of more efficient charcoal production. TaTEDO has more than twenty years of experience in sustainable energy development projects and programs in rural areas. www.tatedo.org

---

[1] Swahili 'Mtandao wa Jamii wa Usimamizi wa Misitu Tanzania'.

1.3 Goal of this study

The overall aim of the study is to assess different sustainability aspects of the improved charcoal value chain which is developed within the SDC project compared to the traditional value chain. The focus of this study is put on the assessment of the global warming potential, while the social and environmental impact assessment (SEIA) is conducted by the Center of Development and Environment (CDE)[2] in parallel.

The goal of this study is to prospectively assess the global warming potential of different charcoal value chains based on the life cycle assessment (LCA) methodology. Thereby, all processing steps of the current charcoal value chain (traditional) and various alternatives are analyzed, including the harvesting of the raw materials, processing, transport to the final use. The specific **objectives** are:

- To define in a participatory approach the charcoal systems to be compared, including forest management, charcoal kiln technologies, trading systems, transport systems, wholesale, retailing and the final use in specific stoves.
- To evaluate and compare the global warming potential (GWP) of different charcoal production systems and uses.
- To identify effective measures to mitigate the greenhouse gas (GHG) emissions of the traditional charcoal value chain.

The gained knowledge will help to further improve project structure and implementation – thus, to optimize the "sustainable charcoal value" chain before it is established. The progress and results will be reported to and discussed with the project partners and relevant stakeholders along the value chain. The knowledge gained from the comparison of different charcoal value chains (traditional versus different improvement options) can further be used for marketing purposes, as well as a knowledge basis for the formulation of national energy strategy and for policy decisions within the energy sector.

It has to be kept in mind that the assessment is prospective, meaning that not all expected impacts will be measurable during the period of the mandate.

---

[2] CDE is the University of Bern's centre for sustainable development research with the aim of fostering sustainable development-oriented research. www.cde.unibe.ch

PART II- METHODOLOGY

2 Life Cycle Assessment

A leading tool for assessing environmental performance is life cycle assessment (LCA), a method defined by the International Organization for Standardization (ISO) 14040-14044 standards (ISO 2006a; ISO 2006b). LCA is an internationally-recognized approach that evaluates the relative potential environmental and human health impacts of products and services throughout their life cycle, beginning with raw material extraction and including all aspects of transportation, production, use, and end-of-life treatment. Among other uses, LCA can identify opportunities to improve the environmental performance of products, inform decision-making, and support marketing, communication, and educational efforts.

A LCA generally contains four main phases which are displayed in Figure 1:

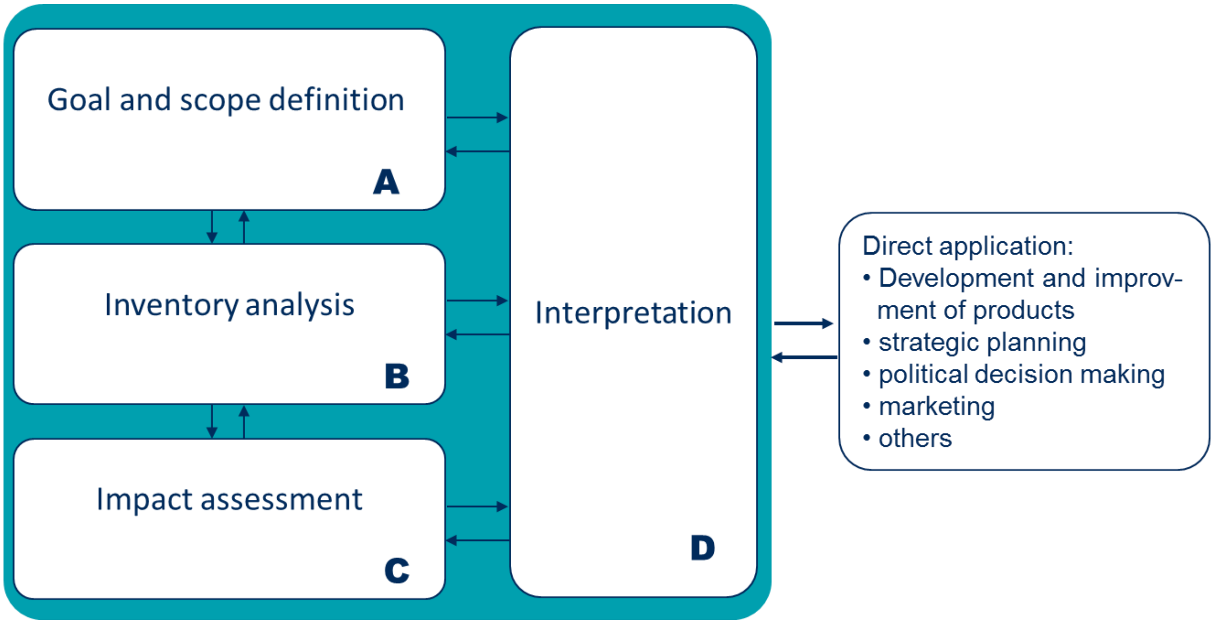


Figure 1: Four main phases of an LCA according to ISO 14040.

The **definition of goals and scope** is the first step of an LCA. In this step the outline of the study must be clearly defined. The final results of the study are only valid for the defined scope (see chapter 3) and goals (see chapter 1.3). The scope definition is done in line with the goal definition, meaning that the scope should be sufficiently well defined to ensure that the breadth, depth and detail of the study are compatible and sufficient to address the stated goal.

In the **life cycle inventory (LCI)** analysis the material and energy flows of the system processes are quantified (see chapter 4). By assessing all the inputs and outputs of the system, the exchanges - and thus the impacts – of the compared systems with the environment can be assessed.

Life cycle impact assessment (LCIA) methodologies aim to connect the flows of materials, energy, and emissions into and out of each product system (LCI results) to the corresponding environmental impacts (see chapter 5). According to ISO 14040, the LCIA proceeds through two mandatory (classification & characterization) and two optional steps (normalization & weighting) which are not applied within this study.

- *Classification:* all substances are assigned to the selected impact categories according to the ability to contribute to different environmental problems.
- *Characterization:* the impact from each emission is modelled quantitatively according to the underlying mechanism. The cause and effect mechanism is based on fate, exposure and effect models. The impact is expressed as an impact score in a unit which is common to all contributions within the impact category (e.g. kg CO2-equivalents for greenhouse gases contributing to the impact category climate change) by applying characterization factors (CF).
- *Normalization:* the quantified impact related to a common reference in order to facilitate comparisons across impact categories (e.g. the impacts caused of a European citizen during one year)
- *Weighting:* different value choices are given to the different environmental impact categories to generate a single score.

In **life cycle interpretation**, the results of the found during a life cycle assessment are appraised in order to answer questions posed in the goal definition. The interpretation relates to the intended applications of the LCI/LCA study and is used to develop recommendations.

3 Scope of the study

3.1 Study site description

The study site of the sustainable charcoal project is located in Kilosa District, which is part of the Morogoro region. Kilosa is located approximately 300 km inland from the coast, along one of the old East African caravan routes stretching from Bagamoyo to the eastern part of Democratic Republic of Congo. The district has a size of 14,245 km^2 and counts almost 500,000 inhabitants according to the 2002 census.

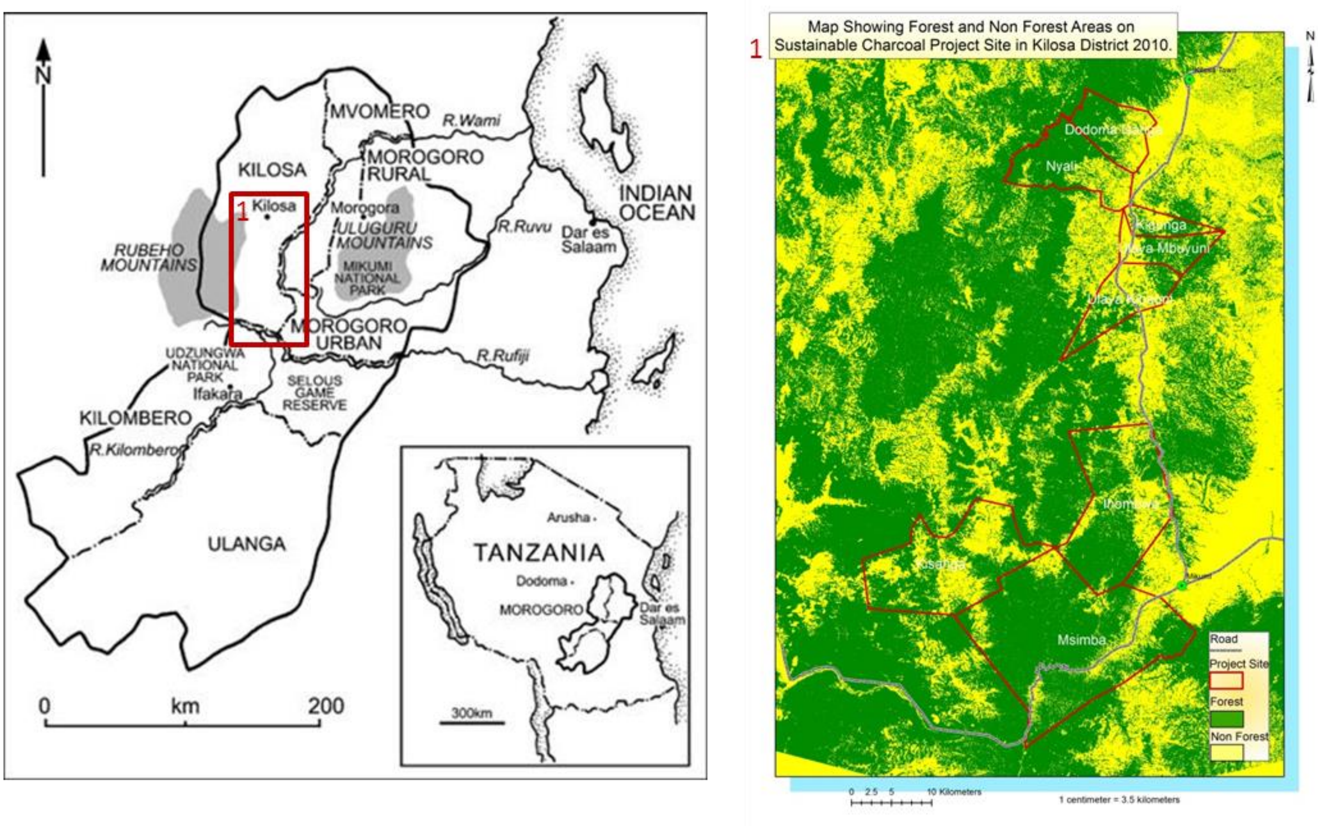


Figure 2: Map of study site. Location of the Kilosa district (left, soruce: (Paavola 2008)*) and the villages under study (right, source: TFCG).*

Kilosa district comprises mostly flat lowland that covers the whole of the eastern part called Mkata Plains. The vegetation in Kilosa District is characterised by Miombo woodland, with grass and shrub covering the soils. Most of the forests are found in the western part of the district along the Eastern Arc mountain range, more specifically around the Rubeho Mountains. The Eastern Arc mountain range has several unique ecosystems with a large variety of species. (Kajembe et al. 2013)

The rainfall starts in October and lasts for about eight months, with the highest levels between March and April (see Figure 3). The rainfall distribution is bimodal in good years, with short rains (October–January), followed by long rains (March –May). The mean annual rainfall ranges between 800 and 1,400 mm. The mean annual temperature in Kilosa is about 25°C.

What is the precipitation in the study site? (Precipitation data specific for the study site are not available; the annual rainfall ranges from 600mm in low lands to 1200mm in the highland plateau. However, there are areas which experience exceptional droughts (with less than 600mm of rainfall and these areas are in Gairo and Mamboya divisions in the North of Kilosa District and

Ngerengere Division in the East of Morogoro Rural District) Source; Morogoro Social Economic Profile.

The main economic activity in the surveyed villages is agriculture, whereby majority of the population in the area depend on agriculture for their livelihood. Farming is noticeably more significant to people's livelihood in the project villages than any other livelihood activity followed by animal husbandry. Major crops grown in the area include maize, banana, cassava, sesame and rice. Majority of the farmers are not harvesting enough to feed their families all year round, in that situation they have to look for alternative source of income of which charcoal is the most common in the area. Apart from agriculture and livestock keeping, other economic activities in the area include casual employment and business (shops, transport, charcoal, etc).

More than 80 per cent of the people in Kilosa depend on agriculture. More than 90 per cent of the agriculture is small scale subsistence farming, while only a few large-scale plantations exist. The agricultural season generally starts before the short rain in September/October with the field preparation and subsequently with planting, weeding and finally with harvesting of crops. Just before the heavy rain in March, crops are planted for a second harvesting between June and August. A variety of crops are grown, including maize, rice, millet, cassava, beans, bananas and cowpeas[3].

Charcoal production was the second economic activity after agriculture. Mainly small scale farmers are involved in charcoal production to generate additional income. Charcoal is produced all year round, but the main production season is after the harvesting of the crops in the dry season. Depending on the financial situation of the farmer, also in the rainy season some charcoal is produced.

---

[3] A more complete list is provided in (Kajembe et al. 2013; Norrlund & Brus 2004).

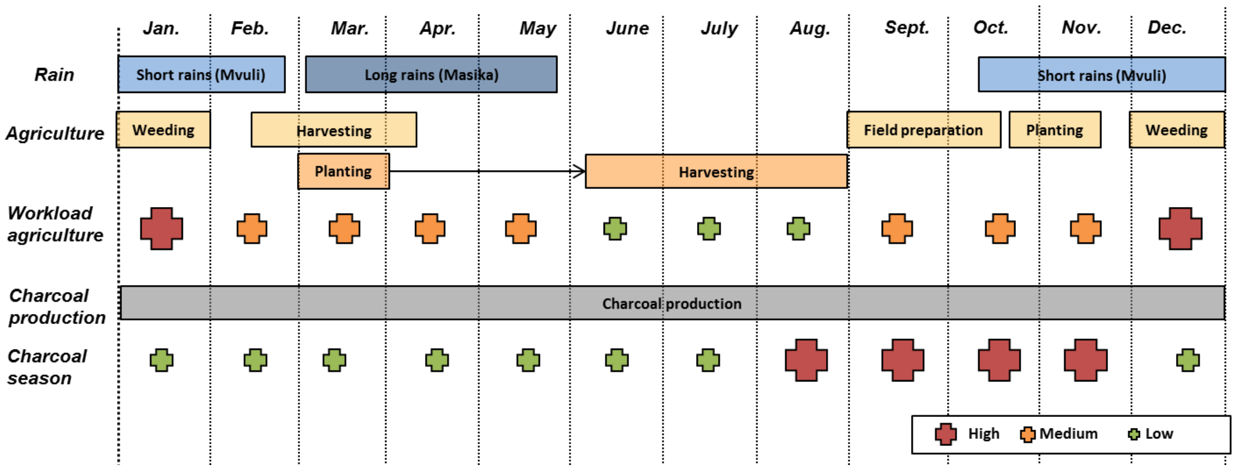


Figure 3: Typical agricultural calendar of a village in Kilosa district (based on field study in Nyali, 2012). The workload for agriculture and charcoal production is indicated by different colors.

The sustainable charcoal project operates in Kilosa district, where TFCG has been supporting a community oriented REDD+[4] project since 2009. The sustainable charcoal project works with 4 villages within the REDD project area and 4 villages in the leakage belt to integrate sustainable charcoal production into the community based forest management process. The sustainability assessment is conducted for 6 villages, including three REDD villages (Msimba, Dodoma Isanga and Nyali) and three adjacent villages in the 'REDD leakage belt' (Ihombwe, Kigunga and Ulaya-mbuyuni). An overview about the main characteristics of the villages under study is provided in Table 1 and the locations are indicated in the map of Figure 2. The data on forest management, charcoal production and transportation is based on field data from the selected villages (TFCG, 2103).

Table 1: Overview about some key characteristics of the selected villages. REDD+ villages are market with an asterisk.

Village name	**Area [ha]**	**Population**	**Estimated amount of charcoal producers**	**Estimated forest size [ha] (Pulsar 2010)**
Msimba*	36448	2792	>150	29571
Dodoma Isanga*	4503	1308	>45	2590

---

[4] Reducing Emissions from Deforestation and Forest Degradation (REDD) is an effort to create a financial value for the carbon stored in forests, offering incentives for developing countries to reduce emissions from forested lands and invest in low-carbon paths to sustainable development. "REDD+" goes beyond deforestation and forest degradation, and includes the role of conservation, sustainable management of forests and enhancement of forest carbon stocks. http://www.un-redd.org

Nyali*	9286	2106	>40	5720
Ihombwe	19017	3324	>100	18320
Kigunga	2673	2090	>45	2086
Ulaya-mbuyuni	4468	3198	>40	3800

3.2 Compared systems

Within this study we compare different traditional charcoal production and use systems, as well as different improved charcoal value chains. Since currently no sustainable charcoal value chains exist (technologies are existing, but not at the study site), the “sustainable” value chains likely to be implemented are selected (prospective character of the assessment).

An overview about the charcoal value chain and the compared processes is provided in Figure 4. The definition of the compared system was an iterative process and has been conducted in a participatory way with all project partners involved.

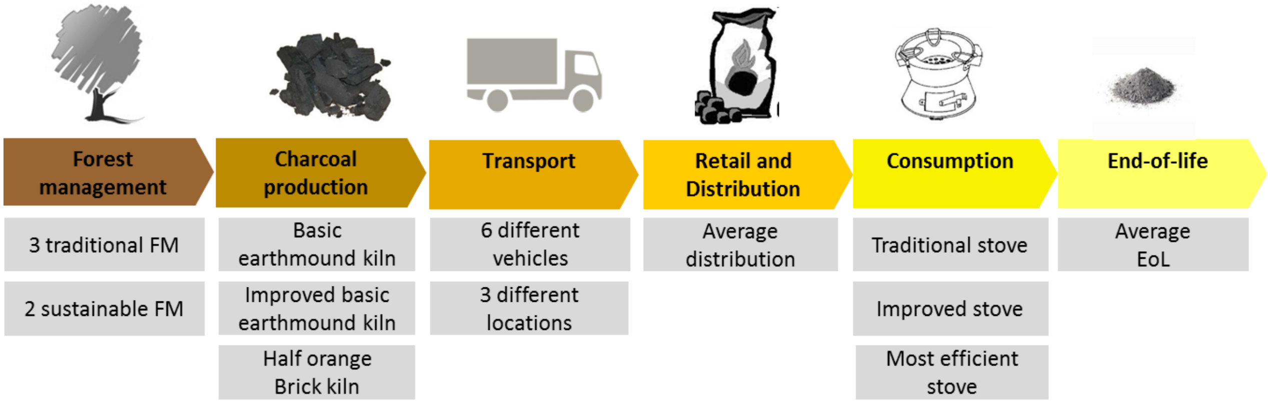


Figure 4: Overview about the charcoal value chain and the compared processes.

Forest management and harvesting: The typical natural Miombo woodland and forest management practices of the 6 study sites in Kilosa were used to model the wood production and harvesting. The villages are Msimba, Dodoma-Isanga and Nyali as REDD villages and Ulaya-Mbuyuni, Ulaya-Kibaoni and Ihombwe as Non-REDD villages. The selection process for the villages was based on three criteria (forest area, person active in charcoal production and remoteness) which best reflect the range of social and environmental conditions.

Charcoal production: The charcoal production systems were selected in collaboration with TaTEDO and TFCG. The traditional earth mound kiln is compared to the improved earth mound kiln which will be introduced by TaTEDO. Furthermore, we also consider a theoretical scenario of implementing an efficient, but stationary half orange brick kiln in order to indicate the impact range.

Transport: Since currently the transportation and marketing of sustainable charcoal are not yet defined, traditional transportation means (6 different vehicles) and three different markets (Kilosa, Morogoro and Dar es Salaam) are considered.

Retail and distribution: A typical retail and distribution system for traditional and sustainable charcoal is considered.

Consumption: Three different cooking stoves are compared. The stoves cover the whole bandwidth in terms of efficiency and include i) traditional stove, ii) most common improved stove (Jiko Bora) and iii) most efficient stove (Sazawa).

End-of-Life treatment: The end-of-life treatment of cooking stoves is considered within this study.

3.3 Functional unit and reference flows

LCA relies on a "functional unit" as a reference for evaluating the components within a single system or among multiple systems on a common basis. It is therefore critical that this parameter is clearly defined and measurable. To fulfil the functional unit, different quantities and types of material are required for each product. These are known as reference flows.

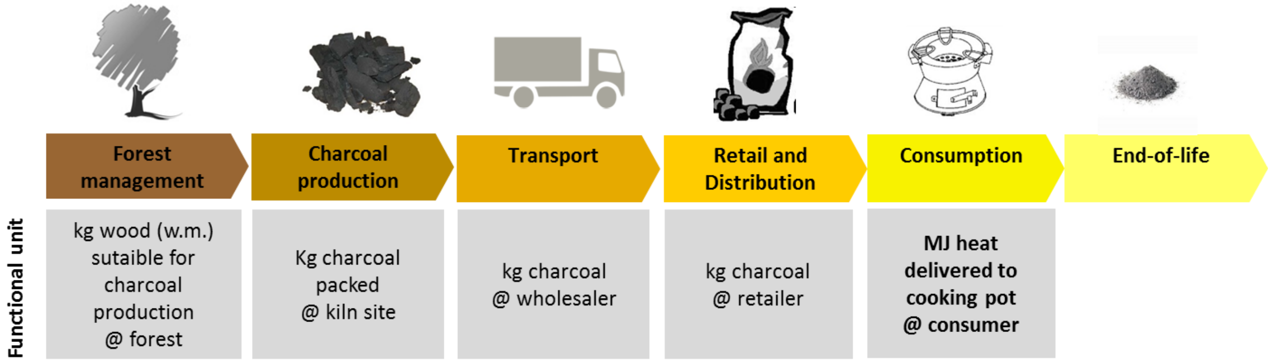


Figure 5: Reference flow unit of main life cycle stages.

Within this study, the functional unit of 1 MJ delivered at cooking pot is used. Thereby the energy efficiency of the stove is accounted for, since the heat received by the pot and not only the heat produced by the stove is considered. However, in order to achieve the function of cooking, different processing steps are required, each with its own reference flow units (see Figure 5).

3.4 System boundaries

The system boundaries identify the life cycle stages, processes, and flows considered in the LCA and should include all activities relevant to attaining the above-mentioned study objectives.

In the following section, the general life cycle stages are described, while the detailed description of each stage is provided in the respective chapters of part III.

Forest management and harvesting: This stage includes the management of the forest and the harvesting of forest products. Since the forest management and the harvesting is done manually and no inputs in terms of fertilizer, irrigation and machinery are used, only the change in carbon stock of living biomass and soil is considered.

Charcoal production: The impact related to the production and disposal of the materials used to establish the charcoal kiln, the emissions of the carbonization process and the packaging of charcoal is considered within this stage.

Transport and trade: The emissions and losses of charcoal related to the transport of charcoal bags from the kiln site to the wholesaler in town are considered within this life cycle stage.

Retail and distribution: The distribution stage includes the transport from the wholesaler to the retailer, as well as the storage and the operation of the distribution shop (thereby only the charcoal losses are considered). Further, also the impact of the charcoal carrying bag from the retailer to home is considered (charcoal packaging).

Consumption: The combustion emissions of typical charcoal stoves used by small households in urban areas are considered. Furthermore, the manufacturing and disposal of the compared cooking stoves is also considered. The shopping trip of the consumer is assumed to have a marginal impact and thus are neglected. It has to be noted that the impact associated to the meals (e.g. production of food) can have higher environmental impacts than the cooking fuel used to prepare the meals. However, the impact strongly depends on the consumer behaviour (e.g. type and amount of food prepared) and is not subject of this study.

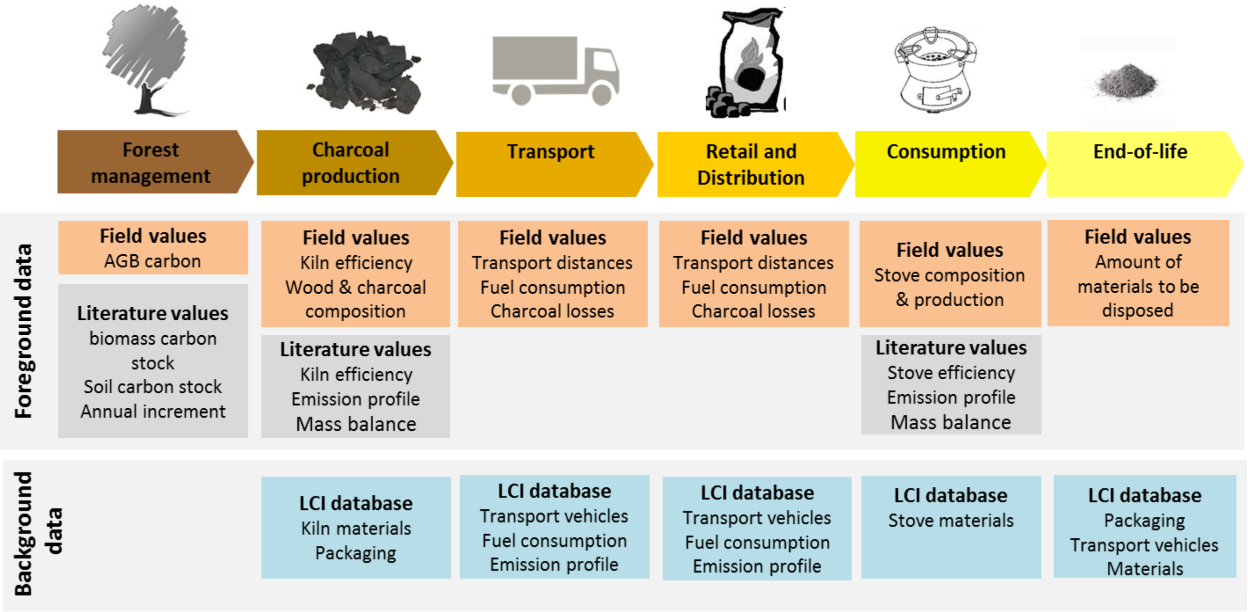
End-of-life treatment: The stove disposal is considered in the end-of-life (EoL) stage, while the ash disposal is assumed to have no significant impacts on the carbon balance and is therefore neglected.

4 Inventory data collection

4.1 Data types and sources

In general, the inventory can be split in foreground and background data. Foreground data are related specifically to the product system. They are verified data which are collected directly in the field by expert interviews or from relevant literature. Several interviews were conducted in the study sites and used measured values obtained by our project partners on forest carbon stocks, kiln and stove efficiencies, as well as on input materials. The primary data from the field is validated and data gaps are closed by using literature values.

Background data on the other hand are not specifically related to the product system and are usually derived from generic LCI databases. Typical examples are transport datasets and datasets related to material production and electricity generation. Those background data is derived from the LCI database Ecoinvent v 2.2 (ecoinvent centre 2007). Ecoinvent is internationally recognized by many experts in the field as one of the most complete LCI databases available, from a quantitative (number of included processes) and a qualitative (quality of the validation processes, data completeness, etc.) perspective.



	Forest management	Charcoal production	Transport	Retail and Distribution	Consumption	End-of-life
Foreground data	**Field values** AGB carbon	**Field values** Kiln efficiency Wood & charcoal composition	**Field values** Transport distances Fuel consumption Charcoal losses	**Field values** Transport distances Fuel consumption Charcoal losses	**Field values** Stove composition & production	**Field values** Amount of materials to be disposed
	Literature values biomass carbon stock Soil carbon stock Annual increment	**Literature values** Kiln efficiency Emission profile Mass balance			**Literature values** Stove efficiency Emission profile Mass balance	
Background data		**LCI database** Kiln materials Packaging	**LCI database** Transport vehicles Fuel consumption Emission profile	**LCI database** Transport vehicles Fuel consumption Emission profile	**LCI database** Stove materials	**LCI database** Packaging Transport vehicles Materials

Figure 6: Source of inventory data for specific processes.

The data sources and assumptions are documented in respective chapters. Inventory modelling and LCIA calculations are conducted in Simapro 7.3[5].

4.2 Inventory modelling principles

We apply the attributional inventory modelling and true value allocation[6] as applied in ecoinvent v2.2 (ecoinvent centre 2007). For the EoL treatment the cut-off approach is used to treat recycling of waste products (Frischknecht et al. 2007). Thereby the impacts associated with the collection of materials being recycled and with the recycling process of these materials are attributed to the products using the recycled materials. It is therefore oriented towards extended producer responsibility and is used as a default approach in all ecoinvent v2.2 processes. The choice of the EoL approach used is assumed to not significantly influence the results.

4.3 Biogenic carbon emissions

Biogenic CO_2 are usually not considered in the LCA to assess the global warming potential (i.e. both uptake by plants and release during degradation/consumption). This assumption is based on the concept of "carbon neutrality", where the atmospheric carbon fixation and end-of-life carbon emissions occur in such a short period of time that they can be regarded as offsetting each other.

However, different studies showed significant carbon emissions related to land use change (Searchinger 2008; Fargione et al. 2008). Also wood extraction and use leads to at least a temporal change in the CO_2 concentration of the atmosphere. If forest is converted to agricultural land, the change in carbon stocks is more permanent (see Figure 7). Consequently, an accounting error is caused if biogenic carbon emissions related to land use change are ignored.

---

[5] http://www.pre-sustainability.com/

[6] In the ecoinvent default allocation, the allocation property is identical to the price, unless the property "true value relation" is specifically provided in the original dataset (e.g. use of exergy to allocate between electricity and useful heat). In ecoinvent an allocation correction for carbon is implemented to ensure carbon balance.

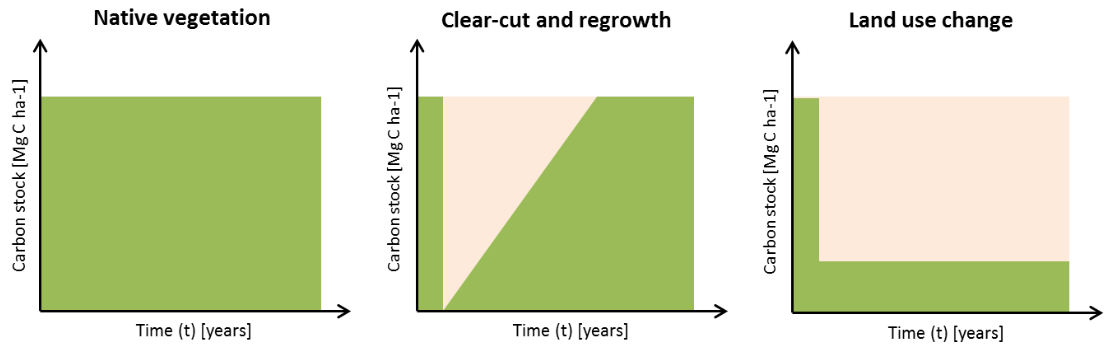
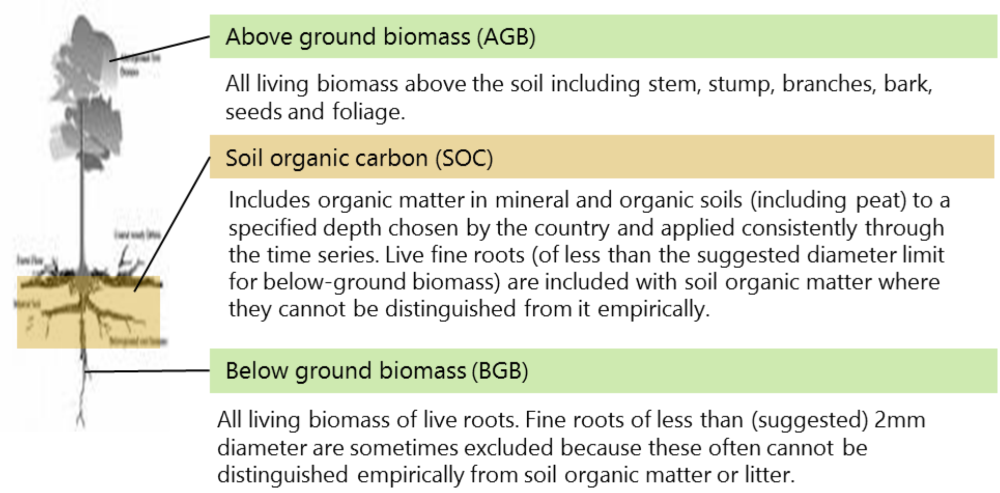


Figure 7: Schematic developments of carbon stock of native vegetation (left), a harvesting scenario (middle) and a land use change (e.g. from forest to agriculture, right).

In this study we analyse the forest carbon pools and the corresponding net carbon flux between the stand and the atmosphere for each of the compared land use schemes. The carbon stocks and fluxes are quantified over a time period of 100 years. In this study we consider carbon contained in aboveground biomass (AGB), belowground biomass (BGB) and also soil organic carbon (SOC) stocks (see Figure 8). The carbon contained in the dead organic matter (DOM) is neglected.



Above ground biomass (AGB)

All living biomass above the soil including stem, stump, branches, bark, seeds and foliage.

Soil organic carbon (SOC)

Includes organic matter in mineral and organic soils (including peat) to a specified depth chosen by the country and applied consistently through the time series. Live fine roots (of less than the suggested diameter limit for below-ground biomass) are included with soil organic matter where they cannot be distinguished from it empirically.

Below ground biomass (BGB)

All living biomass of live roots. Fine roots of less than (suggested) 2mm diameter are sometimes excluded because these often cannot be distinguished empirically from soil organic matter or litter.

Figure 8: Overview about carbon pools considered.

For each compared scenario the total carbon stock (C_T) at any time (t) is modeled as the sum of the carbon contained in AGB, BGB and SOC.

$$C_T(t) = C_{AGB}(t) + C_{BGB}(t) + C_{SOC}(t)$$

The average carbon stock ($\bar{C}_T$) over a time period of 100 years is used to assess the land occupation impact and is calculated as

$$\bar{C}_T = \frac{\sum_{i=1}^{100} C_T(t_i)}{100}$$

For each scenario the dynamic carbon stock over a 100 year period is presented graphically (example in figure below).

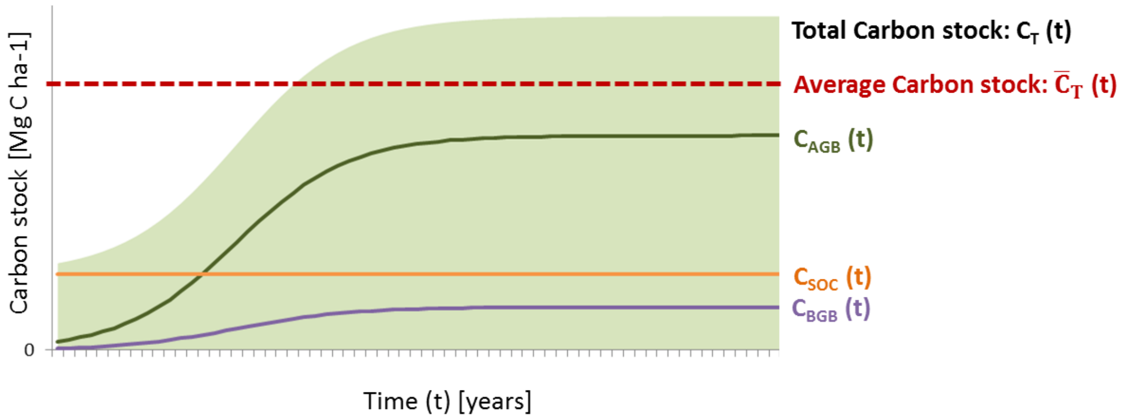


Figure 9: Example: Carbon stock of afforestation or forest regeneration.

4.4 Time horizon

Two different time aspects have to be considered in the modelling of the emissions and impacts related to climate change: the time period of the analysis and the time period used for the impact assessment. First, the time period of assessing the emissions and removal of GHGs has to be defined. We consider the land use scheme of 100 years. Further, we assume that the charcoal is used in the same year as the trees are cut to produce the charcoal.

Second, the time horizon of the impact assessment (choosing a time beyond which radiative forcing is neglected). In an infinite time perspective temporal release of carbon emissions becomes insignificant. Most widely the time horizon of 100 years is used.

Consequently for both, the assessment period of modelling the emissions and the impact is set at 100 years. This time horizon is widely accepted and recommended by PAS 2050 and the ILCD guidelines (BSI 2011; European Commission 2010). However, we also assess the sensitivity of the LCA results by calculating the GWP for a 500 year time horizon (see chapter 15.5).

5 Impact assessment

In this study we calculate the impact in terms of the global warming potential (GWP), which accounts for radiative forcing caused by greenhouse gas emissions. The capacity of a greenhouse gas to influence radiative forcing is expressed in terms of a reference substance (e.g.

CO_2-equivalent units). In other words, the concept of GWP is a relative measure of how much heat a GHG traps in the atmosphere compared to the heat trapped by a similar mass of CO_2. Consequently the GWP of CO_2 is 1.

The fraction of an initial CO2 pulse that remains in the atmosphere at time t is based on the decay function of the Bern 2.5CC carbon cycle model (see black line in Figure 10). Since the decay and radiative efficiency of other GHG differs from CO_2, the characterization factors are dependent on the time horizon. The GWP of other GHG is commonly calculated over time horizon of 20, 100 and 500 years (see Table 2 for GWP of the top 3 GHGs).

Table 2: Global warming potential of carbon dioxide, methane and nitrous oxide for a 20, 100 and 500 year time horizon (IPCC, 2007).

Name	**Formula**	**Lifetime (years)**	**Radiative Efficiency (W m–2 ppb–1)**	**Global warming potential for given time Horizon**		
				20 - yr	100-yr	500-yr
Carbon dioxide	CO2	see Fig 10	1.4*10^-5	1	1	1
Methane	CH4	12	3.7*10^-4	72	25	7.6
Nitrous oxide	N2O	114	3.03*10^-3	289	298	153

Each CO_2 emission contributes to global warming, no matter whether it is from biogenic or from a fossil fuel. However, as soon as the biomass starts to regrow, there is an uptake of CO_2. Taking the time profile of the regrowth into account, the calculated lifetime of a CO_2 pulse from biomass (red line in Figure 10) was found to be shorter than a pulse of CO_2 from fossil fuels (black line in Figure 10). Consequently it seems reasonable that the GWP of CO_2 from bioenergy in systems with regrowth is smaller than the potential warming impact of “fossil” CO_2.

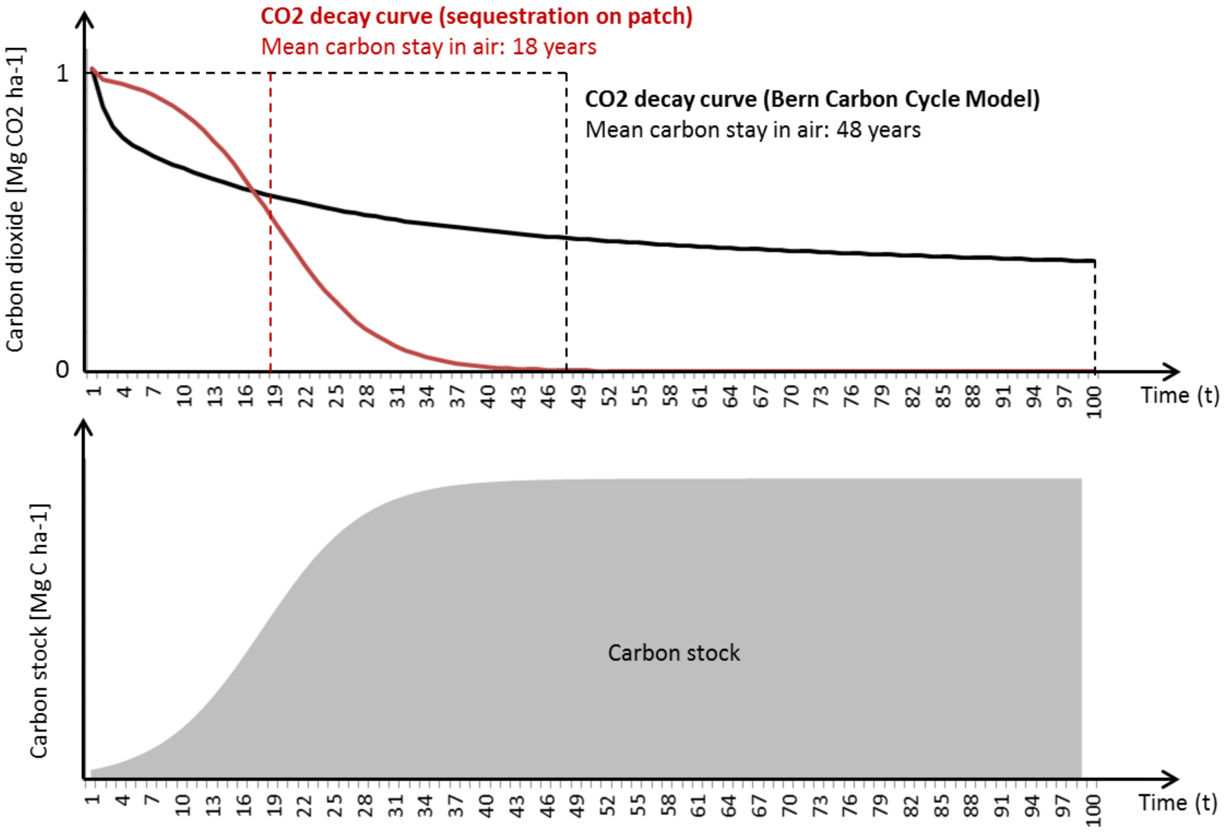


Figure 10: Example of carbon stock and emissions of forest regrowth after clear-cut. The carbon dioxide emissions released in year 0 and the subsequent uptake of carbon dioxide due to regrowth is indicated by the red line. The carbon stock as a function of time is indicated in grey. The carbon dioxide decay curve for fossil CO2, which is based on the Bern carbon cycle model, is indicated in black. At a 100 year time horizon the mean carbon stay in air is 18, respectively 48 years.

Different studies provided an approach on how to adapt the GWP in order to take the time profile of the regrowth and thus the actual CO_2 concentration in the atmosphere into account (Müller-Wenk & Brandão 2010; Holtsmark 2013; Cherubini et al. 2011).

Müller-Wenk & Brandão (2010) proposed to calculate the mean carbon stay in air for a given time horizon. Based on the mean carbon stay in air, the duration factor is calculated as the ratio between the average carbon stay in air due to the land use and 48 years[7]. The mean carbon stay is calculated as the integral of the CO_2 decay curve over 100 years. In our case a duration factor

---

[7] Müller-Wenk & Brandão (2010) recommend to use a time horizon of 500 years. For 500 year time horizon the mean carbon stay is 157 years and consequently a different duration factor results.

of 0.38 (18/48) results, which means that 1 kg CO_2 emitted due to clear-cutting and using the wood is equal to 0.38 kg of fossil CO_2 emission.

The impact factor calculated above is related to land transformation (CO_2 pulse emission). However, if a series of land occupation follows land conversion, the relaxation is postponed (see Figure 11). According to Müller-Wenk and Brandão (2010) the impact of avoided regeneration can be calculated as the difference between the carbon stock of the natural vegetation ($\bar{C}_{natural\,vegetation}$) and the average carbon stock ($\bar{C}_{agriculture}$) of the new land use system. The impact of occupation depends on the change in average carbon stock (ΔC), the duration of occupation and the duration factor (df). The df for a 100 year time horizon is calculated as 1/48 and a default occupation duration of 100 years is assumed.

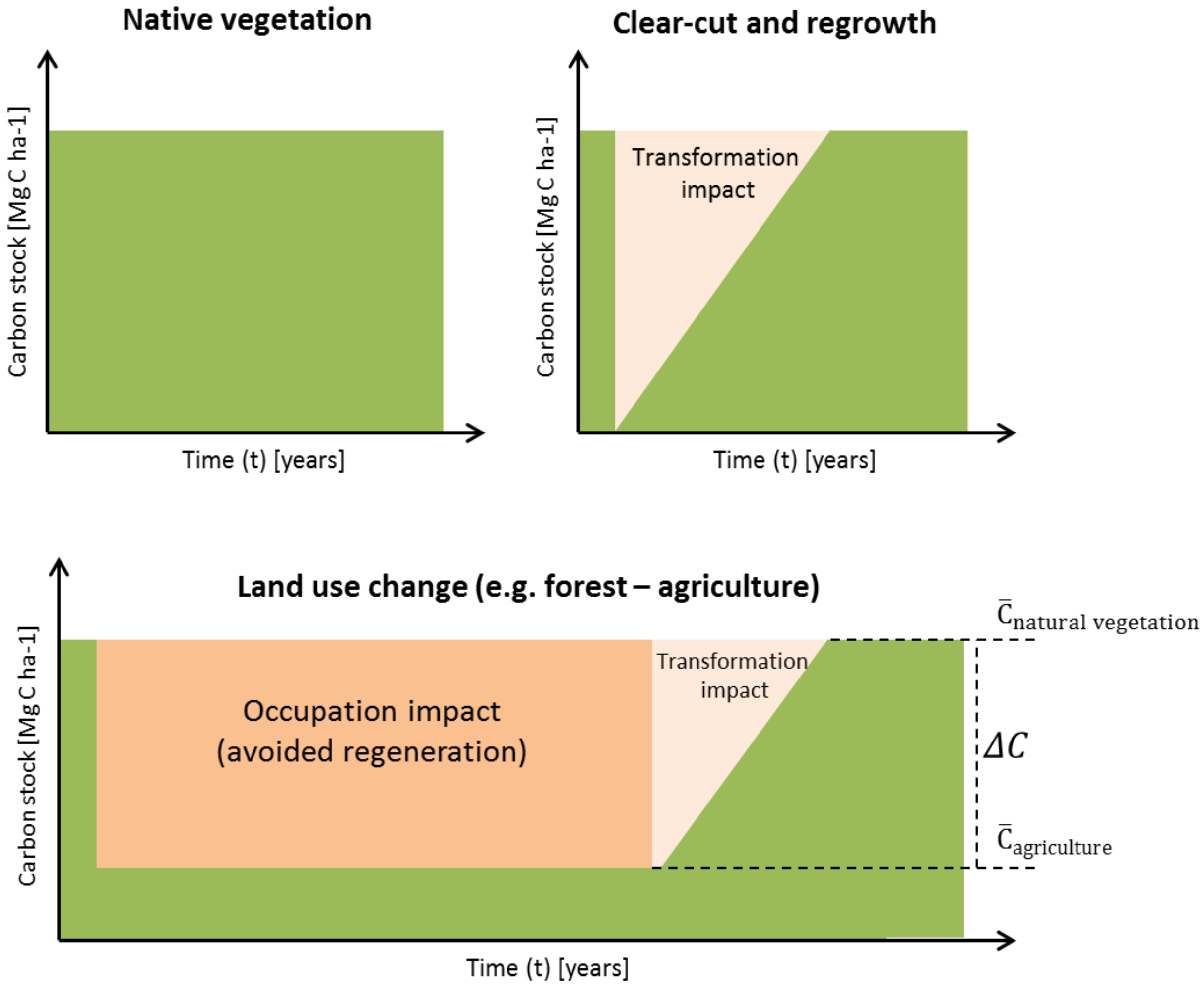


Figure 11: Concept of calculating the land transformation and land occupation impact in terms of global warming potential.

Within this study the approach proposed by Müller-Wenk and Brandão (2010) is used and the transformation and occupation impacts are calculated using a 100 year time horizon. As a sensitivity analysis, the results are compared to using a 500 year time horizon and to the carbon neutrality concept of biogenic CO_2 emissions (see section 15.5).

6 Limitations of the study

The LCA study provides a comprehensive overview about the main environmental impacts along the charcoal value chain. However, while interpreting the results following limitations have to be considered:

Scope: Conclusions should be considered applicable only within the scope of the study. Thereby the temporal, the geographic scope, as well as the system boundaries and modelling principles have to be kept in mind.

Charcoal is produced, transported and used in many different ways. Within this study we have captured many different aspects of current and future charcoal systems by assessing different scenario for each processing step along the value chain. Even though a broad range of scenarios is presented, not all possible options might have been considered. Furthermore, the sustainable charcoal value chain is not yet fully established and thus a prospective impact assessment is conducted. Depending on the future development of the improved value chain, the results of this study require an update.

The LCA results are geographically dependent. It should be noted that most, though not all, of the data within ecoinvent is of European origin and produced to represent European industrial conditions and processes.

Inventory data: The assessment of environmental impacts in the life cycle usually requires a large set of data and model assumptions. These assumptions have to be considered while interpreting the results.

The uncertainties related to the inventory data were not quantified. However, the sensitivity of results on different inventory assumptions was treated by the evaluation of different scenarios (e.g. different traditional charcoal kilns).

The carbon stock model is mainly based on literature values, since the data availability on regeneration curves, soil carbon stocks and below ground biomass is limited. Detailed inventory data which are specifically collected in the study area will improve the data accuracy.

Both the emissions from the charcoal kiln and charcoal stoves are sensitive to the local conditions and might vary substantially. We based our study on average emission based on an extensive literature review. However, direct measurements of emissions, but also of conversion efficiencies, would increase the accuracy.

Impact Assessment: It is important to note that, rather than direct measurements of real impacts, LCA estimates relative, potential impacts.

Uncertainties in impact assessment modeling were treated by conducting a sensitivity analysis using different impact factors. For this study we compared the GWP 100 and GWP 500 results as a sensitivity analysis.

Changing land use schemes might also cause a change in surface albedo. Thus not only the changes in carbon pools, but also changes of the physical properties of the land surface can perturb the climate, both by exerting a radiative forcing (RF) and by modifying other processes such as the fluxes of latent and sensible heat and the transfer of momentum from the atmosphere (IPCC 2007). Given the little data availability, this effect was not considered within this study.

The focus of the study is put on the assessment of the global warming potential. Other environmental impacts associated by charcoal production and use are not addressed within this study. For instance impacts on the hydrology, biodiversity and ecosystem services related to different forest management and land use schemes are not included in the study. Further, also impacts on soil quality at the kiln site and human health impacts of charcoal combustion emission are not considered in this study.

Overall sustainability: Although the LCA methodology is adequate to assess key aspects of environmental sustainability, it is not to assess the social context in which these products are produced or the socio-economic impacts they generate. In order to obtain a complete view of sustainability, the results of the LCA study should be interpreted together with other assessments of the study.

PART III – CHARCOAL VALUE CHAIN

7 Overview about the charcoal value chain

In the following chapter the charcoal value chain is described in detail and the inventory data generated is provided. Figure 12 provides an overview about the structure of part III and about selected key aspects relevant for conducting a charcoal LCA.

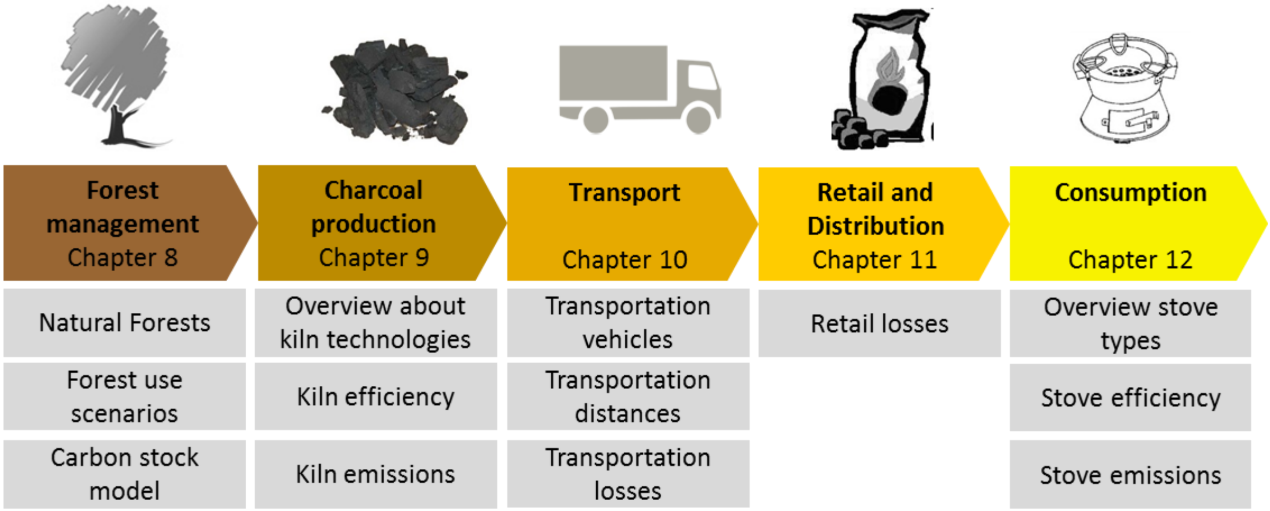


Figure 12: Overview about the charcoal value chain and selected key aspects relevant for conducting a charcoal LCA.

8 Forest management

Tanzania shows a significantly high annual deforestation of approximately 403 000 ha (FAO, 2010), which equals an annual forest decrease of more than 1 % for Tanzania with its total forest area of 31 million ha. Chidumayo et al. calculated the country specific land requirements to fulfill the charcoal national charcoal production and compared the area to the total deforested area (Chidumayo & Gumbo 2013). In Tanzania the charcoal consumption is about 1 million ton for which an area of about 100 000 ha forest needs to be clear-cut. This is roughly one quarter of the total deforested area in Tanzania. However, charcoal production just leads to temporal deforestation and not to a permanent land use change.

In the following chapter, the natural forest system and different forest use schemes are described and data on the carbon stock dynamics is provided.

8.1 Forest types in Kilosa area

There exists two type of forest in the study area: i) Montane Forest and ii) Miombo woodland. The forests differ in terms of tree height, canopy cover, diversity, carbon stock and elevation.

Montane forest: Out of the 6 villages only Msimba and Kisanga have montane forest as part of their village forest reserves. However, such closed forest types are located at high altitudes. Consequently, they are typically far away from villages and due to the poor accessibility they are generally not used for charcoal production. Therefore, we exclude this forest type from our study.

Miombo woodland: Closed or Miombo (broadleaved) woodlands are found throughout Tanzania at altitudes ranging from 300 m to 1300 m depending on the climatic conditions. There is no continuous canopy although crowns can be in close proximity to each other. Most trees are single stemmed and evergreen, semi-evergreen or deciduous. The major species are *Brachystegia spp* and *Jubernardia spp*. The majority of Miombo woodland species have deep taproots with access to deep soil moisture and nutrients and shed leaves during the dry season (Dallu 2002).

The dry Miombo woodland is the dominant forest type in the study site and available in all villages.

Figure 13: Dry Miombo woodland (left) and montane forest (right, source: TFCG).

8.2 Forest use scenarios

In the context of charcoal production we differentiate between two drivers for clear-cutting forest. Either the forest is cut to use the biomass for charcoal production or the main driver for deforestation is the expansion of agricultural land. In the following the drivers are described and also the sustainable forest management approach is introduced.

Figure 14: Forest clear-cut for expansion of extensive agricultural area (left) and for charcoal production (right).

8.2.1 Scenario 1: Temporary deforestation - driver charcoal

There are two different ways to clear the forest, either by using an axe or saw to cut the tree about 40cm above ground or by controlled fire. Before the fire is set the bark is peeled off so that the tree dries. The wood is either used (firewood, charcoal or timber) or left aside. There exist preferred tree species for charcoal production and if sufficient trees are available, selective cutting of well suited species for charcoal making is conducted. However, in most cases the forest is clear-cut and all the biomass is used for charcoal production.

After clear-cutting, the woodland is left for regeneration. According to Malimbwi & Zahabu (2004) it takes 10-15 years until the trees can be harvested again for charcoal production.

8.2.2 Scenario 2: Permanent deforestation - driver agriculture

The main driver for deforestation in this scenario is the expansion of agriculture. Within this study we distinguish between long-term agriculture and shifting cultivation. While long-term agriculture is the permanent cultivation of land, shifting cultivation is only a temporary cultivation system and includes following steps:

1. Clear-cut: All trees are cut and the wood is either used (firewood, charcoal or timber) or left aside (decomposing process).

2. Agriculture. After clear-cutting the field is prepared. Thereby the stumps are usually left on the field, since they will decompose within a few years. Maize is the dominant crop grown in the study site and for its cultivation tillage is applied, but in general no fertilizers are used. After 7 to 10 years the soil nutrient level decreases to a level that yields fall and farming is not feasible anymore.

3. Regrowth: During a period of 3 to 4 years the field is left aside and the soil recovers. The fertility of the land is indicated by the type of vegetation.

4. Clear-cutting: The regeneration time of a few years is too short for substantial biomass production and the diameter of the wood logs is too low to use the accumulated biomass for charcoal production. Thus, the cut wood is either used as firewood or left aside.

The shifting cultivation practice of one study site, Ihombwe, is further described in (Norrlund & Brus 2004).

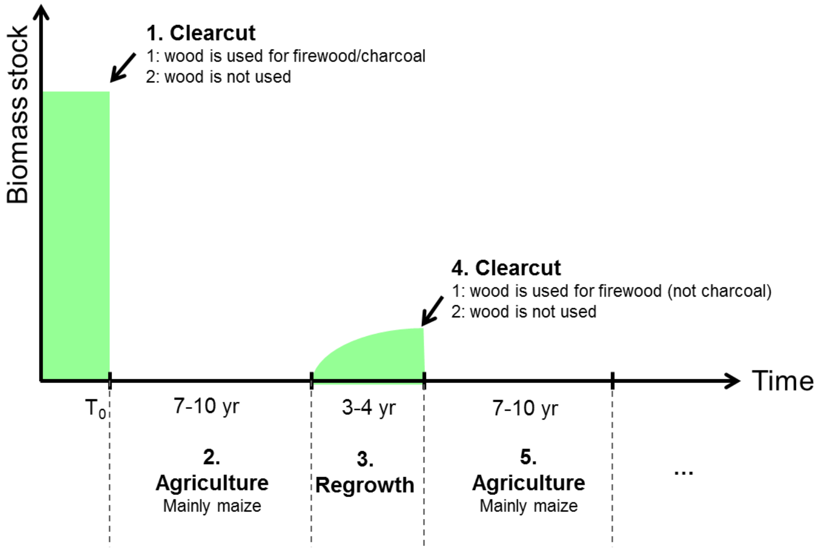


Figure 15: Schematic overview about the biomass stock of Miombo woodland clear-cut for agricultural purposes.

8.2.3 Scenario 3: Sustainable forest management

The sustainable forest management guidelines are currently under development and will be defined and implemented on a village level within the next year. We've used the draft harvesting guidelines developed by TFCG to define the sustainable forest management scenario. However, it has to be noted that the described practice might slightly change in future.

Clear-cutting versus selective cutting: Clear-cutting removes the entire canopy and this is seen as the best way of promoting regeneration of tropical forests regenerating from stump sprouts. Selective cutting might give competitive advantage to uncut trees. That might supress regrowth of cut trees and suppressed saplings, which can cause more permanent forest degradation.

The harvesting guidelines advise clear-cutting and only trees of high value in diversity or monetary terms are exempt (e.g. threatened or endangered species, rare species, valuable timber species or big trees which are habitat for wildlife). However, for the analysis we do not consider such special trees.

However, clear-cutting on the other hand might cause soil erosion. To reduce the impact of harvesting on soil erosion clear cutting is though unsuitable for large areas, steep slopes, or in riverine vegetation.

Cutting period: Most of the trees in the Miombo woodland are deciduous and produce their new growth at or before the start of the rains. The best period to cut is after the long rain season, when trees will be dormant and cutting may not significantly affect resources stored belowground.

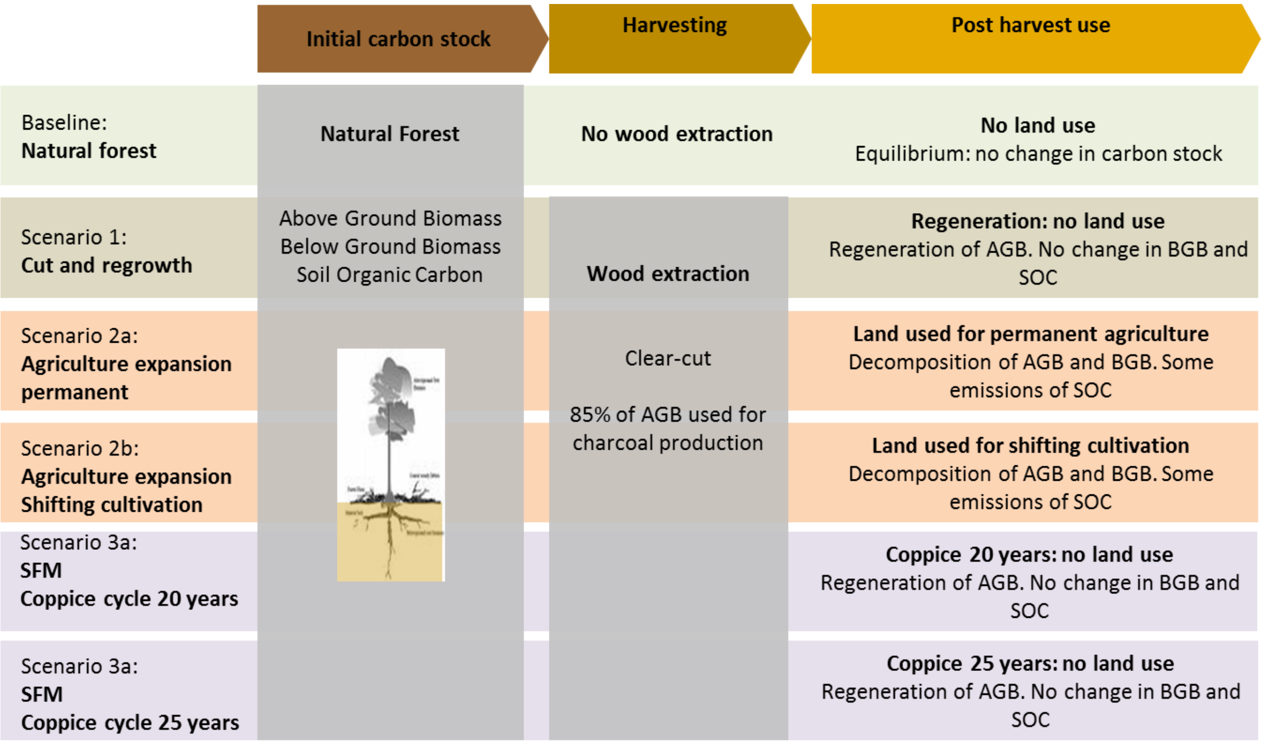
Tree cutting height: Coppice shoots can be produced anywhere along the stem and branches, not just around the root collar. Coppice production and growth is affected by the height above the ground at which the stem is broken. If *B. spiciformis* and *J. globiflora*, and other species often found in Miombo woodland are cut close to the ground (<5 cm) they produce less coppice growth than plants cut higher up at 1.3 m (Grundy 1990). In the FMU allocated for charcoal production it is recommended to cut the trees a knee height to maximize the available wood for charcoal production and at the same time ensure fast regrowth.

Coppice cycle: Stem height increments in regrowth Miombo woodland are highest in the first or second year and decline thereafter. Mean stem height may reach 4-5 m by 15-18 years in regrowth dry Miombo woodland. The village natural resource council (VNRC) will prevent over-utilization by developing a scheme for rotation between the 'charcoal' coupes based on the biomass production. The regrowth woodland is expected to peak between 20 and 25 years (2 scenarios are used in our analysis).

Post harvesting practices: Regrowth can be thinned at 10-20 years by selective harvesting of small poles, while reserving other stems for the production of large wood products. Further, the recovery period is prolonged by by grazing and uncontrolled burning. Consequently, post harvesting practices preventing the disturbance of the forest by animals and fires should be implemented. However, in practice effective measures are difficult to implement (e.g. conflicts with cattle-grazing or prevention of wild fires) and we're not considering such measures in our analysis.

8.3 Carbon stock model

The carbon stock depends on the carbon stored in the natural Miombo woodland (initial carbon stock), the harvesting technique and the post-harvest use of the land. For all scenarios the same natural Miombo woodland and harvesting techniques are assumed. However, the post-harvesting management differs (see Figure 16). In the following chapters the data used and the assumptions made to determine the carbon stocks and fluxes of each scenario are further described.



	Initial carbon stock	**Harvesting**	**Post harvest use**
Baseline: **Natural forest**	**Natural Forest**	**No wood extraction**	**No land use** Equilibrium: no change in carbon stock
Scenario 1: **Cut and regrowth**	Above Ground Biomass Below Ground Biomass Soil Organic Carbon	**Wood extraction**	**Regeneration: no land use** Regeneration of AGB. No change in BGB and SOC
Scenario 2a: **Agriculture expansion permanent**		Clear-cut 85% of AGB used for charcoal production	**Land used for permanent agriculture** Decomposition of AGB and BGB. Some emissions of SOC
Scenario 2b: **Agriculture expansion Shifting cultivation**			**Land used for shifting cultivation** Decomposition of AGB and BGB. Some emissions of SOC
Scenario 3a: **SFM** **Coppice cycle 20 years**			**Coppice 20 years: no land use** Regeneration of AGB. No change in BGB and SOC
Scenario 3a: **SFM** **Coppice cycle 25 years**			**Coppice 25 years: no land use** Regeneration of AGB. No change in BGB and SOC

Figure 16: Overview about the compared scenarios.

8.3.1 Above ground biomass carbon stocks

Average aboveground biomass in old growth Miombo woodland varies mostly from around 30 to about 140 Mg ha^{-1}, depending on the amount of annual rainfall and edaphic properties (Malimbwi & Zahabu 2009). Thereby the harvestable tree volume in East Tanzania from dry Miombo woodland is indicated with 35 m^{3} ha^{-1} (Malimbwi & Zahabu 2009). Given the greater basal area of wet Miombo stands, it can be assumed that stand volume will be correspondingly greater than this value.

The reported biomass stocks of Miombo woodland ranges from 4 Mg ha^{-1} (Ryan et al. 2011) to 230 Mg ha^{-1} (Kutsch et al. 2011) and is in average 53 Mg ha^{-1} (see Table 3) based on a literature review (Ryan et al. 2011; Kutsch et al. 2011; Malimbwi & Zahabu 2009; Hunter 2012; Shirima et al. 2011; Williams et al. 2008; Hammarstrand & Särnberger 2013). Values specific for dry Miombo woodland in Tanzania are reported to be 20 Mg ha^{-1} (Malimbwi & Zahabu 2009).

Based on the biomass stock, the carbon stock can be calculated based on the carbon content, the wood density and the moisture content. The carbon content diverges among species, substrate and location. An average **carbon content** of Miombo woodland of 47% is used for this study. No differences between trunk, branch and root carbon content were observed (Ryan et al. 2011). The **wood density** for individual species ranged from 0.40 to 0.71 t m^{-3} (average 0.56 t m^{-3}), depending on the tree species (Williams et al. 2008). Within this study an average wood density of 0.56 t m^{-3} is used. The **dry matter fraction** (DMF) of Miombo wood was in average 0.65 for the trunk, 0.59 for the branches and 0.59 for roots (Ryan et al. 2011). We've used a DMF of 0.65 throughout the study.

Preliminary results from four SCP projects villages indicate biomass stock (above ground biomass) to be within 51-94 Mg wet mass ha^{-1} (16 – 28 Mg C ha^{-1}). In each village, 50 plots were analysed and the average carbon stock of 24 Mg C ha^{-1} is used for this study. The average carbon stock is close to the average value from literature. The aboveground woody biomass (B in Mg ha^{-1}) of old- growth, mixed-age stands of Miombo woodland increases with mean annual rainfall (P in mm) (Campbell 1996) according to following linear equation:

$$B = 0.14 * P - 56.21$$

Using an average annual rainfall of 800mm for Kilosa area, an average biomass stock of 55.8 Mg ha^{-1} results. Overall, the slightly lower carbon stock in the study site may also be explained since the sampling in the study site includes only woody biomass of a diameter at breast height of more than 5cm.

Table 3: Above ground biomass and carbon stock of Miombo woodland, based on different sources.

		AGB [t d.m. / ha]			AGB -C [t C / ha]				
Forest type	**Country**	**min**	**average**	**max**	**min**	**average**	**max**	**Source**	**Comment**
Miombo woodland - natural	Zambia	107.6	150.0	228.2	50.5	70.5	107.2	Kutsch et al. (2011)	
Miombo woodland - disturbed	Zambia		24.0			11.3		Kutsch et al. (2011)	
Dry miombo woodland	Tanzania		19.6			9.2		Malimbwi & Zahabu (2009)	Based on a wood density of 560 kg/m3.
wet miombo woodland	Tanzania	23.0		56.0	10.8		26.3	Endean 1968	Based on a wood density of 560 kg/m3.
Old growth miombo woodland	Tanzania	30.0		140.0	14.1		65.8	Malimbwi & Zahabu (2009)	
old-growth, mixed-age stands Miombo	Zambia / Zimbabwe		55.0			25.9		Malimbwi & Zahabu (2009)	
old-growth stands in wet miombo woodland	Zambia / Zimbabwe		90.0			42.3		Malimbwi & Zahabu (2009)	
Miombo woodland	Africa		31.7			14.90		Hunter (2012)	Mix of literature review
Miombo woodland	Eastern Arc, TZ	30.2	51.49	65.3	14.2	24.2	30.7	Shirima et al. (2011)	
Miombo woodland	Mozambique	4.0	45.11	129.6	1.9	21.2	60.9	Ryan et al. (2011)	
Miombo woodland	Mozambique	25.5	40.43	51.1	12.0	19.0	24.0	Williams et al. (2008)	Only stem carbon considered.
Miombo woodland	Mbozi, TZ		40.68			19.1		Munishi et al. (2010)	
Miombo woodland - natural	Kilosa, TZ	51.0		94.0	24.0		44.2	TFCG (2013)	Preliminary results from the SCP projects villages indicate biomass stock (AGB)
Miombo woodland - natural	Ulaya Mbuyuni, TZ		19.9			9.37		TFCG (2013)	Based on a wood density of 560 kg/m3 and a dry matter fraction of 0.59.
Average		**38.76**	**51.63**	**109.16**	**18.22**	**24.27**	**51.31**		
Value used			**51.63**			**24.27**			

The carbon stock of trunks remaining after clear-cutting is estimated based on harvesting practice (cut 30 cm above ground), the stocking density (600 trees ha^{-1}) and the estimated diameter of the tree stumps (30cm). Based on the carbon content, the wood density and the moisture content (values see above), an above ground carbon stock of 2 Mg C ha^{-1} remains after clear-cutting.

The aboveground stock of annual crop cultivation is assumed to be zero according to the IPCC guidelines (IPCC 2006).

8.3.2 Above ground biomass regrowth

The post harvesting regrowth of the forest can either take place by seed germination (sexual) or by vegetative means (sprouts from existing trees that are cut or damage, often referred to as coppice). In tropical dry forested the regeneration from saplings is more important.

The regrowth in biomass, also referred to as the mean annual increment (MAI), for dry Miombo woodlands range from 1.2-2.0 Mg ha^{-1} (Chidumayo 1991). Slightly higher rates of 2.2 to 3.4 Mg ha^{-1} are recorded in wet Miombo woodland (Chidumayo 1990).

Malimbwi and Zahabu (2009) reported that the MAI in mature Miombo woodland ranges from 0.58 to 3 m^3 ha^{-1} (2-3% of the standing stock). Using a wood density of 0.7 t m^{-3}, a MAI of 0.4 to 2.1 Mg ha^{-1} is calculated (Malimbwi & Zahabu 2009). The mean annual C stock accumulation of stem wood is 0.75 Mg C ha^{-1}during regeneration according to (Williams et al. 2008). The carbon stored in stem wood is about 40% of the carbon stored in all the AGB (Muishi et al. 2010). Using the carbon content of 47%, this results in a MAI of 4 Mg ha^{-1}.

We use the regression model by Campbell (1996) in order to calculate the annual increment as a function of tree age. The stand biomass (Mg ha^{-1}) as a function of the age of regrowth (years) is provided in Figure 17. The average MAI of the first 10 years is 1.4 Mg ha^{-1}, for the first 20 years 2.6 Mg ha^{-1} and for the first 30 years 2.5 Mg ha^{-1}.

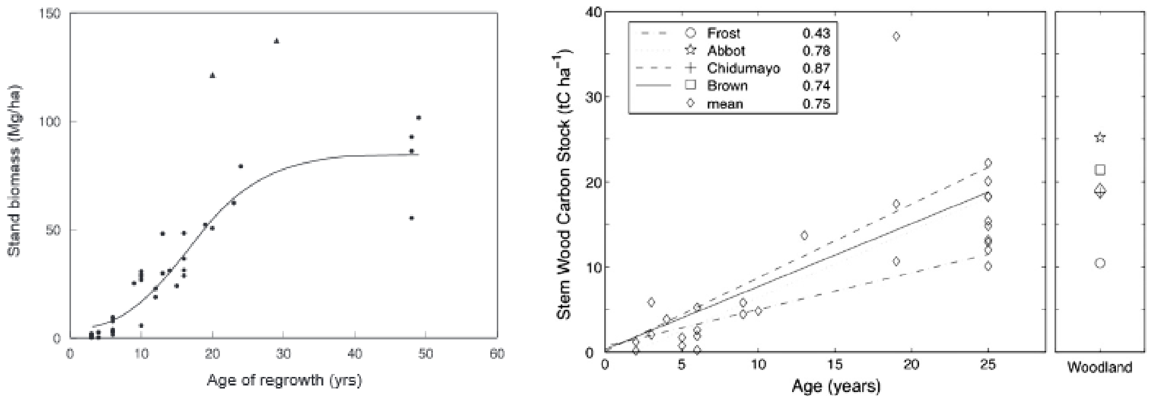


Figure 17: the stand biomass as a function of the age of regrowth (left) based on (Campbell 1996) *and the stem wood carbon stock (tC ha-1) per year (right) based on* (Williams et al. 2008)

The MAI and the relative biomass increment (Mg/Mg-1ha-1) used in the study (based on the regression curve in Figure 17) for the first 50 years are illustrated in Figure 18.

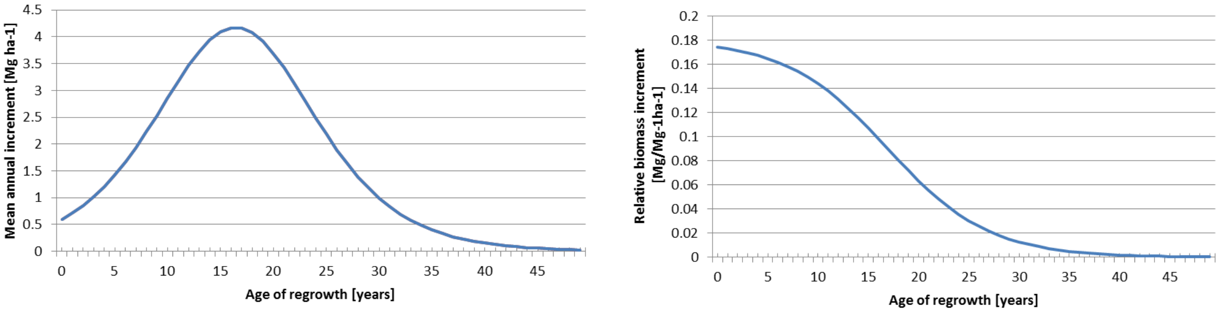


Figure 18: Mean annual increment (Mg ha-1) and biomass increment (Mg/Mg-1ha-1) relative to the biomass stock of Miombo woodland regeneration of the first 50 years.

Overall there was no significant difference in stem C stocks on woodlands and on abandoned farmland 30 years old (Williams et al. 2008). Also Ryan et al. (2011) indicated that within 30 years of abandonment of agricultural activities, the woodland recovers to pre-disturbance level. However, the recovery period is prolonged by grazing and uncontrolled burning.

The regrowing plots did not contain the defining miombo species, and total stem numbers were significantly greater than in woodland plots, but species richness and diversity were similar in older abandonments and miombo woodlands (Williams et al. 2008).

8.3.3 Below ground biomass

Miombo species have horizontally and vertically extensive root systems, but less is known about the amount of woody biomass belowground. For Zambian dry miombo sites, the root biomass averaged 35% of total biomass(Campbell 1996). In Mozambique the root biomass averaged at

28% of the total biomass (Ryan et al. 2011). In contrast, in disturbed dry miombo woodland in central Tanzania, root biomass apparently accounted for only 20% of a total biomass of 33 Mg ha-1 (Malimbwi et al. 1994).

The belowground carbon stock of annual crop cultivation is assumed to be zero according to the IPCC guidelines (IPCC 2006).

The value of 20% was used, even though the value seems low. The root system dies after the conversion of forest land to agricultural land. The decomposition rate of the initial belowground biomass is assumed to be 0.2 year^{-1}.

8.3.4 Soil carbon stock

The carbon stock in Miombo woodland landscape in Mozambique is almost uniformly distributed and ranges from 32 to 133 Mg C ha^{-1} (average 76.3 Mg C ha^{-1}) of the first 50cm (Ryan et al. 2011). In the first 30 cm of soil, the carbon stock in Zambia was reported to range between 13.7 and 14.6 Mg C ha^{-1} (Kutsch et al. 2011). Clay content was significantly positively correlated with soil carbon in the top 40 cm and therefore areas of higher clay content contained elevated carbon levels (Walker & Desanker 2004).

The soil carbon stock for natural Miombo woodland in Kilosa is assumed to be 76.3 Mg C ha^{-1} of the first 50cm of soil.

In Savanna woodland, the soil carbon stock typically exceed the biomass carbon stock and when forests are cleared significant amount of carbon might be emitted (Ryan et al. 2011). According to IPCC guidelines, the amount of soil carbon emitted can be estimated based on the land use factor, the tillage practice and the fertilization rate. In tropical dry climate region a default emission value of 42% is provided for long term cultivated crops and for shifting cultivation a value of 36% is indicated. Williams et al. (2008) indicated that there are no clear trends in soil carbon stocks in the top 30cm along the abandoned machambas. Nevertheless, Williams et al. (2008) calculated that abandoned agricultural land had a median C stock 23% lower than the surrounding woodlands.

We use a carbon loss due to agricultural activities of 47%, based on the field measurements presented in Figure 19 (Walker & Desanker 2004). For shifting cultivation agriculture, a lower value of 23% is used (Williams 2008). Carbon did not appear to decline slowly as the age of the field increased and we assume that the SOC reaches a new equilibrium point after 20 years (time horizon of IPCC).

Besides a loss in Carbon stock, also a mineralization of N is associated with the loss of soil C (IPCC 2006). However, the impact is generally low and thus not considered within this study.

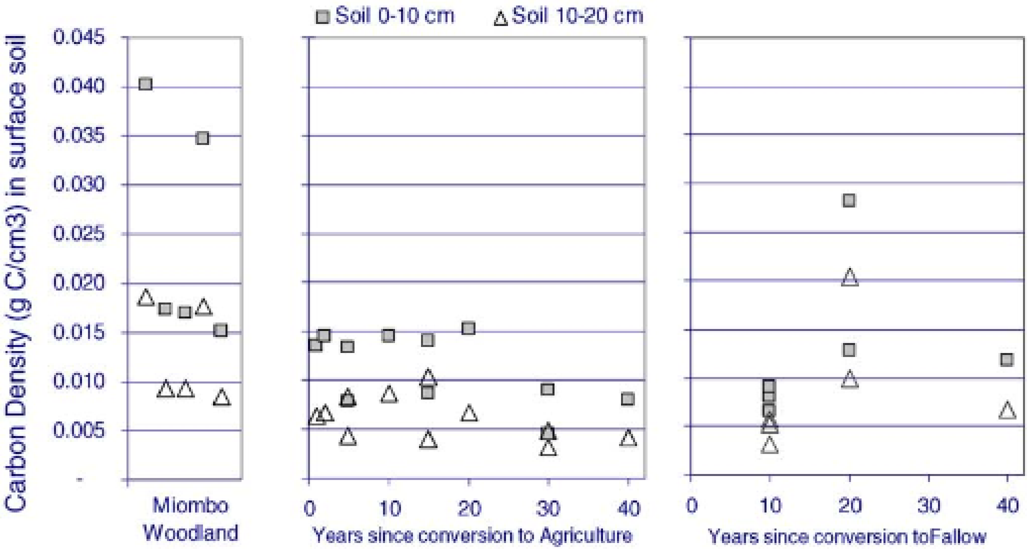


Figure 19: Correlation between age of land use and surface soil carbon density (Walker & Desanker 2004).

We assume that harvesting and straight regrowth does not affect the soil organic carbon content.

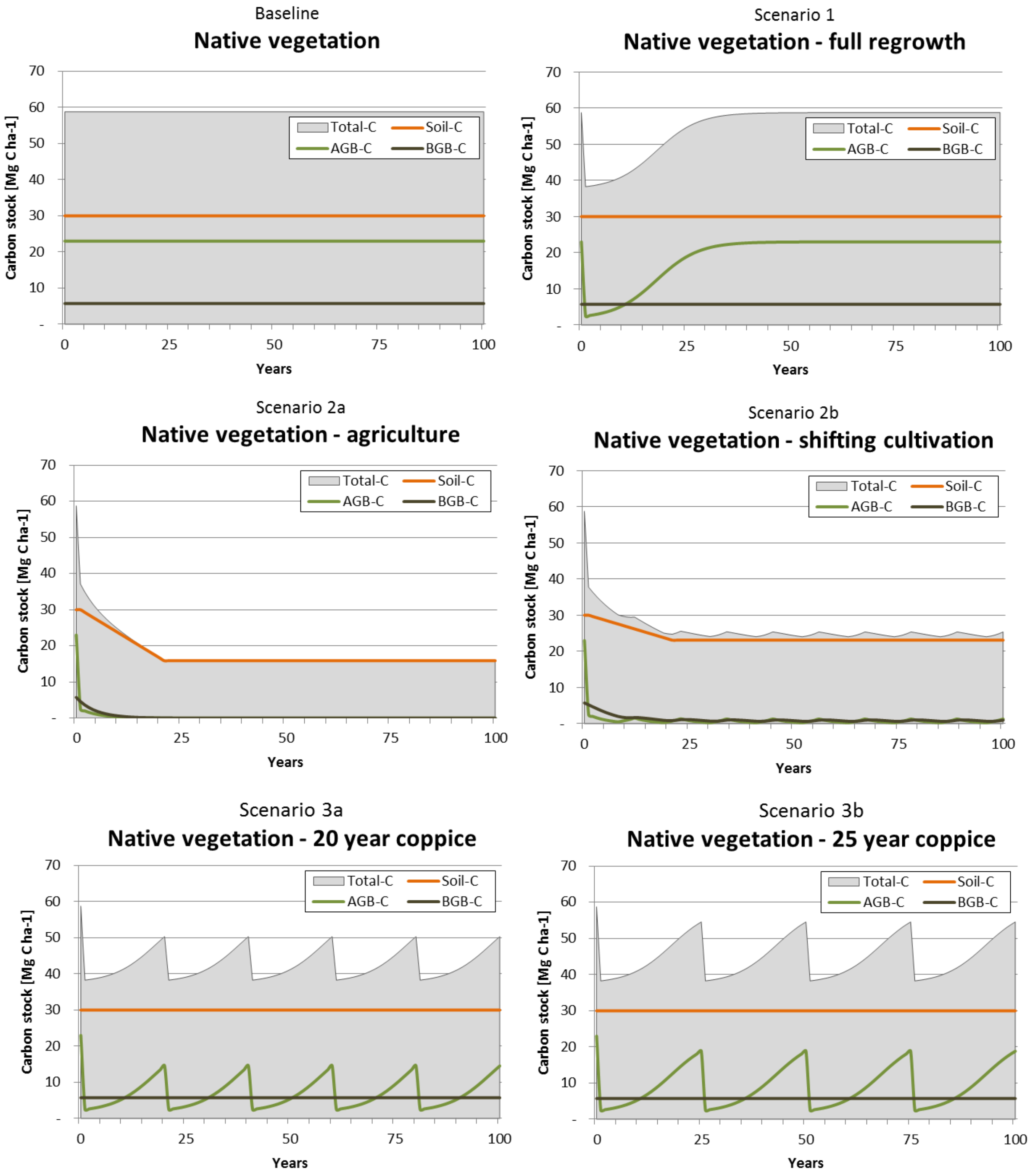
8.3.5 Wood harvesting

Ninety percent of the aboveground biomass in Miombo woodland is suitable for charcoal making by the earth kiln method (Chidumayo 1991). We have used a slightly more conservative value of 85% of the biomass (above 5cm diameter at breast height) used for charcoal production.

The decomposition rate of above ground biomass is assumed to be 0.2 year^{-1} and all carbon contained in the biomass is considered to be emitted as CO_2 to the atmosphere.

8.4 Dynamic carbon stock change

The carbon stock over a 100 year period for six different land management schemes is provided in Figure 20. Each scheme starts with an identical stand of native Miombo woodland and the stand is cleared for charcoal production in year 0. Depending on the post-harvest management of the land, the carbon stock recovers (scenario 1), shows a new equilibrium (scenario 2) or remains dynamic (scenario 3).


Baseline
Native vegetation

Scenario 1
Native vegetation - full regrowth

Scenario 2a
Native vegetation - agriculture

Scenario 2b
Native vegetation - shifting cultivation

Scenario 3a
Native vegetation - 20 year coppice

Scenario 3b
Native vegetation - 25 year coppice

Figure 20: Dynamic carbon stock model for 6 scenarios. The total carbon stock includes the carbon contained in the living biomass and the soil organic carbon.

In Table 4 the average carbon stock over 100 years and the amount of harvested wood is indicated. The amount of harvested wood is calculated based on the respective biomass stock, the extraction efficiency and the harvesting schedule.

Table 4: Cumulated CO2 uptake and emissions over 100 years, the adapted GWP characterization factor, the harvestable wood (in ton d.m.) and the resulting GHG emissions (kg CO2 eq / kg wood) for each scenario considered.

No	Scenario	Average C stock [Mg C ha-1]	Wood harvest (d.m.) [Mg ha-1]
0	Natural forest	58.8	0.0
1	Cut and regrowth	55.1	37.0
2a	Agriculture - permanent	18.1	37.0
2b	Agriculture - shifting cultivation	26.1	37.0
3a	Coppice cycle 20 years	42.8	145.9
3b	Coppice cycle 25 years	44.8	155.0

9 Charcoal production

9.1 Introduction

Charcoal is the solid residue remaining, when biomass is carbonized or pyrolysed under controlled conditions in a closed space such as a charcoal kiln (FAO 1987). During the carbonization process the air entry is controlled so that the biomass does not burn as in conventional fire, but decomposes chemically to form charcoal.

Even though wood is the most widely used raw material for charcoal making, theoretically all dry organic material is suitable. Some materials (e.g. crop residues) return very fine grained charcoal pieces and thus the additional process of briquetting is required.

The charcoal making process involves wood cutting (or biomass collection), kiln preparation, carbonization and finally unloading charcoal from the kiln. The carbonization process itself can be split into four stages of combustion, dehydration, exothermic reaction, and cooling (Boutette & Karch 1984):

- **Combustion stage:** The kiln is ignited by burning some of the wood and the temperature increase from ambient temperature to 600°C. At this state, water and carbon dioxide are driven off as heavy smoke. After the fire establishes the ignition point of the kiln is closed.
- **Dehydration stage:** The wood is dried at a temperature scheme of 100°C to 300°C and the mainly water being driven off as vapour.
- **Exothermic reaction stage:** The wood breaks down and heat is produced (temperature scheme of 300°C to 600°C). During this stage, water, methanol, ethanol, acetic acid, carbon monoxide, carbon dioxide, hydrogen, nitrogen, methane, pitch and tars are distillated out of

the wood in thick yellowish smoke. The end of carbonization is indicated by light blue smoking of the Kiln, during which the temperature falls from 600°C to 300°C.

- **Cooling stage** of the glowing carbon (charcoal) to ambient temperature.

9.2 Charcoal kiln technologies

In developing countries traditional earth mound or pit kilns are the most frequently used types. Wood is cut and stacked before being covered by a controlling and damping layer and carbonized. Where the soil is rocky, hard and shallow or has a high groundwater table, mounds are preferred over pits. The efficiency rates of these kilns are typically low. Nonetheless, these kilns represent practical, low-investment options for poor producers, especially when the charcoal sector is informal (FAO 1987).

In Kilosa about four types of traditional charcoal production kilns are used. These include the box type kiln, the rocket kiln, the mdomo wa chupa kiln and the msonge kiln, which are further described in (Sago 2013). The kilns differ in shape and size but all can be classified as basic earth mound kilns, the most commonly used traditional charcoal kiln throughout East Africa.

Besides the charcoal kilns already used in Kilosa, several other traditional (e.g. earth pit kiln), improved (e.g. improved earth mound kiln) and stationary (e.g. brick kilns or retort kilns) charcoal kiln types exist (Sago 2013).

Within this study, we compare the most used traditional kiln (basic earth mound kiln, BEK) to a slightly modified version (improved basic earth mound kiln, IBEK). Even though brick kilns are not considered as practicable for the remote areas, we nevertheless include the half orange brick kiln for a theoretic comparison in order to illustrate the effect of different kiln efficiencies and to cover the whole impact range.

Figure 21: Charcoal kilns compared in this study: basic earth mound kiln (BEK), improved earth mound kiln (IBEK) and half-orange brick kiln (BK) (source: TaTEDO)

9.2.1 Basic earth mound kiln (BEK)

The basic earth mound kiln is one of the oldest and most commonly used kilns all over East Africa. The size of the kiln varies from a few cubic meters capacity to over 100 cubic meters. The log pieces are stacked vertically or horizontally and the kiln shape varies from circular to rectangular, depending on the method of stacking. To seal the pile, first straw, leaves, coarse grass, etc., are spread over the pile and then earth or sand spread over this layer. The coating should seal all cracks and the air holes at the base of the mound remain open (FAO 1987).

Large kilns are built and operated by a team of three to four people, while small is normally operated by one person. The yield from these kilns varies depending on the construction, weather condition, wood species and the experience of the operator. Carbonization time is between 10- 14 days and cooling time is 24-48 hour on the average (Sago 2013).

9.2.2 Improved basic earth mound kiln (IBEK)

The improved basic earth mound kiln (IBEK) technology is based on a range of several low cost improvements of the traditional earth mound kiln aiming to increase the efficiency. The improvement includes the introduction of a chimney, an air circulation apron (arrangement of logs), as well as ensuring that wood used is adequately dried and cut into approximately similar sizes. During loading, plenty of small wood and branches is needed to fill the interspaces between logs so that oxygen supply becomes limited during carbonization (Sago 2013).

TaTEDO has developed and promoted this technology for more than ten years. Even though the IBEK shows an increased efficiency and the carbonization process is shorter, the adoption of the IBEK faces challenges. Especially the time consuming preparation and the added costs for the iron sheet used to form a chimney are mayor drawbacks.

9.2.3 Brick kilns (BK)

A typical brick kiln used in Tanzania is the half orange kiln (HOK), which was introduced in Tanzania by the Ministry of Energy and Minerals in the 1980s. The kiln is made up of fired bricks and has at least ten ventilation holes at the bottom of the kiln. The kiln is a hemisphere of about 6 meters in diameter, with a capacity of about 50 cubic meters. It needs about 6,500 bricks to construct. A mixture of charcoal fines and mud or mud alone is used to join the bricks. The cost of construction and training on the use of HOK is around Tsh 4million. The life of the kiln is 5-10 years.

Like with all other kilns, when unloading charcoal from HOK fire might break out as soon as the door is opened and oxygen is supplied in the kiln. This fire has to be extinguished immediately with water and therefore a reliable water source must be available. The carbonization process takes 14-25 days. BK are stationary kilns with a relatively high efficiency and hence it is advised that this kiln type should be constructed in the areas with many trees or at the sawmill industries so as to reduce cost for transporting raw material needed to produce charcoal (Sago 2013).

9.3 Inventory data used

9.3.1 System description

Carbonization is the process of burning wood or biomass in the absence of air, where wood is converted into charcoal, liquids, gases and solid residues. In Figure 22, the main inputs and outputs of a charcoal kiln are illustrated.

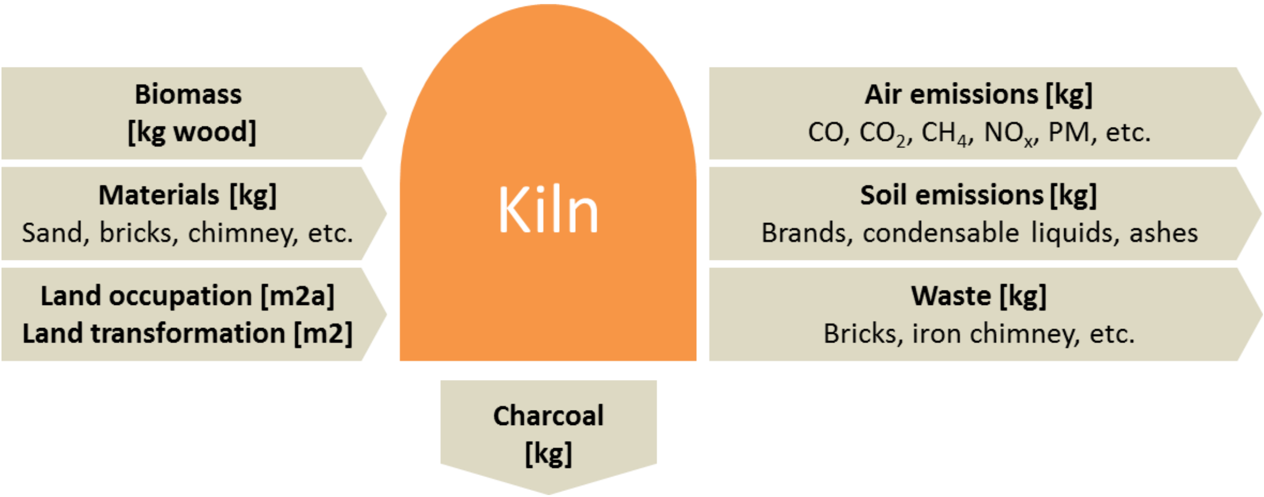


Figure 22: Schematic overview about the main input materials and outputs (charcoal, emissions and wastes) of a charcoal kiln.

The type and amount of **input materials** (i.e. wood and kiln construction materials), as well as the land required to construct the kiln, differ depending on the kiln technology used. The amount of charcoal products from a certain amount of wood is determined by the kiln efficiency.

During the combustion and pyrolysis process various gases are emitted. Some of the **air emissions** (CO_2, CH_4 and N_2O) are greenhouse gases, while others are toxic (CO) or are responsible for acid rains (SO_2). Further, particulate matter (PM) emissions are potentially causing cancerogenic effects on the respiratory system.

Brands are partially carbonized wood products. They are either used as a cooking fuel or remain in the kiln chamber, along with **wood ashes**. According to Pennise et al. (2001) about 3.6% of the wood is emitted as **condensable liquids** (tars and oils).

We use a charcoal carbon content of 73.3% and an energy content of 28 MJ/kg for this study (Müller et al. 2011).

9.3.2 Kiln efficiency and wood demand

The kiln efficiency and the charcoal quality depend on several factors, including the kiln type, the arrangement of the wood logs, the wood species, the moisture content of wood and the management of the carbonization process. In the following the most important ones are described and an overview about the values used is provided.

Wood species: The U.S. Forest Products Laboratory indicates that all investigated wood species can be used to produce charcoal with comparatively high fixed carbon (U.S. Forest Products Labratory 1961). Nevertheless, the charcoal yield and charcoal density vary depending on the wood type and are positively correlated with the basic density of the wood (Ishengoma & Klem 1979).

Wood moisture content: Wood moisture is expected to have a negative effect on the charcoal yield, as the carbonization process only starts once the biomass is completely dry. The fact that seasoned, air dried wood still has a moisture content of 12-18% (depending on the climate) implies, that the remaining moisture has to be evaporated during the charcoal making process. This is done by burning parts of the wood in the kiln to supply the needed energy for evaporation.

Kiln type and management: The air circulation and carbonization temperature depend on the kiln type used and the management (control). An increased air circulation might cause the combustion of the wood to ash. Further, the charcoal quality depends also on the amount of volatiles contained in charcoal. Maintaining higher carbonization temperatures will drive out and burn most volatiles. Therefore lower temperature values of between 300 and 500•C are favourable in maintaining volatiles.

The kiln efficiency values used for this study are based on measured values from the study sites in Kilosa and are validated based on literature values.

Efficiency BEK: In Table 5 the main characteristics of BEK are listed. The charcoal yield measured as kg charcoal per kg wood (d.m.) reported in literature and measured at the study site range from 13.1% to more than 37% (Pennise et al. 2001; ESMAP 1991; Smith & Pennise 1999; Mundhenk et al. 2010; Nturanabo et al. 2010; Kimaryo & Ngerza 1989; Sago 2013; Bailis 2005). The large variations can be explained by the amount of different parameters influencing the kiln efficiency (see above) and might also be caused by different reporting and measurement proceedings. A review study indicated a conversion rate of most commonly used kilns ranged between 11.8% an 25.7% and was in average of 18.8% (Chidumayo & Gumbo 2013). Given the large variations, we model two traditional charcoal kilns, one with the measured efficiency in

Kilosa of 13.1% (BEK1 scenario) and one with the mean efficiency value of 26.3% from 10 Kenyan earth mound kilns (BEK2 scenario) based on Bailis (2013).

Efficiency IBEK: In Table 6 the main characteristics of IBEK are listed. There are not many reported efficiency values for IBEK kilns available. The efficiency is estimated to range between 15% and 25% (Beukering et al. 2007). We've used the values reported from Kilosa of 19.6% efficiency (Sago 2013).

Efficiency BK: In Table 7 the main characteristics of BEK are listed. We've used the average efficiency values of 29.6% (Mohod & Panwar 2011; Smith et al. 1999; Pennise et al. 2001).

Table 5: Basic earth mound kiln: literature values of the charcoal yield under different settings.

		Kiln specifications				Wood input			Yield			
No	**Country**	**Kiln type**	**Size** [m3]	**Stack Density** [kg/m3]	**Firing Time** [h]	**Wood input** [kg d.m.]	**wood moisture** [on a dry basis]]	**Wood Type**	**Charcoal Yield** [kg charcoal (d.m.) / kg wood (d.m.)]	**Carbon Yield** [kg C charcoal/kg C wood]	**Energy Yield** [MJ charcoal/MJ wood]	**Source**
1	Kenya	BEK			170	782	0.667	Croton megalopolis	0.226	0.384	0.459	Pennise et al. (2001)
2	Kenya	BEK			121	350	0.618	Eucalyptus	0.216	0.367	0.339	Pennise et al. (2001)
3	Kenya	BEK			237	25250	0.217	Acacia mearnsii	0.280	0.477	0.470	Pennise et al. (2001)
4	Kenya	BEK			233	16080	0.217	Acacia mearnsii	0.311	0.529	0.522	Pennise et al. (2001)
5	Kenya	BEK			232	14600	0.217	Acacia mearnsii	0.342	0.582	0.574	Pennise et al. (2001)
6	Jamaica	BEK	10	572		5719	0.34	Mix	0.290			ESMAP (1991)
7	Jamaica	BEK	15	433		6501	0.34	Mix	0.260			ESMAP (1991)
8	Jamaica	BEK	10	594		5943	0.16	Mix	0.300			ESMAP (1991)
9	Jamaica	BEK	15	426		6389	0.19	Mix	0.260			ESMAP (1991)
10	Thailand	BEK				177	0.205	Eucalyptus	0.282			Smith et al. (1999)
11	Thailand	BEK				170.6	0.215	Eucalyptus	0.284			Smith et al. (1999)
12	Thailand	BEK				171.3	0.21	Eucalyptus	0.327			Smith et al. (1999)
13	Thailand	BEK				175	0.194	Eucalyptus	0.303			Smith et al. (1999)
14	Senegal	BEK				6568	0.28	Acacia Seyal	0.300			Mundhenk et al. (2010)
15	Senegal	BEK				6846	0.18	Acacia Seyal	0.220			Mundhenk et al. (2010)
16	Uganda	BEK				2756	0.31	Mix	0.156			Nturanabo et al. (2010)
17	Uganda	BEK				3555	0.284	Mix	0.152			Nturanabo et al. (2010)
18	Uganda	BEK				3835	0.272	Mix	0.162			Nturanabo et al. (2010)
19	Uganda	BEK				4709	0.243	Mix	0.157			Nturanabo et al. (2010)
20	Uganda	BEK				5813	0.185	Mix	0.153			Nturanabo et al. (2010)
21	Kenya	BEK	11.5	321.7		3700	0.288	T.camphoratus	0.263			Bailis (2005). average of 10 kilns
22	Tanzania	BEK	7	544		3808	0.28	Acacia xanthophloea	0.280			Kimaryo & Ngereza (1989)
23	Tanzania	BEK	16	532		8512	0.18	Acacia xanthophloea	0.180			Kimaryo & Ngereza (1989)
24	Tanzania	BEK	4	611		2444	0.25	Acacia xanthophloea	0.310			Kimaryo & Ngereza (1989)
25	Tanzania	BEK	3	353		1059	0.61	Acacia xanthophloea	0.240			Kimaryo & Ngereza (1989)
26	Tanzania	BEK	6	306		1836	0.64	Acacia xanthophloea	0.260			Kimaryo & Ngereza (1989)
27	Tanzania	BEK	6	247		1482	0.25	Acacia xanthophloea	0.250			Kimaryo & Ngereza (1989)
28	Tanzania	BEK	3	270		810	0.33	Acacia xanthophloea	0.370			Kimaryo & Ngereza (1989)
29	Tanzania	BEK	6	608		3648	0.31	Acacia xanthophloea	0.200			Kimaryo & Ngereza (1989)
30	Tanzania	BEK	20	1219		24380	0.40	Acacia xanthophloea	0.170			Kimaryo & Ngereza (1989)
31	TZ, Kilosa	BEK	5	800	312	4000	0.42		0.131			Sago (2013) Data from Kilosa
Average		**BEK**	**9**	**522**	**217.57**	**5551**	**0.31**		**0.246**	**0.468**	**0.473**	
Median		**BEK**	**7**	**532**	**232.68**	**3808**	**0.27**		**0.260**	**0.477**	**0.470**	
Min		**BEK**	**3**	**247**	**121.20**	**171**	**0.16**		**0.131**	**0.367**	**0.339**	
Max		**BEK**	**20**	**1219**	**312.00**	**25250**	**0.67**		**0.370**	**0.582**	**0.574**	
Values used		**BEK 1**	**5**	**800**	**312**	**4000**	**0.42**		**0.13**			Sago (2013) Data from Kilosa.
		BEK 2	**5**	**800**	**312**	**4000**	**0**		**0.263**			Bailis (2005). average of 10 kilns

Table 6: Improved basic earth mound kiln: literature values of the charcoal yield under different settings.

		Kiln specifications				Wood input			Yield			
No	**Country**	**Kiln type**	**Size** [m3]	**Stack Density** [kg/m3]	**Firing Time** [h]	**Wood input** [kg d.m.]	**wood moisture** [on a dry basis]]	**Wood Type**	**Charcoal Yield** [kg charcoal (d.m.) / kg wood (d.m.)]	**Carbon Yield** [kg C charcoal/kg C wood]	**Energy Yield** [MJ charcoal/MJ wood]	**Source**
1	Tanzania	IBEK	14.4	0.7		7100		mix	0.250			Kempf (2007) yield according to expert guesses
2	TZ, Kilosa	IBEK	5	800	144	4000	0.4196	Acacia xanthophloea	0.196			Sago (2013) Data from Kilosa
3	TZ, Kilosa	IBEK	5	800	312	4000	0.4196	Acacia xanthophloea	0.196			Sago (2013) Data from Kilosa
Average		**IBEK**	**8**	**534**	**228.00**	**5033**	**0.42**		**0.214**			
Median		**IBEK**	**5**	**800**	**228.00**	**4000**	**0.42**		**0.196**			
Min		**IBEK**	**5**	**1**	**144.00**	**4000**	**0.42**		**0.196**			
Max		**IBEK**	**14**	**800**	**312.00**	**7100**	**0.42**		**0.250**			
Values used		**IBEK**	**5**	**800**	**312**	**4000**	**0.42**		**0.20**			

Table 7: Brick kiln: literature values of the charcoal yield under different settings.

		Kiln specifications				Wood input			Yield			
No	**Country**	**Kiln type**	**Size** [m3]	**Stack Density** [kg/m3]	**Firing Time** [h]	**Wood input** [kg d.m.]	**wood moisture** [on a dry basis]]	**Wood Type**	**Charcoal Yield** [kg charcoal (d.m.) / kg wood (d.m.)]	**Carbon Yield** [kg C charcoal/kg C wood]	**Energy Yield** [MJ charcoal/MJ wood]	**Source**
1	India	HOK	19	370		7035	0.285	mix	0.283			Mohod (2011)
2	India	HOK	19	371		7055	0.283	mix	0.278			Mohod (2011)
3	India	HOK	19	382		7250	0.293	mix	0.274			Mohod (2011)
4	India	HOK	19	372		7070	0.3	mix	0.277			Mohod (2011)
5	India	HOK	19	376		7150	0.286	mix	0.283			Mohod (2011)
6	Thailand	Brick beehive							0.330			Smith et al. (1999)
7	Brasil	Brick beehive			78.96	3430	0.161		0.341	0.521	0.461	Penisse et al. (2001)
Average		**BK**	**19**	**374**	**78.96**	**6498**	**0.27**		**0.295**			
Median		**BK**	**19**	**372**	**78.96**	**7063**	**0.29**		**0.283**			
Min		**BK**	**19**	**370**	**78.96**	**3430**	**0.16**		**0.274**			
Max		**BK**	**19**	**382**	**78.96**	**7250**	**0.30**		**0.341**			
Values used		**BK**	**19**	**374**	**78.96**	**6498**	**0.27**		**0.295**			**average**

9.3.3 Land occupation and transformation

The earth mound kiln is only used for one cycle, and for the inventory it was assumed that the carbonization and cooling takes about 14 days. The land occupation and land transformation of BEK is based on the lifespan of the kiln and the kiln area.

9.3.4 Wood input

Particular tree species are favoured for charcoal production because of high calorific value due to dense and hard charcoal they produce. In Kilosa the charcoal producers preferred tree species for charcoal production in order of priority are: Mkambala (*Acacia nigrescents boechmeli*), Mnhondolo (*Jurbernadia globiflora*), Myombo (*Brachystegia bochmii*) and Mhungilo (*Lanmea schmimperi*) (Sago 2013).

The amount of wood demanded per kg charcoal depends on the kiln efficiency (see chapter 9.3.2) and the amount of fresh wood is calculated based on the moisture content. The wood logs used for charcoal production in Kilosa were harvested one week before charcoal production. Results of the moisture sampling showed average moisture content of 41.96 % (Sago 2013). The carbon content was measured as 44%, the ash content as 0.5% and the calorific value is 18MJ/kg dry mass.

9.3.5 Materials

Following material inputs are considered within this study. The kilns were built without the use of machinery and the tools used are not considered within this study (production and disposal of tools is regarded as neglectable).

Earth mound kilns: The materials used to construct earth mound kilns differs from amongst charcoal producers and depends on the available material at the site. For this study we assume that the covering layer is 20 cm thick and is made out of soil. To calculate the amount of soil needed, a rectangular earth mound (6m x 2.7mx2m) was assumed, with sand covering the top area and the side walls. A wet sand density of 1905 kg/m3 was used. Each kiln is only used once.

The improved kiln also requires a chimney. A 2.3m long chimney with a diameter of 10cm is assumed. The chimney is made out of low-alloyed steel with a wall thickness of 2mm and a density of 7850 kg/m3. The chimney is typically used 5 times before it is disposed.

Half orange kiln: The HOK is brick kiln which is stationary and for recurring usage. The material used is bricks and mortar. The FAO report states the number of bricks (0.24x0.12x0.06) needed for a kiln with 6m diameter to be 6000. For the inventory we assumed a 7m- diameter kiln as standard kiln and extrapolated linearly the number of needed bricks to 7000. A mortar layer of 30cm was assumed to cover four of the six sidewalls of the brick.

The HOK is exposed to mechanical impacts during loading and unloading and to temperature changes during carbonization. To keep the kiln functioning for a long period of time, continuous maintenance and replacement of damaged bricks is needed. For the inventory a cycle duration of 14 days and an overall lifetime of 5 years was assumed.

9.3.6 Emission to air

The air emissions are provided per kg of charcoal produced and include CO_2, CO, CH_4, NO, N_2O, NO_x, NMVOC and PM emissions. For the BEK and BK the emission values are based on Pennise et al. (2001) and Smith et al. (1999).

Table 8: Emission profile of different charcoal kilns.

			Air emissions [g/kg charcoal]										
Kiln type	**Country**	**Wood species**	**CO2**	**CO**	**CH4**	**TNMH**	**NO**	**Nox**	**N2O**	**TSP**	**PIC**	**gases+TSP**	**Source / Comment**
BEK	KE	Croton megalopolis	1992	207	35.2	90.3	0.058	0.087	0.12	41.2	374	2366	Penisse et al. (2001)
BEK	KE	eucalyptus	3027	333	46.2	94.9	0.055	0.13	0.3	34.1	508	3535	Penisse et al. (2001)
BEK	KE	Acacia mearnsii	1787	240	47.9	93.8		0.035	0.16	25	407	2194	Penisse et al. (2001)
BEK	KE	Acacia mearnsii	1147	195	61.7	124		0.045	0.084	38.7	419	1566	Penisse et al. (2001)
BEK	KE	Acacia mearnsii	1058	143	32.2	60.1		0.021	0.068	12.8	248	1306	Penisse et al. (2001)
BEK	Thai		1140	302.3	40.7	215.6			0.003	1.5	560	1700	Smith et al. (1999)
BEK	**Average KE**		**1802**	**224**	**45**	**93**	**0.06**	**0.06**	**0.15**	**30**	**391**	**2193**	Average of Kenyan emissions were used
BK	Thai		966	162	31.8	29.7			0.017	1.9	225	1191	Smith et al. (1999)
BK	Brazil		1382	324	47.6	80.9		0.028	0.045		453	1835	Penisse et al. (2001)
BK	**Average**		**1174**	**243**	**39.7**	**55.3**	**0.06**	**0.03**	**0.03**	**1.9**	**339**	**1512.95**	Same NO emissions as from the BEK kiln are assumed.

The emission specific for traditional kilns (BEK1) and improved kilns (IBEK) in Kilosa are approximated, based on the carbon balance (see chapter 9.3.8).

9.3.7 Emission to soil and water

The brands are partially carbonized wood products and are considered to remain at the site. According to Pennise et al. (2001) per kg of charcoal 230 g of brands are produced for BEK, while the amount of brands for BK is significantly lower (38g). The ash is assumed to remain in the soil (0.64g C / kg charcoal) (Pennise et al. 2001).

Even though not having a direct influence on the carbon balance, it has to be noted that the heat release over several days during carbonization (500-600°C) destroys all plants at the kiln site (incl. root stock, seedlings and seeds in the seedbed). Herbaceous vegetation from seed dispersal may establish within few years, while Miombo trees will not be colonized for long terms (slow growth and short distance dispersion of seeds). Farmers interviewed indicated that they perceive the soil as more fertile as compared to the surrounding land and thus suitable for agriculture.

9.3.8 Carbon balance

In Table 9, the carbon balance per kg of charcoal produced is provided for the compared kiln technologies. The carbon input is determined by the carbon content of wood (44%) and the kiln efficiency. The carbon contained in charcoal shows large variations. We've used an average value from an extensive literature review of 73.3% (Müller et al. 2011). The carbon contained in brands, condensables, ashes and total suspended particles is based on (Pennise et al. 2001).

For the BEK2 and BK the emission values as provided in chapter 9.3.6 were used. For the BEK1 and IBEK no emission profile is available. We've calculated subtracted the carbon emitted as solids from the carbon input from wood. The balance is assumed to be emitted as airborne emissions by the same emission shares as for BEK2.

Table 9: Carbon balance for the different kiln per kg charcoal produced.

Exchange	**Unit**	**BEK 1**	**BEK 2**	**IBEK 1**	**BK**
Input					
Carbon in wood	g	3'360	1'600	2'240	1'290
Output					
C-Charcoal	g	733	733	733	733
C-Brands	g	120	120	120	20
C-Condensables	g	101	47	67	42
C-Ash	g	0.6	0.6	0.6	0.6
C-CO2	g	1'692	492	928	320
C-CO	g	330	96	181	104
C-CH4	g	115	33	63	30
C-TNMHC	g	227	66	125	39
C-TSP	g	41	12	23	1

9.3.9 Inventory data

The life cycle inventory data for the compared kilns is provided in Table 10.

Table 10: Life cycle inventory data of the compared kilns.

Exchange	**Unit**	**BEK 1**	**BEK 2**	**IBEK 1**	**BK**	**Comment**	**Ecoinvent name**
Efficiency	*%*	*13.1%*	*27.5%*	*19.6%*	*34.1%*	*Average values from field survey and literature.*	-
Kiln size	*t wood [d.m.]*	4	4	4	42	*Average values from field survey and literature.*	-
Firing time	*h*	312	312	228	79	*Average values from field survey and literature.*	-
Wood input							
wood (dry)	kg	7.64	3.64	5.09	2.93	Calculated based on the efficiency	
wood (moist)	*kg*	*13.64*	*6.49*	*9.09*	*5.24*	*Based on a moisture content of 44%*	
Materials							
Sand	kg	55.65	26.50	37.10		Sand and grass leaves / branches directly from the site are used to construct the kilns. The amount of sand has been calculated based on the kiln surface (6m x 2.7m x 2m) and thickness of the layer (30cm).	sand, extracted for use
Steel	g			0.28878		Calculated based on the total weight of steel used (1.1kg), the lifespan of the chimney (5 times) and the amount of charcoal produced. Both, the	Cast iron, at plant/RER Sheet rolling, steel/RER
Mortar	g				1.8	Calculated based on total weight of mortar (3387 kg) and the lifespan production of the kiln (14305 kg charcoal per cycle and 130 cycles). Since now Tanzanian mortar inventory is available, the process is approximated with Swiss lime mortar production (conservative	Lime mortar, at plant/CH
Bricks	g				13.9	Calculated based on total weight of mortar (26188 kg) and the lifespan production of the kiln (14305 kg charcoal per cycle and 130 cycles). Since now Tanzanian brick inventory is available, the process is approximated with European brick production (conservative assumption).	Brick, at plant/RER
Land use							
Land occupation	m2a	1.1E-03	5.2E-04	5.4E-04	1.8E-05	Calculated based on the firing time, the kiln area and the amount of charcoal produced.	Occupation, mineral extraction site
Land transformation	m2	9.65	4.59	4.70	0.16	Calculated based on the firing time, the kiln area and the amount of charcoal produced.	Transformation, from shrub land Transformation, to mineral extraction site
Emissions							
CO2	g	6204	1802	3402	1174		Carbon dioxide
CO	g	770	224	422	243		Carbon monoxide
CH4	g	154	45	84	40		Methane
NO	g	0.19	0.06	0.11	0.06		Nitrogen monoxide
NOx	g	0.22	0.06	0.12	0.03		Nitrogen oxide
N2O	g	0.50	0.15	0.28	0.03		Dinitrogene oxide
TSP	g	105	30	57	2		Particulates, < 10 um
TNMHC	g	319	93	175	55		NMVOC, non-methane volatile organic compounds, unspecified origin
Wastes							
Brands	g	230	230	230	38	Assumed to be remained on ground. No impacts or benefits are considered.	
Condensables	g	139	65	92	58	Modelled as emissions to soil	Oils, unspecified
Ash	g	64	64	64	64	Modelled as emissions to soil	Disposal, wood ash mixture, pure, 0% water, to land farming/CH
Steel	g			0.3		Assumed to be recycled or reused.	-
Mortar	g				1.8		Disposal, building, cement (in concrete) and mortar, to sorting plant/CH U
Bricks	g				1.8		Disposal, building, brick, to final disposal/CH
Charcoal	**kg**	**1**	**1**	**1**	**1**		

9.4 Charcoal packaging

Charcoal packaging is important in terms of marketing and also to trace the production chain of charcoal. However, the sustainable charcoal packaging is not yet designed. Charcoal is typically bagged in traditional “gunias” (sisal bags) or in plastic bags (Bess 2013). For this study we’ve used a bag out of polypropylene weighing 100g.

10 Transportation

10.1 Introduction

Transportation and trade is an important component of the charcoal value chain and the choice of transportation vehicles does not only influence the economic, but also the environmental cost of charcoal. The transport and trading set-up of charcoal from the production site to the end consumer can differ significantly and in the following an overview about typical transport and trade forms is provided.

Charcoal traders, transporters and middlemen at the supply side: In general charcoal producer sell their charcoal to charcoal traders at the production site, where it is transported by hand or bicycle to a location where the charcoal bags can be loaded on larger transport vehicles. However, about 36 percent of charcoal producers use bicycles and transport the charcoal bags manually to nearby main roads or nearby retailer market (Sago 2013). Between Msimba and Mikumi, approximaly 100 middlemen along the highway to Dar es Salaam buy constantly charcoal from the producers and sell it directly to transporters/traders (Wymann von Dach et al. 2013).

Middlemen at the demand side, wholesalers & retailers: While middlemen function as information brokers establishing links between traders and wholesalers, especially in times of high or low supply, there are also wholesalers who directly purchase charcoal from the producer and act as trader, transporters, and wholesalers (Wymann von Dach et al. 2013). The charcoal bags are typically transported to retailer shops, selling a few bags per months, where charcoal is sold in buckets or tin sizes to the end consumer.

In the following an overview about i) the transportation distances ii) the different transportation vehicles and iii) the data relevant for the LCA study is provided.

10.2 Transportation distances

10.2.1 From village to nearby city

The transportation distances and the road quality from the study sites to the nearby urban centers are provided in Table 11. An average transport distance of 20km on earth road is assumed to transport charcoal from the village to the nearby city (Kilosa or Mikumi).

Table 11: Transportation distances and road quality from the charcoal villages under study area to the nearby city.

Village	**Distance (km)**	**Road quality**[8]	**Comment**
Dodoma-Isanga to Kilosa	17km	Earth road	The road to the village is accessible all year round. In Dodoma Isanga village there is no single charcoal transporter who uses motorbike, also charcoal producers /dealers prefer selling their charcoal in Kilosa, no charcoal is sold along the roadside.
Nyali to Kilosa	23km (long) 19km (short)	Earth road	The road to the village is not well accessible, to get to the village by car a longer route has to be used (the bridge is broken).
Kigunga to Kilosa	20km	Earth road	The road is accessible all year round
Ulaya Mbuyuni to Kilosa	27km	Earth road	The road is accessible throughout the year
Ihombwe to Mikumi	25km	Earth road	Charcoal from Ihombwe is transported to Mikumi, rather than to Kilosa. The road to the village is accessible all year round
Msimba to Mikumi	10km	Tamarc road	In Msimba village charcoal producers/dealers prefer selling their charcoal on the road side than bringing the charcoal to Mikumi town.
Total	20km (average)	Earth road	

10.2.2 From small cities to Morogoro and Dar es Salaam

The transportation distances from Kilosa and Mikumi to Morogoro and Dar es Salaam were measured via google earth and the distances are verified by the driver.

---

[8] Indicate the road quality: Tarmac or earth roads

Table 12: Transportation distances from Kilosa and Mikumi to Morogoro and Dar es Salaam.

Road type	**Unit**	**Kilosa – Morogoro**	**Mikumi – Morogoro**	**Morogoro – Dar es Salaam**
Tarmac road	km	83	122	194
Earth road	km	29	0	0
Total	**km**	**112**	**122**	**194**

10.3 Transportation vehicles

In Table 13 an overview about the main transportation vehicles and their characteristics is provided. The values contained in the table are based on interviews, which are provided in the annex. Even though charcoal transportation by train is currently no alternative, we included a freight transport as a theoretical comparison. Train not considered as an option.

Table 13: Overview about the carrying capacity, the fuel consumption and charcoal losses associated to typical transportation vehicles in the charcoal sector.

Vehicle	**Capacity**	**Fuel (tarmac)**	**Fuel (earth road)**	**Returns**	**Bursts**	**Losses**	**Dataset used / Comment**
	[kg charcoal]	[kg/100km]	[kg/100km]	[% empty]	[% bursts]	[% lost]	
Bicycle	53	-	-	N.A.	21.6%	7.4%	Ecoinvent DS "Transport, bicycle" is used. The unit is personkm. The losses are based on average values from Kilosa (N=10).
Motorcycle	92	2.0	5.3	58.9%	5.3%	3.5%	Ecoinvent DS "Transport, scooter" is used, while the fuel use is adapted according to the average values from Kilosa (N=6).
Truck, small	3.5 - 7.5 tons	15.1	26.9	20.0%	N.A.	0.6%	Ecoinvent DS "Transport, lorry 3.5-7.5t, EURO3" is used, while the fuel use is adapted according to the average values from Kilosa (N=5).
Truck, big	16 - 32 tons	32.8	-	20%	N.A.	0.6%	Ecoinvent DS "Transport, lorry >32t, EURO3/RER" is used as an approximation, while the fuel use is adapted according to the average values from Kilosa (N=4).
Pick up	N.A.	9.1	N.A.	0%	N.A.	0.1%	Ecoinvent DS "Transport, passenger car, diesel, EURO3" is used, while the fuel use is adapted according to the average values from Kilosa (N=2).
Rail	N.A.	0.0107 [kg diesel per ton.km]		0%	N.A.	N.A.	Ecoinvent DS "Transport, freight, rail, diesel" is used as an approximation.

11 Retail and distribution

We have interviewed two wholesalers, five retailers and two acting as both, wholesaler and retailer (see annex 17.5). Depending on the consumer, the charcoal is bought directly from the charcoal producer, from the wholesaler or retailer and thus, the impacts associated to this life cycle stage are highly variable. However, it is assumed that the impacts are low compared to the charcoal production, the long distance transport and the use of charcoal. Thus, we do not focus on assessing the impact of different retail systems, but assume default values for transportation and charcoal losses.

Transportation of charcoal to the retail store: Charcoal is transported from and to wholesalers and retailers by using different vehicles, ranging from wheelbarrows, bicycles, motorcycles to small trucks. In this study we assume that the distribution within an urban area is conducted by a small truck, driving 10km.

Charcoal packaging: Charcoal is usually bought by different tin sizes (2kg to 10kg) and the charcoal is typically transported in small plastic bags from the retail shop to home (10g/kg charcoal). In some cases consumers also buy whole charcoal bags (28kg to 70kg). We assume that a medium size HDPE carrier bag (10g) is used to transport five kg of charcoal (used once).

5kg is on a higher side, the commonly used plastic bags could have average weight of 1kg to 1.5kg

Charcoal losses: Each time the charcoal bag is moved some charcoal is lost and also the charcoal quality is reduced to some extent, since charcoal pieces might be broken into smaller parts and ultimately into charcoal dust. In average at a retail shop between 2% and 14.5% (average of 5.4%) of the charcoal cannot be sold given the small size. While some pieces can still be used by the shop owner for cooking, the fine particles are lost. We assume that most of the losses (5%) are very fine dust, which is generally not used anymore.

Table 14: Life Cycle inventory of charcoal retail (per kg charcoal).

Parameter	Charcoal trade	Unit	Comment	Ecoinvent Name
Charcoal losses	*5%*	*%*	*Based on average losses from Kilosa/DSM (N=9)*	**-**
Material				
Charcoal	1.05	kg		-
Plastic bag	2.00	g	Plastic bag for charcoal transport	Polyethylene, LLDPE, granulate Extrusion, plastic film
Transport				
Truck, small	1.1E-02	tkm	Estimate: 10km with a small lorry from the wholesaler (stop of long distance transport) to the retailer.	Transport, lorry 3.5-7.5t, EURO3
Emissions to soil				
Charcoal dust	50	g	Not used. And disposed on the floor	Disposal, wood ash mixture
Output				
Charcoal, at retailer shop	1	kg		-

12 Charcoal use

12.1 Introduction

Wood and charcoal are by far the main energy source for cooking. Traditionally cooking stoves are built out of metal and are characterized by their poor combustion efficiency resulting in excessive biomass use. Alternatives to traditional cook stoves, so called improved cook stoves (ICS), have been studied, promoted and commercialized in East African countries since the 1980's. However, despite many efforts by a wide variety of stakeholders, the actual use of ICS remains limited. According to UNDP only 1% of the Tanzanian household have access to ICS (UNDP 2009). Riedijk estimated that the market size that can be reached in Tanzania is still more than 4,000,000 households (out of 8,750,000 households in total) mainly located in rural areas, who are not aware of the energy and money saving potential that awaits them when using improved cook stoves (Riedijk 2011).

We compare 3 different cooking stoves used by housholds: traditional metal stove, the most common improved stove (Jiko Bora) and most efficient stove (Sazawa). Both improved stoves are built by SECCO, a spin-off company of TaTEDO. The data is based on primary data from stove producers and is completed with data from literature.

12.2 Overview about the compared stoves

In Tanzania most currently stoves currently used are the "traditional stoves" built out of metal. As indicated above, traditional stoves have low energy efficiencies and release a broad range of pollutants strongly affecting human health (indoor pollution). Thus, increasing efficiency does not only reduce charcoal demands, but also the indoor air pollution.

There exist quite a range of different improved stoves[9] types tailored for different needs in terms of shape, size and materials. The Sazawa and Jiko bora stoves are improved charcoal stove models frequently used by urban households developed by TaTEDO and produced by SEECO. The main improvement is one or two lime ceramic liners which increases the heat storage

---

[9] There is no international standard or definition of an „improved stove". However, in practice an improved stove should generally save more than 50% of the biomass compared to the traditional stove and/or decreases the incomplete combustion of biomass and thus decreases the air pollution.

capacity compared to metal stoves. Thus, the heat losses can be reduced and the energy efficiency increases.

The stove most sold by SEECO is the straight Jiko bora stove being developed in 1988 and promoted since 1992.[10] The Sazawa stove was established and promoted in 1994. The most popular stove size used in urban households is 10 inch (254mm) in diameter, which is also used as the stove size in this study.

Figure 23: Traditional stove (left), Single lime ceramic liner stove Jiko Bora (middle) and the double lime ceramic liner stove Sazawa (right).

On overview about the main characteristics of each stove technology is provided in Table 15.

Table 15: Summary of the main characteristics of traditional and improved charcoal stoves.

	Traditional stove	**Jiko Bora**	**Sazawa**
Weight (kg)	1 kg -2 kg	5 kg	7 kg
Materials	Iron	Iron, clay, cement, vermiculite	Iron, clay, cement, vermiculite
Capacity (g Charcoal)	500g	300g	300g
Efficiency (%)	18-22%	31% (average, WBT)	About 44% (estimate)
Lifespan (days)	1 year	3 years (replace liner) 6 years (dispose)	3 years (replace liner) 6 years (dispose)

---

[10] http://www.tatedo.org/files/publications/Brochures/charcoalstovebro.pdf

Cost (TZS)	2500 TSH	11000 TSH	18000 TSH

12.3 Production of stoves

According to TaTEDO, records have shown that currently more than 20,000 improved charcoal cook stoves are produced by independent producers in Dar es Salaam per month. The majority of stove producers have been in the stove business for more than two years indicating enough experience in stove production and sales for the production of good-quality stoves (Evodius 2010).

SECCO, the spin-off company of TaTEDO, is producing about 350 Jiko bora stoves and 40 Sazawa stoves per month serving the high end market. In general the prices of SECCO stoves are higher, since new metal sheets (instead of cheaper scrap metal) and high quality liner are used. The liner production nevertheless does also sell to independent producer.

These larger scale companies are only found in Dar es Salaam and Morogoro. The majority of the stove producers in Tanzania however operate on a smaller scale in local workshops where they work mostly with manual tools.

While the traditional stove is build out of metal, the improved stove consist out of a metal cladding, ceramic liner and binding material. An overview about the material composition is provided in Table 16.

Table 16: Input materials of different charcoal stoves.

Material	Traditional stove	Jiko Bora	Sazawa
Total weight (kg)	**1.5 kg**	**5 kg**	**7 kg**
Metal	1.5 kg	1 kg Outer part: Provides means of housing a ceramic liner, air hole with door, handles attachment, pot rests and legs Handles: Stand for the pots	1 kg Outer part: Provides means of housing a ceramic liner, air hole with door, handles attachment, pot rests and legs Handles: Stand for the pots
Ceramic liner	-	Inner Part (3 kg)	Two ceramic liners (5 kg)

Binder - Cement	-	Insulation zone (0.3 kg)	Insulation zone (0.3 kg)
Binder - Vermiculite	-	Insulation zone (0.7 kg)	Insulation zone (0.7 kg)
Binder - Water	-	Insulation zone 0.5 litre water	Insulation zone 0.5 litre water

12.3.1 Metal processing

New Iron sheets are used to produce the improved stoves. Metal bending is done manually and for cutting the metal sheets, scissors are used. Metal is expensive for the small scale entrepreneurs, therefore most stove producers often choose to buy scrap metal of less quality. However, high quality stoves from SEECO are constructed out of new metal sheets.

Depending on the stove size and type there are some metal pieces which cannot be reused to shape other parts of the stove. In average about 100g of metal ends up as waste and is sold for 200TSH/kg to a scrap dealer.

Figure 24: Metal workshop (left) and metal scrap (right).

12.3.2 Ceramic liner production

The ceramic liner production is conducted locally and includes following processing steps.

1. The clay is bought from a nearby production site and transported to the SEECO liner production site.

2. The clay is mixed with water and modelled according to the desired shape and size. On the same day, also the characteristic holes are punched out.

3. The liner is sun dried for 3 days.

4. The dried clay is burnt in a kiln for 5 days.

Figure 25: Clay pile and modelling (left), sundried clay liner (middle) and cracked liner (right).

The SEECO kiln has a capacity of 500 liners out of which about 30 do crack or are not burned properly, depending on the quality of firewood. The process endures 5 days during which the fire is maintained continuously. In total about 2 tons of firewood is used for the process.

The ecoinvent inventory data “clay, at mine” has been used to approximate the clay production.

12.3.3 Binder production

A mixture out of cement, water and vermiculite is used to bind the liner to the cladding.

12.3.4 Inventory data of stove production

The life cycle inventory to produce one traditional, the jiko bora and the sazawa stove are provided in Table 17.

Table 17: Life cycle inventory data of stove production. The inputs and outputs are provided per stove produced.

Input	Traditional stove	Jiko Bora	Sazawa	Unit	Comment	Ecoinvent Name
Material						
Metal	1.6	1.1	1.1	kg	Estimate: Weight in final product and considering a scrap rate.	Steel, low-alloyed, at plant Sheet rolling, steel
Liner		3.18	5.3	kg	Estimate: Mass balance and considering a scrap rate of 6%	Lime mortar, at plant
Cement		0.3	0.3	kg	Estimate: Mass balance	Cement, unspecified, at plant
Vermiculite		0.7	0.7	kg	Estimate: Mass balance	Expanded vermiculite, at plant
Water		0.5	0.5	kg	Estimate.	Tap water, at user
Energy						
Wood burned (liner production)		60.0	100.0	MJ	Calculated based on 2tons of wood per 530 clay liner (3kg) and a wood heating value of 15MJ/kg.	Logs, hardwood, burned in wood heater 6kW
Infrastructure						
Building hall	3.33E-04	3.33E-04	3.33E-04	m2	Estimate based on size (100m2), lifespan 50 yrs and annual production 500 stoves per month	Building, hall, steel construction
Transport						
Truck	0.08	0.26	0.37	tkm	Estimate: 50km with a small lorry (metal, cement, clay and vermiculite). For the liner no transport is assumed, since the production site is just next door.	Transport, lorry 3.5-7.5t, EURO3/RER
Waste						
Scrap metal	0.1	0.1	0.1	kg	Recycling process (cut-off).	
Output						
Traditional stove	1			Piece		
Straight wall Jiko Bora		1		Piece		
Sazawa (double liner)			1	Piece		

12.4 Transport of Stoves

The vehicle used to transport the stove from the production site to the end consumer is chosen according to the amount and transportation distance of ordered stoves. It can range from a motorbike transport to the use of heavy trucks. For this study a typical transportation vehicle of a small scale lorry (Transport, lorry 3.5-7.5t, EURO3) and an average transportation distance of 50km to the end consumer are assumed.

12.5 Use of Stoves

12.5.1 Efficiencies and input Material

The performance of a cooking stove depends on a number of factors such as type and quality of fuel, construction material, quality of construction, stove handling, wind conditions and water spoilage. The efficiency of stoves can be measured in different ways. In this study we define efficiency as the ratio of the energy entering the pot to the energy content of the fuel consumed. The standard water boiling test (WBT) is used for testing the efficiency of the stoves.

In the WBT, a known quantity of water is heated on the stove under the conditions of heating up and simmering. Water is brought to boil during the heating up phase and is maintained within 5°C of boiling for 30 minutes. The overall thermal efficiency is defined as the ratio of useful energy (delivered to the cooking pot) to total net energy (in the fuel).

The thermal efficiencies of different stove types are listed in Table 18 and are based on literature (Bhattacharya et al. 2002; Boafo-Mensah et al. 2013; Jetter et al. 2012). The efficiencies of charcoal-fired cooking stoves were varied rather widely from 13% to 36%. The estimated efficiency of traditional charcoal stoves is about 15%. However, Jetter et al. (2012) compared the metal jiko stove from Kenya with the ceramic jiko and indicated that the thermal efficiency (24% to 25%) and fuel consumption were nearly the same for both stoves. Also the stove testing in Ghana indicated a relatively high efficiency of traditional metal stoves of 23%. In order to cover the whole range of potential efficiencies we model 2 traditional stoves, one with 15% efficiency and another one with 24%. For the improved cooking stove “Jiko Bora” we use the WBT measurements from the University of Dar es Salaam, which indicated a cold start thermal efficiency of 29%. Based on the literature values we conclude that the estimated efficiency of 44% of the Sazawa stove[11] is too high and calculate with a more accurate efficiency of 35%.

---

[11] http://www.tatedo.org/files/publications/Brochures/sazawabro.pdf

Table 18: Thermal efficiencies of different stove types.

Stove type	**Thermal efficiency**	**Method**	**Source**
Cambodian traditional	15%	WBT (N=3)	Bhattacharya et al. (2002)
Thai-bucket cookstove	16%	WBT (N=3)	Bhattacharya et al. (2002)
Chinese traditional	13%	WBT (N=3)	Bhattacharya et al. (2002)
QB Phil. charcoal/firewood	27%	WBT (N=3)	Bhattacharya et al. (2002)
Phil. charcoal/wood	22%	WBT (N=3)	Bhattacharya et al. (2002)
Lao improved	17%	WBT (N=3)	Bhattacharya et al. (2002)
Vietnamese improved	25%	WBT (N=3)	Bhattacharya et al. (2002)
Malaysian improved	18%	WBT (N=3)	Bhattacharya et al. (2002)
Bang Sue stove	18%	WBT (N=3)	Bhattacharya et al. (2002)
Tanzania Sahara	29%	WBT (cold start)	UDSM
Tanzania TaTEDO	29%	WBT (cold start)	UDSM
Tanzania KUUTE	35%	WBT (cold start)	UDSM
Ghana Ahinbenso	31%	WBT (cold start)	Boafo-Mensah et al. (2013)
Ghana traditional	23%	WBT (cold start)	Boafo-Mensah et al. (2013)
Ghana improved (Gyapa)	23%	WBT (cold start)	Boafo-Mensah et al. (2013)
GERES, charcoal fuel	25%	WBT (cold start)	Jetter et al. (2012)
Gyapa, charcoal fuel	27%	WBT (cold start)	Jetter et al. (2012)
Jiko Ceramic, charcoal fuel	25%	WBT (cold start)	Jetter et al. (2012)
Jiko Metal, charcoal fuel	24%	WBT (cold start)	Jetter et al. (2012)
KCJ Standard, charcoal fuel	32%	WBT (cold start)	Jetter et al. (2012)
Kenya Uhai, charcoal fuel	30%	WBT (cold start)	Jetter et al. (2012)
StoveTec Charcoal, charcoal fuel	36%	WBT (cold start)	Jetter et al. (2012)
Tanzania traditional 1	**15%**	**Estimated**	**TaTEDO**
Tanzania traditional 2	**24%**	**WBT (cold start)**	**Jetter et al. (2012)**
Tanzania Jiko Bora	**29%**	**WBT**	**UDSM**
Tanzania Sazawa	**35%**	**Estimated**	**TaTEDO**

12.5.2 Transport

The charcoal is usually transported by hand or bicycle from the retailer to home. The environmental impact of charcoal transport to the end consumer (from retailer) is considered as not relevant compared to the environmental impacts related to charcoal production, long distance transport and use.

12.5.3 Air emissions

The airborne emissions are calculated based on several emission profiles of different cooking stoves, as indicated in Table 19 (Bhattacharya et al. 2002; Jetter et al. 2012; Brocard et al. 1998; Bailis et al. 2003; Smith & Pennise 1999). The air emissions depend on many variables, including the fuel quality, the stove types, the environmental conditions and the operation of the stoves. Given the large variations amongst the laboratory and field tests, no stove specific emission ratios could be established. Instead, the average emissions per kg charcoal burned was used to model the emission. Thereby, the emissions per kg charcoal burned was multiplied with the amount of charcoal used to establish the stove specific emission profiles (g/MJ delivered).

Table 19: Emission profile of several charcoal cooking stoves measured in g per MJ delivered (green) and g per kg fuel (purple).

		Air emissions [g / MJ delivered to pot]							**Air emissions [g / kg fuel]**							
Stove type	**Thermal efficiency**	**CO**	**CO_2**	**CH_4**	**TNMOC**	**NO_x**	**THC**	**PM**	**CO**	**CO_2**	**CH_4**	**TNMOC**	**NO_x**	**THC**	**PM**	**Source**
Cambodian traditional	15%	8.4	579.3	1.9	1.6	0.02			34.2	2352.0	7.7	6.5	0.07			Bhattacharya et al. (2002)
Thai-bucket cookstove	16%	7.9	475.1	1.5	1.3	0.01			35.7	2155.0	6.8	5.8	0.03			Bhattacharya et al. (2002)
Chinese traditional	13%	50.0	696.0	2.2	2.4	0.09			175.0	2436.0	7.8	8.5	0.30			Bhattacharya et al. (2002)
QB Phil. charcoal/firewood	27%	26.2	301.1	1.1	1.3	0.03			198.0	2276.0	8.0	9.7	0.22			Bhattacharya et al. (2002)
Phil. charcoal/wood	22%	25.7	426.4	1.3	1.4	0.02			155.0	2567.0	7.8	8.5	0.14			Bhattacharya et al. (2002)
Lao improved	17%	29.0	530.5	2.1	1.4	0.04			134.0	2451.0	9.8	6.3	0.19			Bhattacharya et al. (2002)
Vietnamese improved	25%	12.5	319.0	1.5	0.7	0.04			87.2	2233.0	10.8	4.8	0.30			Bhattacharya et al. (2002)
Malaysian improved	18%	30.8	511.1	1.6	1.2	0.09			155.0	2576.0	8.2	6.2	0.43			Bhattacharya et al. (2002)
Bang Sue stove	18%	34.9	501.4	1.7	1.5	0.08			178.0	2555.0	8.7	7.8	0.42			Bhattacharya et al. (2002)
GERES, charcoal fuel	25%	43.7	402	2.8			4.4	0.9	303.5	2791.5	19.4			30.6	6.2	Jetter et al. (2012)
Gyapa, charcoal fuel	27%	38.1	333	1.6			3.2	1.06	282.7	2470.9	11.9			23.7	7.9	Jetter et al. (2012)
Jiko Ceramic, charcoal fuel	25%	41.6	539	3.3			5.6	1.02	294.7	3818.3	23.4			39.7	7.2	Jetter et al. (2012)
Jiko Metal, charcoal fuel	24%	30.9	464	4.2			7.5	1.05	210.2	3157.1	28.6			51.0	7.1	Jetter et al. (2012)
KCJ Standard, charcoal fuel	32%	40.4	320	1.6			2.5	0.84	365.4	2894.1	14.5			22.6	7.6	Jetter et al. (2012)
Kenya Uhai, charcoal fuel	30%	16.9	367	1.5			2.2	0.39	142.4	3093.1	12.6			18.5	3.3	Jetter et al. (2012)
StoveTec Charcoal, charcoal fuel	36%		301	0.7			5.4	0.43		3042.5	7.1			54.6	4.3	Jetter et al. (2012)
Kenya - charcoal stove									260.0	2280.0	18.0	3.2			0.4	Bailis et al. (2003)
India - charcoal cooking stove									275.0	2410.0	7.9	10.5			2.4	Smith et al. (1999)
West Africa - charcoal fuel									211.0	2260.0	2.4	0.4				Brocard et al. (1998)
IPCC default factor									200.0	2400.0	6.0	3.0			2.4	IPCC
Average	23%	29.1	441.6	1.9	1.4	0.05	4.4	0.8	194.6	2'610.9	11.4	6.2	0.23	34.4	4.9	
Min	13%	7.9	301.0	0.7	0.7	0.01	2.2	0.4	34.2	2'155.0	2.4	0.4	0.03	18.5	0.4	
Max	36%	50.0	696.0	4.2	2.4	0.09	7.5	1.1	365.4	3'818.3	28.6	10.5	0.43	54.6	7.9	
Tanzania traditional 1	**15%**	46.3	621.6	2.7	1.5	0.056	8.2	1.2	194.6	2610.9	11.4	6.2	0.2	34.4	4.9	
Tanzania traditional 2	**24%**	28.6	383.7	1.7	0.9	0.0	5.1	0.7	194.6	2610.9	11.4	6.2	0.2	34.4	4.9	
Tanzania Jiko Bora	**29%**	24.0	321.5	1.4	0.8	0.029	4.2	0.6	194.6	2610.9	11.4	6.2	0.2	34.4	4.9	
Tanzania Sazawa	**35%**	19.9	266.4	1.2	0.6	0.024	3.5	0.5	194.6	2610.9	11.4	6.2	0.2	34.4	4.9	

12.6 Disposal of ash and stoves

The lifespan of the traditional stove is according to experts about 1-2 years, while the improve stove lasts up to 3 years. After 3 years the liner is usually broken and as to be replaced. After replacing the liner, the stove lasts another 3 years until it has to be disposed. The liner is usually landfilled and the metal parts are collected and recycled. The disposal of the ash is assumed to be carbon neutral.

Figure 26: Picture of a waste stove

12.7 Inventory data

In Table 20 the life cycle inventory data of the compared charcoal stoves is provided.

Table 20: Life cycle inventory data of compared charcoal stoves per MJ heat delivered to pot.

	Traditional stove 1	**Traditional stove 2**	**Jiko Bora**	**Sazawa**	**Unit**	**Comment**
Efficiency	*15.0%*	*24.3%*	*29.0%*	*35.0%*	*%*	*MJ delivered to pot / MJ fuel*
Lifespan	1460	1460	8760	8760	hours	
Material						
Charcoal	0.28	0.17	0.14	0.12	kg	Calorific value of charcoal (23.9MJ/kg)
Stove	5.3E-04	3.3E-04	4.6E-05	3.8E-05	piece	Based on the lifespan, a burning rate of 6g/min and the efficiency of the stove
Transport						
Truck	4.2E-05	8.6E-05	1.2E-05	1.4E-05	tkm	Estimate: 50km with a small lorry from the stove production site to the end consumer. Ecoinvent name: Transport, lorry 3.5-7.5t, EURO3/RER
Emissions to air						
CO	46.3	28.6	24.0	19.9	g	Carbon monoxide
CO2	621.6	383.7	321.5	266.4	g	Carbon dioxide
CH4	2.7	1.7	1.4	1.2	g	Methane
TNMOC	1.5	0.9	0.8	0.6	g	NMVOC, non-methane volatile organic compounds, unspecified origin
NOx	0.056	0.034	0.029	0.024	g	Nitrogen oxides
PM	1.164	0.719	0.602	0.499	g	Particulates, < 10 um
Waste						
Ash	19.247	11.881	9.955	8.249	g	Calculated based on the ash content of the charcoal of 6.9%.
Stove (used)	5.3E-04	3.3E-04	4.6E-05	3.8E-05	piece	Recycling process (cut-off).
Output						
Heat, cooking	1	1	1	1	MJ delivered at pot	

The carbon balance for the different cooking stoves is conducted, taking the carbon input (carbon content of charcoal of 71%) and the carbon output contained in the air emissions and any unconsumed carbon in char and ash.

Table 21: Carbon balance of cooking stove.

	Traditional stove 1	Traditional stove 2	Jiko Bora	Sazawa	Unit	Comment
Input						
Charcoal	278.94	172.19	144.28	119.55	g	
C-Charcoal	204.46	126.21	105.76	87.63	g	Calculated based on the carbon content of charcoal of 73.3%
Output						
C-CO	19.86	12.26	10.27	8.51	g	Calculated based on emissions and the molar masses
C-CO2	169.54	104.65	87.69	72.66	g	Calculated based on emissions and the molar masses
C-CH4	2.03	1.25	1.05	0.87	g	Calculated based on emissions and the molar masses
C-TNMHC	0.73	0.45	0.38	0.31	g	Calculated based on the molar mass ratio of 12/24.5
C-TSP	0.57	0.35	0.30	0.24	g	Calculated based on the IPCC value of 2.4g C per kg charcoal burnt.
C-ash / C-char	11.74	7.25	6.07	5.03	g	Assumed that 5.7% of the carbon is contained in the ash
Total	**204.46**	**126.21**	**105.76**	**87.63**	g	

PART III - RESULTS AND DISCUSSION

13 Compared charcoal value chains

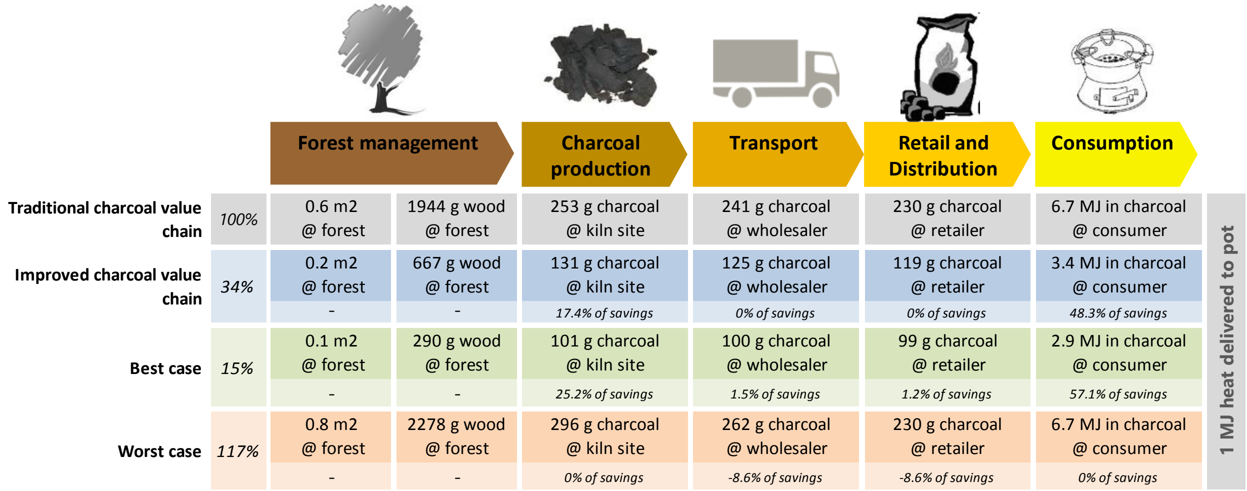
As illustrated in the previous section, there exists a wide range of different options to extract wood, as well as to produce, transport and use charcoal. Instead of providing results for all possible combinations, we establish "typical" charcoal value chains. Thereby we analyse the traditional value chain and show the improvement potential based on the settings identified for sustainable value chain. In addition we also integrate a best case and a worst case to show the extremes.

Table 22: Compared charcoal value chains. For each scenario an overview about the specifications regarding the forest management, kiln technology, transport, retail and consumptions is provided.

Stage	**Traditional charcoal value chain**	**Improved charcoal value chain**	**Best case**	**Worst case**
Forest management	Cut - regrowth	Coppice 25 years	Coppice 25 years	Forest to agriculture
Charcoal kiln	Traditional EBK 13% efficiency	Improved EBK 19.6% efficiency	Half orange BK 35% efficiency	Traditional EBK 13% efficiency
Transport	To DAR 4.7% loss	To DAR 4.7% loss	To DAR 1% loss	To DAR 8.6% loss
Retail	5% loss	5% loss	2% loss	14% loss
Consumption	Traditional charcoal stove 15% efficiency	Improved stove charcoal (Jioko bora) 29% efficiency	Improved charcoal stove (Sazawa) 35% efficiency	Traditional charcoal stove 15% efficiency

14 Material and energy balance

In Figure 27 the material requirements to deliver 1 MJ heat to the cooking pot is provided for each charcoal value chain. Depending on the conversion efficiencies and transportation losses, the wood requirements range from 290g to 2300 g to deliver 1 MJ heat to the cooking pot (almost a factor 8 of difference). Compared to the traditional charcoal value chain, the wood saving potential of improved systems is 66% and can even range up to 85% in a best case. Main savings can be achieved if efficient stoves are used (up to 57% improvement) and also if more efficient kilns are in place (about 20% improvement). The transportation is already efficiently organized and losses are minimized. Consequently the optimization potential of the transportation and retail is limited compared to other measures.



		Forest management		Charcoal production	Transport	Retail and Distribution	Consumption
Traditional charcoal value chain	*100%*	0.6 m2 @ forest	1944 g wood @ forest	253 g charcoal @ kiln site	241 g charcoal @ wholesaler	230 g charcoal @ retailer	6.7 MJ in charcoal @ consumer
Improved charcoal value chain	*34%*	0.2 m2 @ forest -	667 g wood @ forest -	131 g charcoal @ kiln site *17.4% of savings*	125 g charcoal @ wholesaler *0% of savings*	119 g charcoal @ retailer *0% of savings*	3.4 MJ in charcoal @ consumer *48.3% of savings*
Best case	*15%*	0.1 m2 @ forest -	290 g wood @ forest -	101 g charcoal @ kiln site *25.2% of savings*	100 g charcoal @ wholesaler *1.5% of savings*	99 g charcoal @ retailer *1.2% of savings*	2.9 MJ in charcoal @ consumer *57.1% of savings*
Worst case	*117%*	0.8 m2 @ forest -	2278 g wood @ forest -	296 g charcoal @ kiln site *0% of savings*	262 g charcoal @ wholesaler *-8.6% of savings*	230 g charcoal @ retailer *-8.6% of savings*	6.7 MJ in charcoal @ consumer *0% of savings*

1 MJ heat delivered to pot

Figure 27: Material requirements of the compared charcoal production and use systems per MJ heat delivered to pot. For each life cycle stage the mass flow, as well as the potential savings relative to the traditional charcoal value chain are indicated. The left column indicates the potential saving / increase in wood demand.

In general cooking with charcoal is not very efficient from an energetic perspective as compared to the direct use of wood for cooking. In order to deliver 1 MJ heat to the cooking pot with charcoal, 34 MJ wood are required[12] (traditional value chain). This amount is significantly higher as if fuel wood is directly used, even if a low energy efficiency of wood stoves (e.g. 10%) is assumed. In the optimized systems, the energy requirements from wood are reduced to 5 -12 MJ. In this case, the energy demand is similar to cooking with a wood stove.

Besides the energy contained in wood, also the energy demand linked to the production of materials used for stoves and kilns and the energy used to transport charcoal to the end consumer have to be considered. The non-renewable energy demand ranges from 0.3 up to 0.7 MJ, depending on the scenario. The non-renewable energy demand is mainly related to transport and packaging of the charcoal.

15 Climate change impacts

In Figure 28 the global warming potential of different improved charcoal value chains are compared to the traditional charcoal production system. Overall, the impact is dominated by

---

[12] Using a wood energy content of 18MJ/kg

carbon emissions caused due to the temporal reduction of forest carbon pools and by methane emissions during the carbonization of wood. Even though the impacts of using charcoal in stoves does not show significant impacts, the improvement potential in terms of stove efficiency is nevertheless substantial (reduced upstream impacts).

The overall GHG emissions can be significantly reduced by 63% to 84% by implementing efficiency measures. However, it is also shown that the impacts can be severe if land is permanently converted from forest to cropland (worst case scenario).

In the following the impact of each life cycle stage is further described and mitigation measures are discussed.

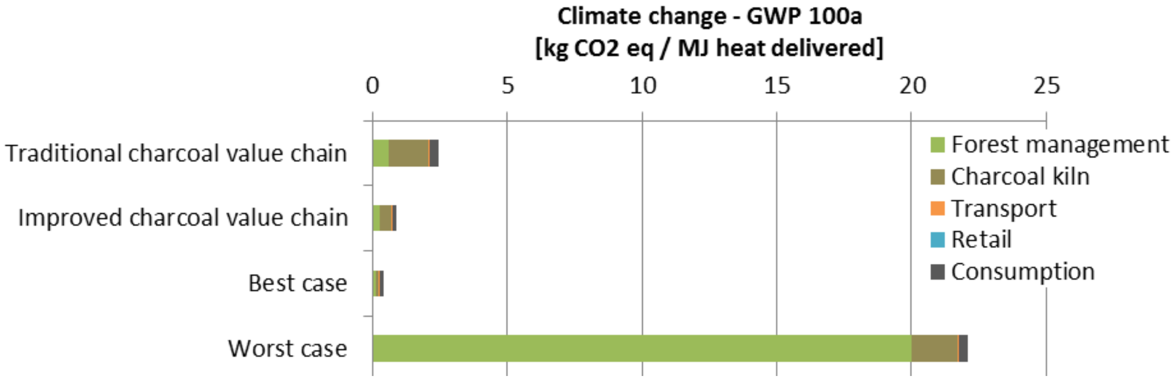


Figure 28: Global warming potential of different charcoal value chains relative to the traditional value chain. The impacts are indicated per life cycle stage.

15.1 Forest management and land use change

In Figure 29 the global warming potential of different forest management and land use scenarios are compared (in kg CO_2 eq per hectare). The impact associated to forest transformation is indicated in green and is for all the scenarios the same, except for natural forest which does not show an impact, but also has no wood output.

The impact associated to postharvest use of the land is indicated in orange and is caused by the avoided regeneration due to occupying land. We have assumed an occupation of 100 years for the agricultural scenarios and the coppice system. Converting a forest to agricultural land significantly reduces the carbon stock compared to natural vegetation – not only in terms of carbon contained in biomass, but also in terms of soil carbon. Overall the shifting cultivation shows a slightly higher carbon stock as compared to permanent agriculture and thus is associated with lower impacts.

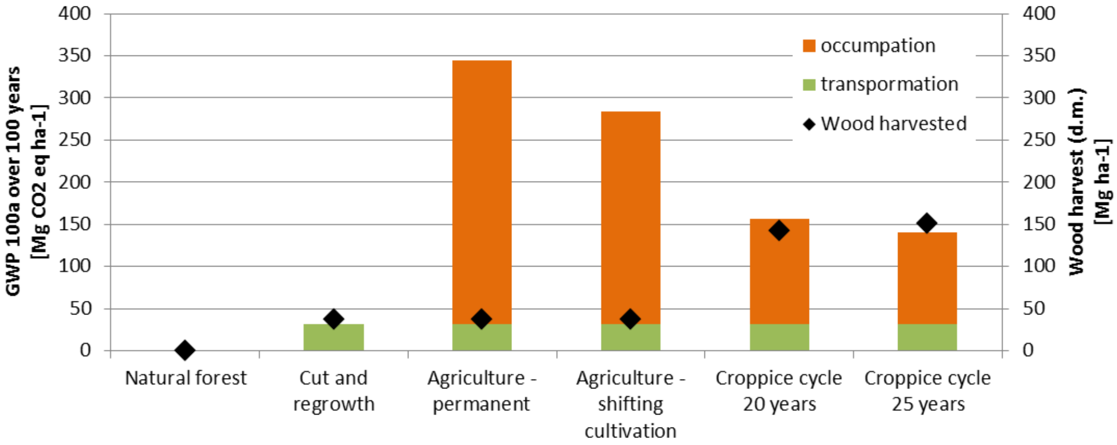


Figure 29: GWP over a 100 year time horizon for different forest management and land use scenarios. The impact related to forest transformation (green) and to land occupation (orange) is indicated as Mg CO2 eq ha-1. Further, the amount of harvested wood is indicated by the rhombus (Mg CO2 eq ha-1).

Also the continuous use of forest in coppice cycles delays full regrowth and leading to a reduced average carbon stock compared to natural vegetation. However, during the 100 year of occupation, wood is continuously extracted and per kg wood harvested the impacts are similar as compared to scenario 1 “cut and regrowth”. The GWP 100a per kg harvestable wood for all scenarios is listed in Table 23 (last column).

The initial CO2 emissions due to land transformation (2 kg CO_2 / kg harvested wood[13]) are slightly higher compared to the carbon contained in wood (1.7 kg CO_2 / kg harvested wood[14]) since not all the clear-cut wood is used for charcoal production.

Table 23: GWP 100a - calculated based on transformation and occupation impacts.

		Transformation			Occupation			Total	
No	**Scenario**	**Initial CO2 emissions**	**Duration factor**	**GWP 100a [Mg CO2 eq ha-1]**	**Reduced average carbon stock [Mg C ha-1]**	**Duration factor**	**GWP 100a over 100 years [Mg CO2 eq ha-1]**	**Wood harvest (d.m.) [Mg ha-1]**	**GHG emission [kg CO2 eq / kg wood (d.m.)**
0	Natural forest	0.0	0.0	0.0	-	-	-	0.0	-
1	Cut and regrowth	75.1	0.4	31.6	-	-	-	37.0	0.9
2a	Agriculture - permanent	75.1	0.4	31.6	40.6	0.02	313.5	37.0	9.3
2b	Agriculture - shifting cultivation	75.1	0.4	31.6	32.7	0.02	252.2	37.0	7.7
3a	Croppice cycle 20 years	75.1	0.4	31.6	16.1	0.02	124.3	142.2	1.1
3b	Croppice cycle 25 years	75.1	0.4	31.6	14.1	0.02	109.0	151.0	0.9

---

[13] 75.1 tons of CO_2 per 37 tons of harvested wood

[14] Based on a carbon fraction of 0.47 and the CO_2/C ratio of 44/12.

The forest transformation impact can be fully allocated to charcoal production and the GWP impact is calculated based on the carbon stock dynamics and the amount of harvested wood (Table 23, green).

For the agricultural scenarios, the impacts are much higher as compared to the forest management systems. However, it is not reasonable to allocate the carbon emissions of occupying land only to the wood extraction (case i and ii in Figure 30). Instead, the impacts caused land occupation is clearly caused by crop cultivation and thus should be allocated to the agricultural products and not to charcoal (case iii in Figure 30). In this case the GWP of wood extraction are similar to scenario 1 "cut and regrowth".

Further it could be argued that the main driver of deforestation is the expansion of agricultural land. Consequently the wood is clear-cut solely because of land expansion and thus is freely available for charcoal production (case iv in Figure 30). This perspective is similar to the carbon neutrality perspective, since no impacts from temporal carbon stock changes are allocated to wood.

In addition the transformation impact could also be allocated to wood extraction and agricultural products by using an economic approach (revenue based allocation). The impacts would be in between scenario iii) and iv).

For this study we apply case iii) for the traditional charcoal production scenario and assume case i) as a worst case (results see Figure 28). The worst case is considered even though it is not justified to allocated agricultural occupation impacts to wood extraction. However, deforestation can also be followed by desertification (e.g. due to soil erosion and harsh climatic conditions). This would cause severe impacts which might be even higher as scenario i), since regeneration is permanently avoided.

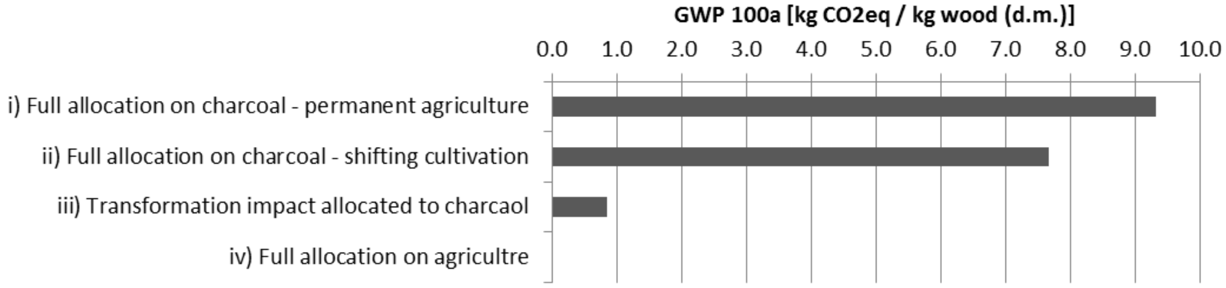


Figure 30: Comparison of different allocation perspectives of the GWP of the agricultural scenarios.

15.2 Charcoal production

In Figure 31 the global warming potential of charcoal production using different kilns is indicated per kg charcoal produced. The impacts related to wood extraction are excluded. A significant difference amongst the compared kiln can be observed, which is mainly explained by the different kiln efficiencies. We have modelled two traditional kilns in order to illustrate the bandwidth of impacts caused by different reported efficiencies and emission profiles. Even though the assumptions of the traditional kiln 2 are very optimistic, it shows that the improved kilns might not necessarily be better performing than traditional kilns. Consequently, the performance of the kilns at the study site should be carefully evaluated in order to point out effective benefits.

Generally, the main GHG is carbon dioxide, flowed by methane. However, it has to be noted that the carbon emitted is from a renewable resource and will be sequestered again by plants within some decades (except for agriculture scenarios). Consequently, the impact of CO2 emissions cannot be directly compared with methane emissions and do not directly contribute to the climate change score (see previous chapter on biogenic CO2 emissions).

There exist different (stationary) kilns (e.g. a different retort kilns), where methane contained in the residual gas is captured in abatement units and destroyed through combustion (UNFCCC 2012).

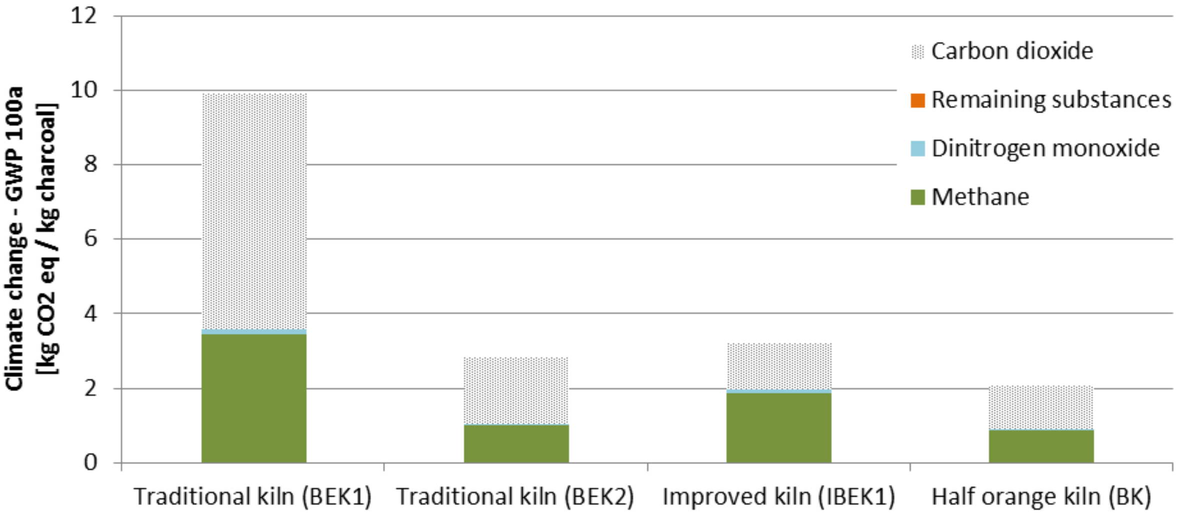


Figure 31: Global warming potential of charcoal production using different kiln technologies. The impacts are indicated per kg charcoal (excluding wood extraction and the contribution from each GHG is indicated.

15.3 Transport and distribution

In Figure 32 the global warming potential of charcoal transportation to Kilosa, Morogoro and Dar es Salaam (DSM) are indicated. The impacts exclude the impact caused by wood extraction and charcoal production (see previous chapters). In addition also the charcoal losses due to transportation are indicated. The values are based on primary data and are dependent on the vehicle type and transportation distance.

The charcoal transport from villages to the nearby cities is either conducted by motor cycles or bicycles. The motor cycle transport is causing about 5 times the impact of a bicycle transport. However, transporting charcoal by bicycle is also related to higher losses compared to motorcycle transport according to field interviews. Higher losses lead to an increased wood demand and consequently to higher upstream impacts.

For longer distances trucks are used. We assume that the charcoal is transported by motor cycle from the village to the nearby city and loaded to small or big trucks for long distance transport (to Morogoro or DSM). Larger and full loaded trucks thereby show slightly lower emissions per kg charcoal transported.

Charcoal is also directly bought on the road side by end-consumers and is transported by a private cars (here referred to as pick up). Depending on the transportation distance, the emissions are significantly higher compared to all other transportation means. However, most private buyers are not primarily driving to buy charcoal, but they are on the way anyway. Consequently not all the impact of the journey can be allocated to charcoal.

The railway from Kilosa to Dar es Salaam would be the most environmental option. However, the transportation is not reliable and not legal according to the Tanzanian Railway Cooperation transportation policy.

Overall the different transportation modes show substantial differences in terms of losses and GWP. However, compared to the other processes along the charcoal value chain, the impact of transport is marginal.

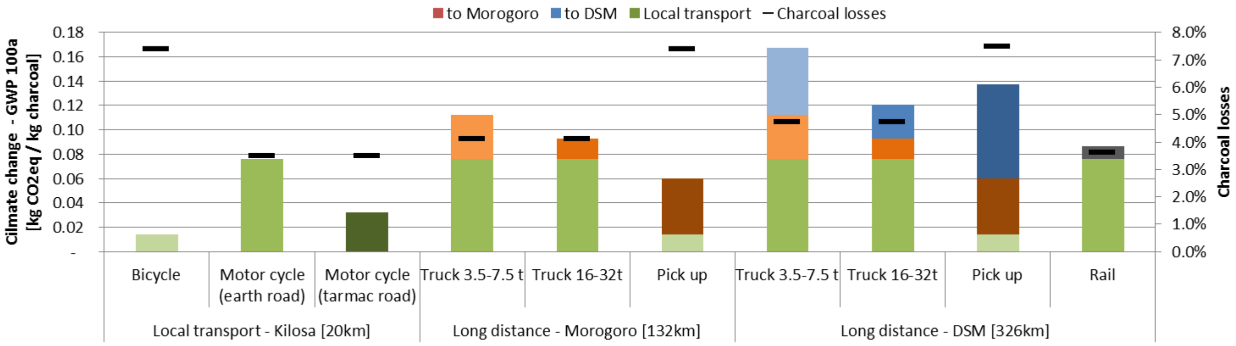


Figure 32: Global warming potential of charcoal transportation to Kilosa (green), Morogoro (orange, red) and Dar es Salaam (DSM, blue). The impacts are indicated per kg charcoal transported (excluding wood extraction and charcoal production). The losses of charcoal depend on the transportation vehicle and distance and are indicated by the black bars (in %).

15.4 Consumption

In Figure 33 the global warming potential of cooking with charcoal stoves is indicated. The impacts are calculated per MJ heat delivered to the cooking pot and exclude the impact caused by charcoal production and transport (see previous chapters).

The GWP of charcoal consumption strongly depends on the stoves type. The most efficient stove is emitting more than two times less GHGs as compared to the traditional metal stove. However, the reported efficiencies of the same stove type can vary substantially. For instance the performance of the traditional stove ranges between 0.4 and 0.7 kg CO_2 eq[15] per MJ heat delivered to the pot. Consequently a good performance of a traditional stove is just slightly higher as compared to the improved stoves.

Even though the direct impact from fuel combustion shows a significant impact, the main environmental burden or benefit is caused indirectly, since the stove efficiency strongly influences the upstream impacts.

---

[15] Note: The biogenic CO_2 emissions are not directly contributing to the global warming impact (see previous chapter on biogenic CO_2 emissions)

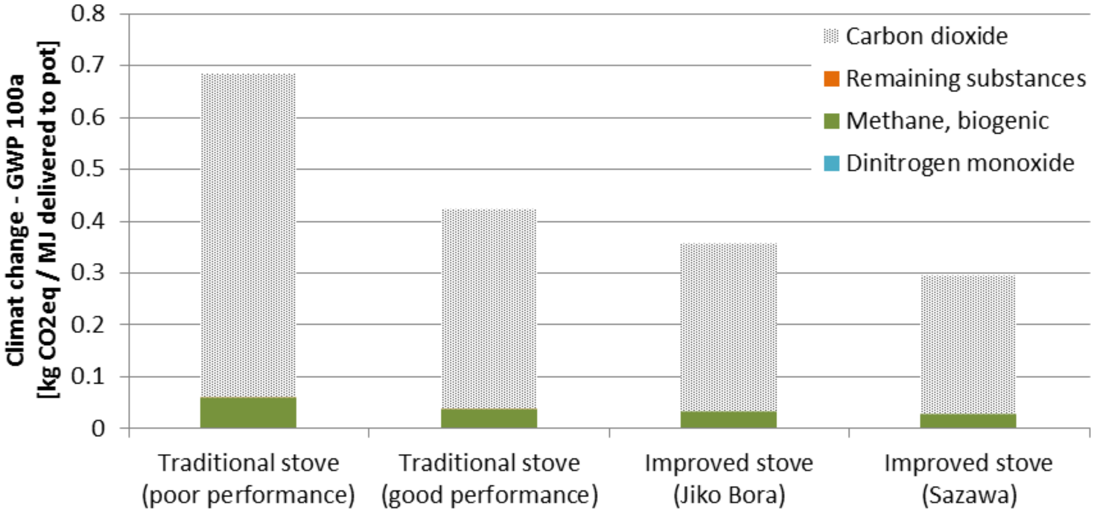


Figure 33: Global warming potential of cooking with different charcoal stoves. The impacts are indicated per MJ delivered to the cooking pot (excluding charcoal production and transport).

15.5 Sensitivity analysis –500 year time horizon

The time horizon of the impact assessment does significantly influence the results. In an infinite time perspective temporal releases of carbon emissions become insignificant. If the time horizon is in contrary just a few years biogenic CO_2 emissions are treated as CO_2 emissions from fossil fuels (regrowth is neglected).

Most widely the time horizon of 100 years is used. However, Müller-Wenk and Brandao (2010) indicated that a cut-off at 100 years is favouring carbon from fossil combustion and suggests to use a 500 year perspective. Choosing a 500 year time horizon is not only changing the impacts of biogenic carbon emissions (a factor 157 is used instead of 48, see chapter 5), but also the characterization factors of other GHG change (see Table 2 and (IPCC 2006)).

The GWP of wood extraction for a 500 year time horizon are provided in Table 24. Compared to the values based on a 100 year (see Table 23), the duration factor is significantly reduced and thus also the impact of temporarily releasing biogenic CO_2 emissions is reduced.

Table 24: GWP 500a - calculated based on transformation and occupation impacts.

		Transformation			Occupation			Total	
No	**Scenario**	**Initial CO2 emissions**	**Duration factor**	**GWP 500a [Mg CO2 eq ha-1]**	**Reduced average carbon stock [Mg C ha-1]**	**Duration factor**	**GWP 500a 100 year occupation [Mg CO2 eq ha-1]**	**Wood harvest (d.m.) [Mg ha-1]**	**GWP 500a [Mg CO2 eq ha-1]**
0	Natural forest	0.0	0.0	0.0	-	0.00	-	0.0	-
1	Cut and regrowth	75.1	0.1	8.4	-	0.00	-	37.0	0.2
2a	Agriculture - permanent	75.1	0.1	8.4	40.6	0.01	94.9	37.0	2.8
2b	Agriculture - shifting cultivation	75.1	0.1	8.4	32.7	0.01	76.3	37.0	2.3
3a	Croppice cycle 20 years	75.1	0.1	8.4	16.0	0.01	37.3	145.9	0.3
3b	Croppice cycle 25 years	75.1	0.1	8.4	13.9	0.01	32.5	155.0	0.3

The charcoal value chain results for a 100 year and 500 year time horizon are indicated in Table 25. In addition, also the results of assuming that the temporal change in carbon stocks in forest has no impact are provided (concept of "carbon neutrality" as described in chapter 4.3).

Table 25: Comparison of different GWP assessment methods (in kg CO2 eq per MJ heat deliver to the pot).

	Unit	**Traditional charcoal value chain**	**Improved charcoal value chain**	**Best case**	**Worst case**
GWP 100a	kg CO2eq/MJ at pot	2.44	0.90	0.39	22.09
GWP 100a CO2 biogenic = 0	kg CO2eq/MJ at pot	1.00	0.32	0.14	1.12
GWP 500a	kg CO2eq/MJ at pot	0.71	0.24	0.12	6.66

Changing the time horizon from 100 to 500 years leads to a reduction of the impact by more than a factor of 3. The GWP calculated based on the carbon neutrality perspective of biogenic CO_2 emission is slightly higher than the GWP 500. However, the relative ranking of the different value chains does not change if different time horizons are used.

15.6 Comparison with alternative fuel types and literature values

The GWP of charcoal production calculated in this study is generally higher as compared to literature values. The difference is mainly caused by higher kiln and stove efficiency values used in literature and by differences in the approaches used to model the GWP of biogenic CO2 emissions. In the following the results from literature are described and discussed in more details.

Bailis (2005) compared different charcoal production and use systems in Kenya. The impact ranges from -300 g to 1300 g of CO2 eq per MJ heat delivered to the cooking pot (Bailis 2005). Negative values (carbon benefits) are linked to the scenario where natural forest was displaced by eucalyptus plantation, storing more carbon. Rousset (2011) also indicated that charcoal production and use leads to carbon emission savings of up to 4kg per kg of charcoal. However, the allocated benefits due to carbon sequestration are questionable, since the carbon stocks of natural vegetation was not used as a reference (Rousset et al. 2011).

According to Bailis (2005), the GWP of coppice systems is assessed with an impact of 110 g CO_2 eq per MJ heat delivered to the cooking pot. Thereby, a stove efficiency of 25% and a kiln efficiency of 20% was assumed, which is comparable to the improved value chain scenario of this study. However, the calculated impacts of Bailis (2005) are twice as low as compared to this study, which is explained by different assessment methods for biogenic carbon emissions.

Highest CO2 emissions are caused if forest is converted to agricultural land and all emissions are allocated on charcoal production. Also Bailis (2005) indicates that as soon as regeneration is postponed, as it is the case in agricultural systems, the GWP of charcoal is dominated by the emissions from land use change.

If biogenic carbon emissions are not accounted for, the GWP 100 of charcoal in literature is indicated with 293g (Benoist et al. 2011), 203 g (Bailis 2005) and 49 g[16] (Norgate et al. 2011) CO_2 eq per MJ heat delivered to the pot. The GWP results of this study range from 140 g to 1100 g CO_2 and is 320g CO_2 in the improved system. The slightly higher emissions as compared to the literature value can be explained by slightly different kiln and stove efficiency assumptions, by slightly different energy contents of the produced charcoal and by the consideration of transport losses, which is excluded in all other studies.

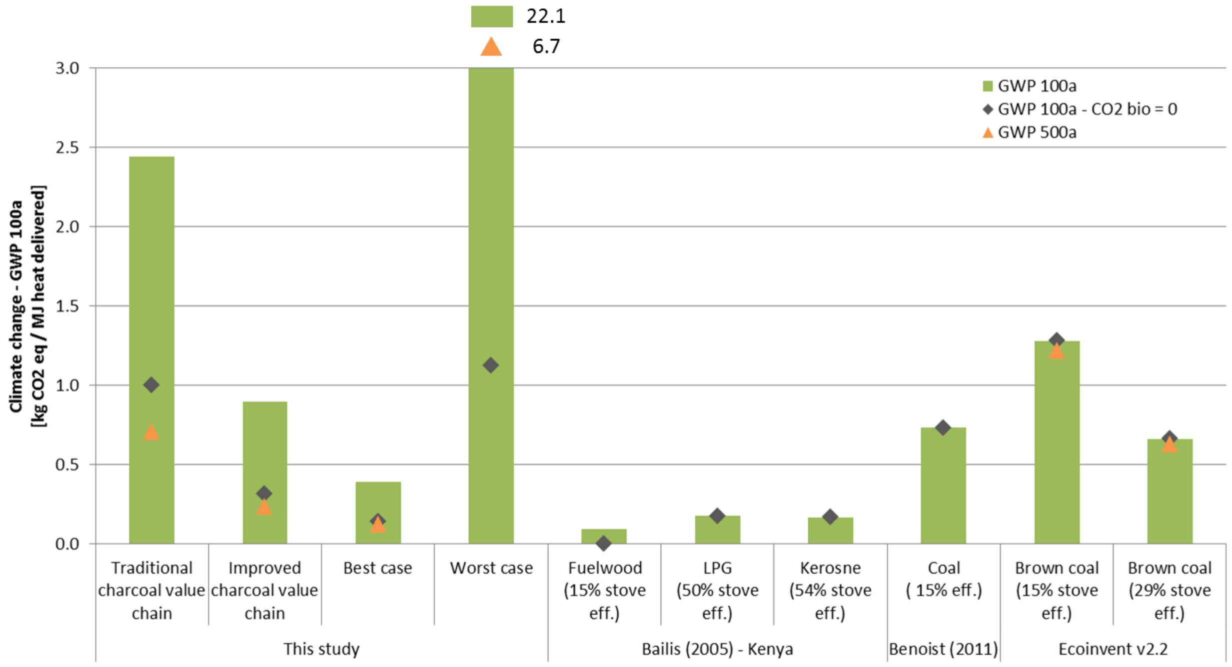


Figure 34: Global warming potential of different charcoal value chains compared to alternative cooking options. The GWP impact based on 100 year time horizon is indicated in green. The values of GWP 500 are indicated by orange triangles and GWP 100 impacts, but not accounting for biogenic CO2 emissions, are indicated by the grey rhombus. Values higher as 3 kg CO2 eq per MJ heat delivered to the cooking pot are cut-off, but the values are indicated on the top of the figure.

---

[16] Calculated based on the figure of 220kg CO_2 eq per ton charcoal, a charcoal energy content of 30MJ per kg and a stove efficiency of 15%.

In Figure 34, the GWP results of this study are illustrated and compared to the different alternative cooking options. It has to be noted that the values of alternative cooking systems are taken from literature and the impacts are not consistently modeled by using the same approaches. Even though the results should not be over interpreted, indications and general conclusions can be drawn.

The direct use of firewood for cooking generates lower impacts as converting wood to charcoal before using it as a cooking fuel. This result is achieved since no conversion losses are caused and are valid even though the energy efficiency of wood stoves is generally low. Consequently from a resource and climate perspective it makes sense to use wood directly for cooking in rural areas. However, the conclusion might change if also other aspects are considered (e.g. impact on human health).

Modern energy carriers such as LPG or kerosene used for cooking show relatively low impacts compared to charcoal (Bailis 2005). Also other studies indicated that LP grilling is about three times lower carbon footprint as compared to charcoal grilling (Johnson 2009) and that LPG has a lower GWP than biogas and charcoal (Afrane & Ntiamoah 2011). The impact of using brown coal is however relatively higher as compared to other modern fuels. These effects are mainly explained by the high conversion efficiency of gaseous and liquid fuels as compared to solid fuels used for cooking.

However, the comparison of fossil energy carrier to charcoal strongly depends on the perspective of assessing biogenic carbon emissions and on the chosen time horizon. While the GWP of fossil fuels is only marginally sensitive[17] to these modelling characteristics, the GWP of charcoal system can change significantly in absolute terms. Depending on the perspective, the ranking of the cooking options changes. In a GWP 100 year perspective, charcoal systems perform generally worse compared to most other cooking alternatives. Using the GWP over a 500 year time horizon or using a carbon neutral perspective, the impacts of (improved) charcoal systems are similar to fossil fuels and much lower as heat from coal.

---

[17] Minor effects due to the lower impact factor of methane is caused by using a 500 year time horizon instead of 100 years.

PART V – CONCLUSION AND RECOMMENDATION

16 Conclusions and recommendations

Overall, the charcoal value chain shows high variations and a huge optimization potential in terms of resource efficiency and climate change. The GWP of charcoal is highly dependent on the conversion efficiencies, the land management regime that is in place and on the assumptions related to the impact modeling.

Land use planning and sustainable forest management are key: Using biomass for charcoal production does not lead to permanent deforestation, even though the carbon stocks are temporarily decreased. However, if forests are converted to agricultural areas, the regeneration of the forest is postponed and also a share of the soil carbon is emitted to air. Consequently measures reducing agricultural expansion are an integral part of reducing deforestation.

The project partners are currently establishing land use plans and provide training in conservation agriculture, which are important measures to reduce the pressure on forests. In addition also sustainable forest management is important in order to enhance the optimal regeneration of the forest. Thereby, measures targeted towards the prevention of hot fires and cattle grazing support forest regrowth.

Eco-efficient stoves and improved kilns are a prerequisite for sustainable charcoal production: By implementing different efficiency measures, the wood demand can be reduced by 66% up to 85%. The main increase in efficiency can be achieved if traditional stoves are replaced with improved stoves. Consequently, changing the charcoal sector should also involve measures to enhance the market penetration of efficient stoves. Also improvements in the conversion of biomass to charcoal show a tremendous potential for reductions in the associated GHG emissions. Thereby incentives to efficiently use wood resources efficiently are enabling the adoption of efficient technology. Currently the producers from the informal sector do not have an incentive to save wood as it is typically sourced for free. Economic incentives or barriers (e.g. payments for natural resources) could be considered as a measure to enhance the adoption of efficient kilns.

Transport and retail show marginal impact on climate: In any case, transportation plays a small role in charcoal's climate impact. The transportation is already efficient and transportation losses are minimal. Consequently the optimization potential of the transportation and retail is limited compared to other measures. However, it has to be noted that successfully establishing a sustainable charcoal value chain is not possible without the involvement of transporters.

Baseline remains unclear – further research is needed: The traditional charcoal value chain shows large variations and the impacts strongly depend on the local context. Also in literature different values in terms of efficiency and emission are listed. Some indicate that the traditional system can be as efficient as with implementing the proposed improvements. Consequently, measurements from the study sites are required to properly assess the conversion efficiencies and the charcoal quality of both, the improved and the traditional system. Further, methane emissions are strongly influencing the LCA results and direct measurement from the study area will improve the accuracy of results.

Comparison with alternative fuels - expansion of study: The direct use of fuel wood for cooking shows less resource demand and carbon emission as compared to charcoal. However, cooking with fire wood is only feasible in rural areas and other impacts might be higher as compared to using charcoal. From a global warming perspective, LPG and Kerosene seem to have slight advantage over charcoal fuels and it most likely also is more favorable at the cooking stage, in terms of its effect on the human health. Nevertheless, the availability and affordability of alternative fuels is limited and thus a shift to modern fuels in near future seems unlikely. Since the shift to modern fuels is perceived by many stakeholders as the way forward, a consistent assessment of the sustainability aspects of different cooking options is highly valuable to support knowledge based decision making.

Overall sustainability: This study showed that there is substantial potential to optimize the current charcoal value chain. However, the conclusions are drawn from a resource and climate perspective. In order to obtain a complete view of sustainability, the results of the LCA study should be interpreted together with other assessments focusing on the social and economic dimensions.

REFERENCES

Afrane, G. & Ntiamoah, A., 2011. Comparative Life Cycle Assessment of Charcoal, Biogas, and Liquefied Petroleum Gas as Cooking Fuels in Ghana. *Journal of Industrial Ecology*, 15(4), pp.539–549. Available at: http://dx.doi.org/10.1111/j.1530-9290.2011.00350.x.

Bailis, R., 2005. *Fuel from the Savanna: the Social and Environmental Implications of the Charcoal Trade in Sub-Saharan Africa*,

Bailis, R., Ezzati, M. & Kammen, D.M., 2003. Greenhouse Gas Implications of Household Energy Technology in Kenya. *Environmental Science & Technology*, 37(10), pp.2051–2059. Available at: http://pubs.acs.org/doi/abs/10.1021/es026058q.

Benoist, A. et al., 2011. Life Cycle Assessment (LCA) of traditional charcoal production in Madagascar. In Montpellier, France: CIRAD.

Bess, M., 2013. *Market Research for Sustainably-Produced Charcoal*,

Beukering, P. van et al., 2007. *Optimization of the charcoal chain in Tanzania*, Amsterdam, The Netherlands.

Bhattacharya, S.C., Albina, D.O. & Salam, P.A., 2002. Emission factors of wood and charcoal-fired cookstoves. *Biomass and Bioenergy*, 23(6), pp.453–469. Available at: http://www.sciencedirect.com/science/article/pii/S0961953402000727.

Boafo-Mensah, G. et al., 2013. Thermal efficiency of charcoal fired cookstoves in Ghana. *Global Advanced Research Journal of Engineering, Technology and Innovation (GARJETI)*, 2(3), p.pp 102–110.

Boutette, M. & Karch, E., 1984. *Charcoal : small scale production and use* D. G. für T. Zusammenarbeit, ed., Braunschweig: F. Vieweg.

Brocard, D., Lacaux, J.-P. & Eva, H., 1998. Domestic biomass combustion and associated atmospheric emissions in West Africa. *Global Biogeochemical Cycles*, 12(1), pp.127–139. Available at: http://dx.doi.org/10.1029/97GB02269.

BSI, 2011. *PAS 2050:2011 - Specification for the assessment of the life cycle greenhouse gas emissions of goods and services*,

Campbell, B., 1996. *The Miombo in Transition: Woodlands and Welfare in Africa*, Bogor, Indonesia: Center for International Forestry Research.

Cherubini, F. et al., 2011. CO2 emissions from biomass combustion for bioenergy: atmospheric decay and contribution to global warming. *GCB Bioenergy*, 3(5), pp.413–426. Available at: http://dx.doi.org/10.1111/j.1757-1707.2011.01102.x.

Chidumayo, E.N., 1990. Above-ground woody biomass structure and productivity in a Zambezian woodland. *Forest Ecology and Management*, 36(1), pp.33–46. Available at: http://www.sciencedirect.com/science/article/pii/037811279090062G.

Chidumayo, E.N., 1991. Woody biomass structure and utilisation for charcoal production in a Zambian Miombo woodland. *Bioresource Technology*, 37(1), pp.43–52. Available at: http://www.sciencedirect.com/science/article/pii/0960852491901106.

Chidumayo, E.N. & Gumbo, D.J., 2013. The environmental impacts of charcoal production in tropical ecosystems of the world: A synthesis. *Energy for Sustainable Development*, 17(2), pp.86–94. Available at: http://www.sciencedirect.com/science/article/pii/S0973082612000476.

Dallu, 2002. *TROPICAL SECONDARY FOREST MANAGEMENT IN AFRICA - Coutnry paper: tanzania*,

ecoinvent centre, 2007. *ecoinvent data v2.2*, Dübendorf, CH: Swiss Centre for Life Cycle Inventories. Available at: www.ecoinvent.ch.

ESMAP, 1991. *Rwanda: Commercialization of Improved Charcoal Stoves and Carbonization Techniques - Mid-Term Progress Report.*,

European Commission, 2010. International Reference Life Cycle Data System (ILCD) Handbook - General guide for Life Cycle Assessment - Detailed guidance.

FAO, 1987. *Simple technologies for charcoal making - Forestry paper 41*, Rome, Italy. Available at: http://www.fao.org/docrep/x5328e/x5328e00.htm.

Fargione, J. et al., 2008. Land Clearing and the Biofuel Carbon Debt. *Science*, 319(5867), pp.1235–1238. Available at: DOI: 10.1126/science.1152747.

Frischknecht, R. et al., 2007. *Implementation of Life Cycle Impact Assessment Methods - ecoinvent report no. 3 - Data v2.2*, Dübendorf.

Grundy, I., 1990. *The potential for management of the indigenous woodland in communal farming areas of Zimbabwe with reference to the regeneration of Brachystegia spiciformis and Julbernardia globiflora.*, Harare, Zimbabwe.

Hammarstrand, L. & Särnberger, A., 2013. *Comparative evaluation of two forest systems under different management regimes in Miombo woodlands - A case study in Kitulangalo area, Tanzania*. CHALMERS UNIVERSITY OF TECHNOLOGY.

Holtsmark, B., 2013. Quantifying the global warming potential of CO2 emissions from wood fuels. *GCB Bioenergy*, p.n/a–n/a. Available at: http://dx.doi.org/10.1111/gcbb.12110.

Hunter, R., 2012. *Improved Cooking Stove Programme (Zambia)*,

IPCC, 2007. *Climate Change 2007-the physical science basis* S. Solomon D et al., eds., The Edinburgh Building Shaftesbury Road, Cambridge, UK: Cambridge University Press. Available at: www.grida.no/climate/ipcc_tar/wg1/.

IPCC, 2006. *Guidelines for National Greenhouse Gas Inventories, Volume 4 Agriculture Forestry and Other Land Uses. Available from http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html*,

Ishengoma, R.C. & Klem, G.S., 1979. *Yield, quality, cost and market acceptability of charcoal from softwood slabs* Record, Di.,

ISO, 2006a. *14040 - Environmental management - Life cycle assessment - Principles and framework*, Geneve, Switzerland: International Standard Organisation.

ISO, 2006b. *14044 - Environmental management - Life cycle assessment - Requirements and guidelines* 2nd ed., Geneva, CH: International Organization for Standardization.

Jetter, J. et al., 2012. Pollutant Emissions and Energy Efficiency under Controlled Conditions for Household Biomass Cookstoves and Implications for Metrics Useful in Setting International Test Standards. *Environmental Science & Technology*, 46(19), pp.10827–10834. Available at: http://dx.doi.org/10.1021/es301693f.

Johnson, E., 2009. Charcoal versus {LPG} grilling: A carbon-footprint comparison. *Environmental Impact Assessment Review*, 29(6), pp.370–378. Available at: http://www.sciencedirect.com/science/article/pii/S0195925509000420.

Kajembe, G.C. et al., 2013. *The Kilosa District REDD+ pilot project, Tanzania. A socioeconomic baseline study IIED*, London.

Kimaryo, B. & Ngerza, K., 1989. *Charcoal production in Tanzania using improved traditional earth kilns*, Moshi, Tanzania.

Kutsch, W. et al., 2011. The charcoal trap: Miombo forests and the energy needs of people. *Carbon Balance and Management*, 6(1), p.5. Available at: http://www.cbmjournal.com/content/6/1/5.

Malimbwi, R.E., Solberg, B. & Luoga, E., 1994. Estimation of biomass and volume in Miombo woodland at Kitulangalo forest reserve, Tanzania. *Journal of Tropical Forest Science*, 7(2), pp.230–242.

Malimbwi, R.E. & Zahabu, E., 2009. The analysis of sustainable charcoal production systems in Tanzania. In *Criteria and indicators for sustainable woodfuels*. FAO.

Mohod, A.G. & Panwar, N.L., 2011. Evaluation of traditional half orange type charcoal kiln for carbonisation: a case study. *World Review of Science, Technology and Sustainable Development*, 8(2), pp.196–202. Available at: http://dx.doi.org/10.1504/WRSTSD.2011.044216.

Muishi, P.K.T. et al., 2010. The role of the Miombo Woodlands of the Southern Highlands of Tanzania as carbon sinks. *Journal of Ecology and the Natural Environment*, 2(12).

Müller, N., Michaelowa, A. & Eschman, M., 2011. *PROPOSAL FOR A NEW STANDARDISED BASELINE FOR CHARCOAL PROJECTS IN THE CLEAN DEVELOPMENT MECHANISM*,

Müller-Wenk, R. & Brandão, M., 2010. Climatic impact of land use in LCA—carbon transfers between vegetation/soil and air. *The International Journal of Life Cycle Assessment*, 15(2), pp.172–182. Available at: http://dx.doi.org/10.1007/s11367-009-0144-y.

Mundhenk, P., Gomis, O. & Coumba, M., 2010. *Comparaison des rendements de production de charbon de bois entre la meule traditionnel le et la meule Casamance dans la forêt communautaire de Sambandé, Programme pour la promotion de l'électrification rurale et de l'approvisionnement durable en combusti*, Dakar, Senegal.

Norgate, T. et al., 2011. The greenhouse gas footprint of charcoal production and of some applications in steelmaking. In *7th Australian Conference on Life Cycle Assessment*. Melbourne.

Norrlund, L. & Brus, L., 2004. *Agricultural Practices in Relation to Soil Properties and Water Supply in a Miombo Forest Village*. Uppsala University, Sweden.

Nturanabo, F., Byamuisha, G. & Colonna Preti, G., 2010. *Performance appraisal of the casamance kiln as replacement to the traditional charcoal kilns in Uganda*, Kampala, Uganda.

Paavola, J., 2008. Livelihoods, vulnerability and adaptation to climate change in Morogoro, Tanzania. *Environmental Science & Policy*, 11(7), pp.642–654. Available at: http://www.sciencedirect.com/science/article/pii/S1462901108000695.

Pennise, D.M. et al., 2001. Emissions of greenhouse gases and other airborne pollutants from charcoal making in Kenya and Brazil. *Journal of geophysical research*, 196.

Rousset, P. et al., 2011. {LCA} of eucalyptus wood charcoal briquettes. *Journal of Cleaner Production*, 19(14), pp.1647–1653. Available at: http://www.sciencedirect.com/science/article/pii/S0959652611001855.

Ryan, C.M., Williams, M. & Grace, J., 2011. Above- and Belowground Carbon Stocks in a Miombo Woodland Landscape of Mozambique. *Biotropica*, 43(4), pp.423–432. Available at: http://dx.doi.org/10.1111/j.1744-7429.2010.00713.x.

Sago, S., 2013. *BASELINE ASSESSMENT OF EXISTING CHARCOAL MAKING METHODS AND EFFICIENCIES*, Dar Es Salaam.

Searchinger, T.D., 2008. Biofuels: Effects on land and fire - Response. *Science*, 321(5886), pp.200–201. Available at: <Go to ISI>://000257512900013.

Shirima, D.D. et al., 2011. Carbon storage, structure and composition of miombo woodlands in Tanzania's Eastern Arc Mountains. *African Journal of Ecology*, 49(3), pp.332–342. Available at: http://dx.doi.org/10.1111/j.1365-2028.2011.01269.x.

Smith, J.P., Lawn, R.J. & Nable, R.O., 1999. Investigations into the root:shoot relationship of sugarcane, and some implications for crop productivity in the presence of sub-optimal soil conditions. Proc. Aust. Soc. Sugar Cane Technol. 21 (1999), pp. 108–113.

Smith, K.R. & Pennise, D.M., 1999. *Greenhouse Gases from Small-scale Combustion in Developing Countries: charcoal making kilns in Thailand.*, Research Triangle Park, NC.

U.S. Forest Products Labratory, 1961. *Charcoal production, marketing and use*,

UNFCCC, 2012. *Reduction of emissions from charcoal production by improved kiln design and/or abatement of methane - ACM0021*,

Walker, S.M. & Desanker, P. V., 2004. The impact of land use on soil carbon in Miombo Woodlands of Malawi. *Forest Ecology and Management*, 203, pp.345–360.

Williams, M. et al., 2008. Carbon sequestration and biodiversity of re-growing miombo woodlands in Mozambique. *Forest Ecology and Management*, 254, pp.145–155.

World Bank, 2009. *Environmental crisis or sustainable development opportunity? Transforming the charcoal sector in Tanzania : a policy note*,

Wymann von Dach, S., Basil, S. & Höggel, U., 2013. *Adoption of innovations in the charcoal sector of Kilosa, Tanzania*,

ANNEX

17 Annex

17.1 Interviews: Transportation vehicles - Bicycles

Parameter	1	2	3	4	5	6	7	8	9	10	Average
Name	Mr. Athuman Waziri	Mr. Mohamed Masumbuko	Joseph Luka	Juma Damian	Jackson Meshack	Baraka Yona	Mohamed Masumbuko	N/A	N/A	Venance Makanda	-
Location	Kigunga village	Dodoma Isanga village	Msimba village	Ulaya Mbuyuni village	Nyali village	Nyali village	N.A.	Changalawe village in Miyombo	Zombo village	Ihombwe	-
Bycicle Model	Avon	Phoenix	Phoenix	Bambucha	Phoenix	Phoenix	Phoenix	Phoenix	Phoenix	Phoenix	**Dominantly Phoenix**
Weight, unloaded [kg]	5-10 kg	5-10 kg	15 to 20kg	15-20kg	15-20kg	15-20kg	15-20Kg	15-20Kg	15-20Kg	15-20Kg	**20kg**
Material (predominant)	Steel	Steel	Steel	Steel	Steel	Steel	Steel	Steel	Steel	Steel	**Steel**
Capacity [kg charcoal]	He normally carries 1 bag (50-60 kg)	1bag (50-55kg)	2 bags, each bag is filled with 6tins of charcoal (volume of each tin is 20 litres)	1bag (35-40kg)	1bag (9-10 tins), in dry season 1bag is about 50kg but in rain season it ranges between 60-70kg (according to him, in rain season charcoal is a bit wet)	1 bag (8-9 tins) about 50-60kg	1 bag (9-10 tins) about 60-65kg	8 to 9 tins, 40Kg to 50Kg	1 bag (8-9 tins) about 50-60kg	1 bag (8-9 tins) about 50-60kg	**37.5-62.5 kg (Average 53kg)**
	55	52.5		37.5	60	55	62.5	45	55	55	
Lifespan	He has used the bicycle for 3 years			He has used the bike for 10 years	The bike is 5yrs old	The bike is 3 years old	N.A.	N.A.	N.A.	N.A.	**Assumption: 10 years**
End-of-live-treatment	He will dispose it he has no intention to use it for any purpose (Landfill)	He is expecting to sell it as a scraper (Remelted)	He will dispose it he has no intention to use it for any purpose (Landfill)	He is expecting to sell it as a scraper (remelted)	He will sell it as a scraper (remelted)	He is intending to sell it to people who are buying for recycling (Remelted)	Landfill	Landfill	Remelted	Remelted	**Assumption: Remelted**
Charcoal price	He sells 1 bag for TSH 13,000/14,000 when the bag bursts he sells it for TSH 11,000/12,000	he sells 1 bag for TSH 14,000/15,000 when the bag bursts he sells for TSH 10,000/11,000/12,000 it depends on the customer and season of the year	He sells the charcoal for TSH12,000/13,000 when a bag bursts he sells for TSH 10,000/11,000	he sells a bag for TSH 5000/6000, if the bag burst he sells it for TSH 4000/5000	he sells 1bag for TSH 12,000/13,000 when the bag bursts he sells for TSH 10,000/9000/8000 depending on the season	he sells a bag of charcoal for TSH 12000/13000, when a bag bursts he sells it for about TSH 10,000/9,000	N.A.	N.A.	N.A.	N.A.	**5500-14000 TSH (Average 11667TSH)**
	13000	14000	12500	5500	12500	12500					
Frequency Loss of charcoal during transportation	He carries charcoal to to Kilosa 2-3 times/month, He is doing the business 5months out 12 months in a year, He gets 3-4 bursts in 5 months	He works for around 16-18 days/month, each day he transport 1 bag, he gets around 5 bursts each month	He transports around 45 bags/month, about 4 bags burst in each month,	He is transporting charcoal 4months in a year, 2trips/day*6days/week*4weeks*4months= 192 bags (I doubt, but he insisted that is how he transport charcoal)), 8-12bursts in 4 months	He transport charcoal 7-8 trips a month, in each month he gets around 2 bursts	He transport charcoal 7-9 trips each month, on average he gets 1 burst each month,	He transports 14-20 bags/month, he gets 5-7 bursts/month 2.5-3 Kg (1-2 sados) which is 4.4%	He transports charcoal 3times a week X 4weeks (in a month), he does the business 2months a year He gets 2-3 bursts/month, in each burst he losses 0.5-0.75 of a tin (7.35%)	He transports charcoal 20times/month, he works 6months/year He gets 3-5bursts/month, he looses 3-5kg on each burst (7.27%)	He transports charcoal 10 trips/month, 2-3 bursts/month, he looses 0.5-1.0 tin (8.82%)	
Bursts (%)	28%	29%	9%	5%	31%	13%	35%	21%	20%	25%	**5.2 - 35.3 % (Average 21.6%)**
Loss of charcoal (%)							4%	8%	7%	10%	**4.4 - 9.5 % (Average 7.4%)**
Maintenance	He replaces about 10 spokes after every month , He changes 1 tyre after every 6months, changes 2 tubes after every 2 months, changes freewheel once per month	He changes around 10 spokes/month, 2tubes after every 6 months, Quarter pins-2 pieces/month, 2 pedals after every 3 months	In each month he changes the following things; 1 tyre (rear tyre), 1tube, about 5 spokes, 20 bearings, front hub bolt, 1 bearings cover (vikombe vya beringi)	He changes about 20 spokes/month, 1 tire/month, he also do occasional services depending on the condition of the bicycle-greasing, changes 42 bearings, 1 bearing cover	He repairs his bicycle 3-5times/month, in each time he replaces 7-8 spokes, he changes bearings cover once per month, changes tires after every 5-6 months, tire tubes after every 4-5 months,	He changes tyres after every 6-7 months, 2 tyre tubes after 5-6 months, 5-6 spokes each month, 1 rear hub bolt each month	He changes tyres after every 5-6 months, 7-10spokes/month, pedals every 2months, Freewheel after every 1.5 to 2 months, bearings 22/month, he changes brake quarter pins twice per month	He changes 2tubes/month, 22 bearings, 2 tyres after every two month, he changes spokes 3 times/month each time 2-5 spokes	He changes spokes 10-15 spokes/month, 2 tubes every two month, 2 tires after every 3 months, 22 bearings/month, 3 hub bolts (front, centre and rear) every two months	2 tires after every 4-5 months, 2 tubes after every 2 to 3 months likewise for pedals,	

17.2 Interviews: Transportation vehicles - Motorbikes

Parameter	1	2	3	4	5	6	Average
Name	Felician Lengamka	Mr Rajabu Maulid	Peter Simon	Hussein Said	N.A.	N.A.	-
Location	N.A.	Msimba village	Dodoma Isanga village	Ulaya Mbuyuni village	N.A.	N.A.	-
Motorbike Model	T-better	Sanlag	N.A.	T-Better	Sunny	Sanlag	**T-better**
Weight, unloaded [kg]	50kg to 55kg	About 65kg	40-50kg	40-50kg	90 kg	70 kg	
Material (predominant)	Iron	Iron	Iron	Iron	Iron	Iron	
Capacity [kg charcoal]	H e normally carries 10 tins of charcoal, each tin is about 15kg	He normally transport 2 bags, each bag is about 50kg	normally carries 1 bag of charcoal/ trip, 50-60kg	He normally carries two bags, each bag is 35-40kg	Carries 28kg everyday	One bag of charcoal of about 40-50kg	
	150	200	55	75	28	45	**28-200 kg (Average 92kg)**
Lifespan	He has used the bike for 5 years	Estimation from bicycle shop owner	N.A.	N.A.	N.A.	Does not know	
End-of-live-treatment	He will sell the bike before end of life	Will sell it before end of life	He is going to dispose it	He will sell before it is completely unusable	Sell it to another person before end of life	Sell it to another person before end of life	
Loss of charcoal during transportation	He transport 2bags/day (two trips) for 23-26 days in a month, 1-2 incidences of burst/month, he transport charcoal 10months out of 12 months in a year	He has never had any burst, he is in business for about 6 months now, He transports about 200bags/month to Mikumi which is 10km from the village	He transports 3bags/day, for 18-20days in a month, he normally gets about 10 bursts/month,	He operates/transport charcoal all year round (12 months), he has had two bursts in the past two years, on average he transports 12-15bags/month	Loss approximately 5%	Around 2% per trip (estimated)	
Bursts (%)	3%	0%	18%	1%			**0-17.5 % (Average 5.3%)**
Loss of charcoal (%)					5%	2%	**2-5 % (Average 3.5%)**
Charcoal price	N.A.	N.A.	he sells a bag of charcoal for TSH 14,000/15000 when a bag bursts he sells it for TSH 10,000/12,000	He sells a bag of charcoal for TSH 5000/6000 when the bag bursts he sells it for TSH 4000/5000	N.A.	N.A.	
			14500	5500			
Maintenance	Engine oil 1litre/month , 1 Sprocket after every 4 months, 2tyres after every 8 months, 1 clutch cable after every 3months	Engine oil 1litre/month, Rear bearing after every 3 months	2 tyres once per year, 1litre engine oil every month, 1 clutch carpet/month	1litre of engine oil/month, he changes rear tube after every 2-3 months, 1 gear liver after every 2-4months, welding the seat occasionally,	Engine oil 1litre per 15days, change of sprocket after every 3months.	Plug 1 every two months, 2 tyres every six months, brakes, engine oil (1litre),	
Fuel consumption	Petrol; 1litre to 20km	Petrol; 1litre to 40km	Petrol; he uses 1.5litres to drive to Kilosa and back	Petrol; He uses 2 litres to drive to Kilosa and back (Kilosa-Ulaya Mbuyuni)	Petrol; 20km per 1litre and sometimes 10km per litre bad road	Petrol; 1 litre to 15 km	
Petrol (l/100km)	5.0	2.5	4.4	3.7	5.0	6.7	**2.5-6.7 l (Average 5l)**
Return transport	About 0.5 of the days he operates (23-26days) he gets passengers when driving back	On average 6trips out 10 trips he drives back with a passenger	Out of 18-20 days he operates in a month he gets around 7passengers	Travelling empty	Carrying two passengers per trip about 15days/month	Sometimes carry passengers on returning trip (around 50% per month travel with passengers)	
Empty rides (%)	50%	40%	63%	100%	50%	50%	**40-100 % (Average 58.9%)**

17.3 Interviews: Transportation vehicles - Small trucks

Parameter	1	2	3	4	5	**Average**
Location of interview	N.A.	Kilosa Uhindini	Kilosa Uhindini	Kilosa Uhindini	Mikumi	-
Truck Model	N.A.	Fuso Mistubishi	Fuso Forward	Fuso Hino	Mistubishi Canter	
Weight, unloaded [ton]	2.8	5.5	5	5.5	3.5	
Material (predominant)	Iron	Iron	Iron	Iron	Iron	
Capacity [kg charcoal]	80 bags, 9-10 tins (80-100)kg each bag	4 tons but it can load up to 10 tons (it was modified locally to carry more load)	4tons but it can load up to 10 tons (the truck has been modified to carry more load)	4tons but it can load up to 10tons (the vehicle has been modified)	40 bags (about 1120kgs of charcoal)	
	7200				1120	**1120-7200 kg (Average 4160kg)**
Lifespan	N.A.	N.A.	N.A.	N.A.		
End-of-live-treatment	He will sale to another person (the assumption is that it might end up as landfill or remelted)		Assumption: Remelted or Landfill	Assumption: Remelted or Landfill	Does not know (assumption: Remelted or Landfill)	
Loss of charcoal during transportation	3-4 tins (each tin has 12-15kg)	1 to 2 tins (7-9 kg)	0.5 to 1bucket (1bucket is equivalent to approximately 7-9 kg)	Around 1bucket/tin	Half a tin of charcoal per trip from the forest to the market in Ruaha	
Loss of charcoal (%)	0.7%				0.6%	**0.580357142857143-0.7 %**
Maintenance	Engine service after every 10000km, he changes Oil filter, Diesel filter, Engine oil (13litres), Greese (3Kg)	Change engine oil (12litres), oil filter, use 4kg of grease	Change engine oil (10 litres), oil filter, grease 1 kg	Change oil filter, diesel filter, engine oil (12 litres), occasional maintenance eg welding, acid water (for battery),	Welding springs, change oil filter every month, diesel filter, engine oil (5litres)	
Diesel tarmac road (l/100km)	12.5				12.5	**12.5-12.5 l (Average 13l)**
Diesel earth road (l/100km)	14.3	25	25	25		**14.3-25 l (Average 22l)**
Return transport	The truck drives back with shop goods	The truck drives back with shop goods	The truck drives back with shop goods	The truck drives back with shop goods	Returns empty	
Empty rides (%)	0%	0%	0%	0%	100%	**0-100 % (Average 20%)**

17.4 Interviews: Transportation vehicles - Big trucks

Parameter	1	2	3	4	**Average**
Location of interview	Mikumi	Mikumi	Mikumi	Mikumi	-
Truck Model	Scania R.420	Freight liner	DAF CF		
Weight, unloaded [ton]	17	15.24	13.5	20	
Material (predominant)	Iron				
Capacity [kg charcoal]	49100	30480	26000	32500	**26000-49100 kg (Average 34520kg)**
Lifespan	N.A.				
End-of-live-treatment	He will sale to another person (the assumption is that it might end up as landfill or remelted)				
Loss of charcoal during transportation	Average 70 to 90kg/per trip	Average 3%	1 to 2% of the charcoal carried on the truck	No losses	
Loss of charcoal (%)	0.2%	3.0%	1.5%	0.0%	**0-3 % (Average 1.2%)**
Maintenance	Brakes, changing tyres, changing engine oil,	Changing engine oil, oil filter, brake pads, grease, changing tyre tubes,	Grease, Engine oil, oil filter, changing tyre tubes, welding,	Oil filter, grease, engine oil, changing tyres and tubes,	
Diesel tarmac road (l/100km)	28.6	28.6	25.0	26.7	**25-28.6 l (Average 27l)**
Return transport	Most of the time return with load including charcoal (7-9 out of 10 trips)	3-5 out of 10 return trips (carry goods including charcoal)	Empty	Sometimes returns empty (3-5 out of 10 trips)	
Empty rides (%)	20%	25%	100%	25%	**20-100 % (Average 42.5%)**

17.5 Interviews: Charcoal wholesaler and retailer

Parameter	1	2	3	4	5	6	7	8	9	Average
Interview location	Kilosa Mjini	Kilosa Behewa	Kilosa Magomeni	Kilosa Magomeni	Kilosa Mtendeni	Kilosa Mtendeni	Kimara, Dar es Salaam	Kimara, Dar es Salaam	Kimara Mwisho, Dar es Salaam	
Date of interview	20.05.2013	21.05.2013	20.05.2013	20.05.2013	20.05.2013	20.05.2013				
Wholesaler or retailer	Retailer	Wholesaler	Retailer	Retailer	Retailer	Retailer	Wholesaler and retailer	Wholesaler and retailer	Wholesaler	
Amount of charcoal sold [tons/month]	Approximately 2 bags (each bag is around 50-60kg)	30 bags (each 50-60kg)	50 bags (each bag is about 7 tins, each tin is 7-9kg)	12 bags (8 tins per bag)	4 bags (each bag is about 8 tins)	12 bags (of about 7tins each)	Dry season (Around 30-40 bags/per month) Rain season (Around 40-50 bags/month)	Dry season: 20-30bags/month Rain season: 50-60bags/month	Dry season: around 50bags Rain season: around 150 bags	
Charcoal sold comes from [region]	Kilosa (Morogoro)	Kilosa	Kilosa (Morogoro)	Kilosa Morogoro	Kilosa Morogoro	Kilosa Morogoro	Tanga	Tanga and Kisarawe	Tanga, Singida, Morogoro,	
How is charcoal transported to the store?	Bicycle	Bicycle	Bicycle	Bicycle	Bicycle	Bicycle	Trucks (eg. Fuso)	Trucks e.g Mitsubish canter 2.5 tons and Fuso	Canter (for charcoal which is coming from Morogoro and Pwani regions) Big trucks eg Fuso	
[vehicle type]										
Charcoal sold in bags or tins?	Small tins (about 1.5kg) and medium size bucket (about 4-5kg)	Bags	Small tins (1.5 kg)	Small tins (1.5 kg) and medium size buckets (4-5kg)	Small tins (about 1.5kg)	Medium size tins (4-5kg) and small tins (about 1.5kg)	Both in Bags and tins	Both In Bags and Tins	In Bags	
How is charcoal transported home?	By bicycle or by hand	Bicycle or motorcycle	By hand or bicycles	By hand or bicycle	By hand or bicycle	By hand or bicycle	Wheelbarrows, small vehicles, by hand, motorcycles	By hand, wheelbarrow and small vehicles	Small vehicles, wheelbarrows, motorbikes, by hand	
Losses of charcoal per bag at the store site [tins/bag]	1 small tin per bag	Less than a small tin per bag (1 small tin is about 1.5kg)	3 small tins/bag	1to 2tins (of about 1.5kg each per bag of 8tins)	1 tin (7-9 kg) per bag	1 to 2 small tins of (about 1.5kg each) per bag of 7 tins	Around two bags/month Size of a bag is 50-80 kg (bags are not of the same size)	1 to 2 bags/month Size of bag 60-70kg	Could not give estimate of losses, however he normally see people coming to collect the charcoal dust	
	2.7%	1.8%	8.0%	3.5%	14.5%	2.7%	5.0%	5.0%		**2-14.5 % (Average 5.4%)**
How are the losses used?	Use for cooking or thrown(very fine particles)	For cooking (if the size of the particles is a bit larger) or thrown (fine particles)	Some are used for cooking and the rest (very fine particles) are thrown	Thrown	Not used	Some are used for cooking and some are not used	Not used	Losses are not used	he does not know where the dust is taken and for what purpose/use	