De-bushing Project :

Towards a cleaner charcoal production process

Mission Report

M TEMMERMAN
Octobre 2016

Table of content

1 Introduction

The aims and objectives of the assignment are summarised as following:

- To establish a modernised approach to charcoal production that minimises negative environmental impacts as deforestation, smoke fire hazards and excessive environmental harmful waste
- To upgrade technical skills & production knowledge among charcoal producers
- To increase the productivity and profitability of the charcoal production process
- To improve provision for health and safety of workers involved in the charcoal sector

During this mission, the price of fossil fuels (diesel, gasoline, gas, electricity) and the price of energy from wood (wood fire and charcoal) were identified. These prices were then expressed by kWh to achieve a comparable basis. The objective is not to give a comprehensive comparison of prices of different energy sources in Namibia, but rather to highlight the differences in price between fossil fuels and fuels made of wood or charcoal. For example, prices from liquid fuels listed here are based on the prices charged by a single pump in Otjiwarongo. Only three electricity rates were considered while there are more. These data are illustrated by the Figure 1

Three rate groups can be differentiated:

- Fossil fuels with prices ranging from $ 1 N / kWh (liquid fuels) to 1.5 N $ / kWh (gas & electricity small power). It must be highlighted that electricity sold to large consumers is more expensive and exceed $ 2.5 N / kWh
- Wood fuel sold directly to users
- Charcoal at different stages of the production chain (N $ 0.1 / kWh bulk price paid to charcoal makers, 0.36 N $ / kWh paid to charcoal producers for the 60+ quality, see 3.4.7)

Overall, as is often the case, the price of energy from charcoal is much lower than other energy sources

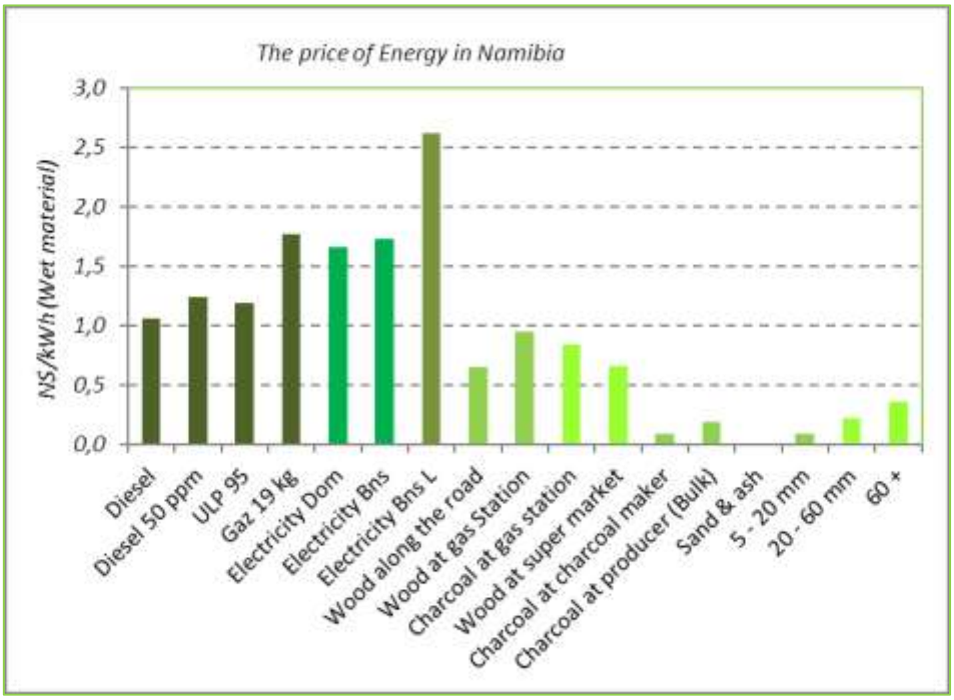


Figure 1: Energy prices in Namibia, including Charcoal (Dom=domestic, Bns=Business, Bns L = Business large)

2 Charcoal production state of the art

2.1 Main Charcoal process phases

While it is possible to carbonize green wood, it is useful to perform a pre-drying. This can be achieved by simply storing the wood in ambient air condition. It will lower wood moisture content to an equilibrium depending on the conditions of temperature and relative humidity of the air in the storage area. Moisture on a wet basis of 25 to 30% (Hbh) is considered acceptable to begin a carbonization cycle. Further drying will benefit carbonization and will result in improved performance. However, in practice this is possible only when external heat source is available, for industrial carbonization systems or when atmospheric conditions are favourable for drying (hot & dry air) as is often the case in drylands.

Without going into the theoretical details of the slow pyrolysis, carbonization can be defined as the degradation of three wood components: cellulose, hemicellulose and lignin. This transformation takes place in three main phases: drying, proper carbonization and cooling. [1]

During drying, the water contained in the wood must be evaporated before the wood components pyrolysis can start, even if a pre-drying was carried out. During this phase, the temperature of the wood is about 100 ° C. Evaporation of water requires a large amount of energy. In case of “partly combusted wood load systems” this energy is taken in the wood load itself and for other systems, an external energy source may be used. Thus, the more wood has been dried before carbonization, the better its performance.

When dry bone, the wood temperature still must be increased to 280 °C. The energy required for this step also comes from the combustion of a portion of the wood load (or an external source); it is still an endothermic reaction.

When the wood is dry bone and heated to 280 °C, it begins to decompose spontaneously to give charcoal, and several components: water vapor, tars and non-condensable gases which will be detailed later. Wood carbonization above 280 ° C is exothermic. This process continues until it remains only the carbonized residue that is charcoal. If there are no new external heat supply the process stops and the temperature reaches a maximum of about 400 ° C. This charcoal, however, still contain significant amounts of tar residues. If the heating is continued, the pure carbon content increases due to the removal and decomposition of a greater proportion of tars.

After carbonization, the load is airtight sealed to avoid any contact with oxygen of the air. It slowly cools by radiation to ambient temperature.

The quality assessment of charcoal production is a combination of process yield and charcoal products quality. Beside the wood load moisture content, the charcoal production process is influenced by the following parameters:

- Temperature
    - This is the most important factor; temperature determines the carbonization yield and the physicochemical properties of produced charcoal. The charcoal quality increases with temperature to the detriment of mass yield. Indeed, the higher the carbonization temperature, the higher volatiles escape from the fuel, the higher its mass decreases and its fixed carbon content increases. A low carbonization temperature leads to a higher mass yield, but to a charcoal of lower quality. A good quality charcoal must have a fixed carbon content of about 75%, which requires a final carbonization temperature of about 500 ° C [1].

- Charring speed

  - During a charcoal production process (slow pyrolysis), the compounds have time to form and react together during side reactions. This is not the case during fast treatments (flash pyrolysis). During flash processes, the contact time and the temperature rise is of about one second. In this case, the main product is not charcoal anymore, but gases and liquids. In practice, this do not take place during traditional charcoal production processes.

- Raw material

  - Dense woods give a dense charcoal and light woods gives charcoal low density. [2]

  - All wood species can be carbonized to produce a usable charcoal, though less dense charcoals are generally less preferred. This is mainly because charcoal is often sold on a volume basis: an empty tin can (though often called "kilo") is the reference to marketing, the bag is another reference (and are called "50 kilos" or “100 kg” bags). Under these conditions, less the wood is dense (so its coal), the less the customer receives energy for the volume he buys.

  - The wood ash content is usually low and has only few variations. The carbonization increases the ash content, but it remains acceptable for its uses. However, the bark contains more mineral material and leads to a lower quality charcoal. The final charcoal ash content may also be affected by dirt, especially in the case of mound kiln processes, in which the product is in direct contact with the ground.

  - As noted hereabove, wood moisture is very important in charcoal production processes. The higher the wood moisture content, the lower the mass yield. Because wood drying needs energy.

  - A wood having a high lignin content gives a higher mass yield, mature and healthy wood is therefore preferred for charcoal production.

- Charcoal maker skills

  - For “partly combusted wood load processes”, qualification of charcoal maker is crucial. Indeed, indicators to assess the effects air excess or lack (e.g. smoke colour, smell or intensity) can be acquired only through long practice.

  - The impact of this factor is not as important for improved carbonization techniques, but training in their use remains necessary.

- weather Influence
  - Rain can severely alter the carbonization process, especially for mound kilns and pits; it significantly increases the process duration.
  - Heavy rain before ignition leads to wood load moisture absorption
  - A strong wind induces a fast carbonization of the side that is exposed and leads it to a fire risk

2.2 General rules to apply for a good carbonization

Sanogo et al [1], reviewed the most important points to complete a good mound kiln carbonisation. These rules also apply to metal and brick kilns and are listed below.

- Wood piling and arrangement should be made in a way that makes the air penetration in the feed easier and more uniform, to prevent uneven carbonizations;
- The wood logs size must be uniform, except brushwood for ignition and to fill the voids
- No wood species mixture
- The carbonization furnace must be as airtight as possible, except for vents
- The logs of bigger diameter are placed in the centre of the load, as these areas remain hot longer
- The carbonization time increases with the size of the wood logs
- The carbonization spot: the site shall be flat, not wet or sponge (if the soil is very moist, wood burning energy would also be used to dry the spot). It shall be close to wood harvesting area, clear and out of vegetation. It shall allow easy handling when loading / unloading wood and charcoal. Moreover, it shall be free of all stones and especially strains. Finally, to avoid fires, the immediate vicinity of the kiln shall be properly cleaned
- A grid may be formed by placing beams at the base of the system, they are made of 10-20 cm diameter healthy wood logs. Their main role is to ease the air and gas flow to the carbonization process inside the kiln.
- The load may be vertical (a wood floor is previously arranged on the grid, then the wood logs are arranged vertically in layers), horizontal (in radius or crown) or bulk (especially in the case of small dimensions wood logs).
- For fire starting and wood load preheating, the use of small wood pieces, twigs or embers is preferred, they are placed at the centre of the ignition point. Fire development is facilitated by creating a "chimney effect" (openings / vents are made at the base and at the top of the furnace). Thus, the fire grows rapidly in the wood load. Consequently, the water contained in the wood is vaporized and escapes under the form of white smoke. The air inlets are then reduced and the wood load continues to dry. The duration of this phase depends on the initial wood moisture. When the fire is powerful enough, carbonization begins, air access is then reduced again and any air input or outlet other than those dedicated to this purpose, are blocked. The carbonization zone can start to grow. During this phase the smoke becomes yellowish, dense and has a slightly pungent smell. Then, carbonization zone spreads, the charcoal maker ensures that the spreading is uniform across the load. To do so, he modulates the air inlets to foster access in the cooler areas and reduce it in too hot areas. For conduct a carbonization, the first hours after starting are crucial.
- When the charring zone is well developed, the air inlets and flue gases outlets are reduced. The objective is then to maintain a temperature above the exothermic phase.
- Extinction: when carbonization is complete, the colour of flue gases changes and becomes blue and transparent. All holes are then sealed and all points that could let in air are clogged.
- The wood load cooling phase starts. Its duration depends on the type of furnace and load (volume, mass & density).
- When the kiln is cooled, charcoal can be taken out the kiln and bagged. Caution is recommended, because the freshly charred charcoal contact with air may start its ignition. Indeed, this oxidation can raise the charcoal temperature to a level high enough to start its spontaneous combustion. In consequence, a waiting time is recommended between taking the charcoal out of the kiln and the bagging.

2.3 *Charcoal: Quality & yields*

Different yields calculation methods are proposed in the literature: Mass yield, Commercial yield, Weighted mass yield, Technological yield and Energy yield [1] [3] [4] [5]. Combined yields have also been described [6] as well as the reference mass yield [7] [8].

In the following paper, different options were chosen in expression of moisture, heating value and yields, they are defined below.

The moisture content of solid biofuels is a percentage of the wet weight

$$H_{bh} = \frac{M_H - M_A}{M_H} 100$$

- H_{bh} : Wet based Moisture Content (%)
- M_H : Wet mass (g)
- M_A : Dry mass after stay in a drying cabinet up to constant mass (anhydrous) (g)

Evaluations conducted as part of this study will be limited to the use of the mass yield (anhydrous basis) as defined in [6]. The mass of unburnt logs is deducted, as well of the mass of charcoal than the mass of initial wood logs. To compare data from different carbonization, the mass yield must always be calculated on an anhydrous basis.

$$RM_{ba} = \frac{M_{ca}}{M_{ba}} 100$$

- RM_{ba} : Mass yield on anhydrous basis (%)
- M_{ca} : Charcoal mass - anhydrous (kg)
- $M_{ba:}$: Wood mass – anhydrous (kg)

Although this yield is not used later in the paper, the (higher) energy yield is presented below. This yield is always greater than the mass yield. Indeed, it considers the energy contained in charcoal products and refers to the energy that is contained the initial load. As the calorific value of charcoal is higher than that of wood, the energy yield is higher than the mass yield.

$$RE' = \frac{M_{ca}}{M_{ba}} \frac{PCS_{ca}}{PCS_{ba}} 100$$

- RE' : (Higher) Energy yield - (%)
- M_{ca} : Charcoal mass - anhydrous (kg)
- $M_{ba:}$: Wood mass – anhydrous (kg)
- PCS_{ca} : Charcoal Gross Calorific value (MJ/kg) – about 20 MJ/kg -
- PCS_{ba} : Woodl Gross Calorific value (MJ/kg) – about 33 MJ/kg

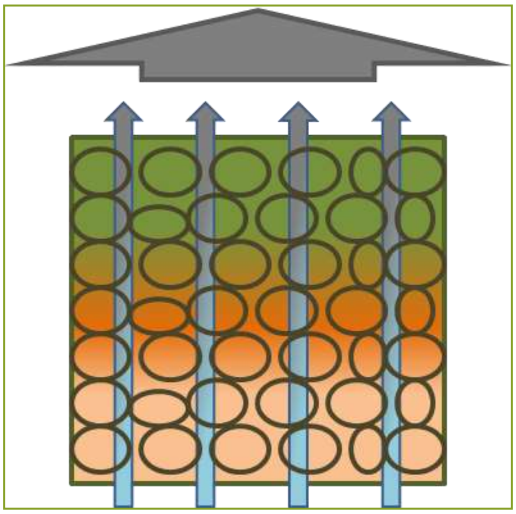
2.4 Charcoal production processes

2.4.1 Two main charcoal production processes

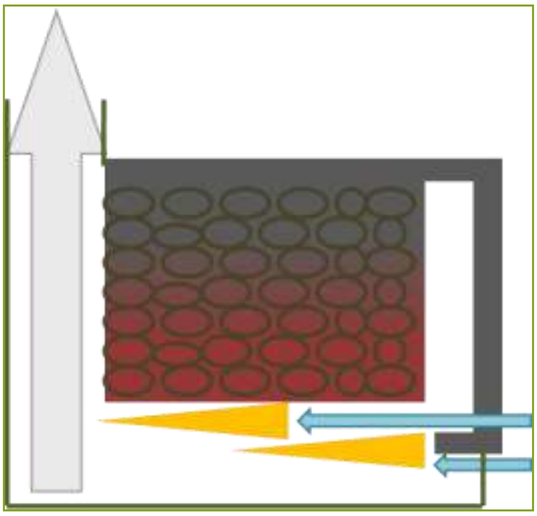
Carbonization techniques are conventionally grouped into “partly combusted wood load processes”, and (industrial) retorts [7]. These two charcoal production principles are illustrated by Picture 1 & Picture 2.

The “partly combusted wood load processes” may be further subdivided in two groups depending if airflow is directly or indirectly generated. [1] The published yields of these alternatives have been collected from various authors and are summarized in Table 1. Different mound kilns techniques are compared in [6]. This review is based on an analysis of more than 20 scientific papers and conclude that mound kilns techniques, if properly conducted achieve yields like those obtained with improved techniques (i.e. metal kilns or Brick kilns).

Retort kilns allow for combustion of gases generated by the carbonization. These gases can be used to supply heat to the kiln itself, or a kiln nearby.



Picture 1: partly combusted wood load process - principle



Picture 2: retort kiln - principle

2.4.2 Partly combusted wood load processes

2.4.2.1 Mound Kilns

Conventionally, there are three types of mound kilns: traditional mound kilns, horizontal mound kilns and improved mound kilns, represented mainly by the Casamance mound kiln in North West Africa and the MATI mound kiln in Madagascar.

Traditional vertical mound kiln has a circular base (Picture 3 & Picture 4), it consists of wood arranged vertically around a central pole and small brushwood arranged in the gaps. When the wood load of the mound kiln is pilled, the central post is removed to make it a fireplace. The cover consists of plant material (straw, grass & branches) topped with a layer of ground (sand or silt if possible).

The ignition of the wood load takes place at the centre of the mound kiln by dropping embers in the fireplace. After the fire, has grown and moved higher in the fireplace and the chimney, the carbonization front progresses from top to bottom, it has a fan shape. The conduct of these mound kilns requires great skill and an almost permanent monitoring.

When carbonization is complete the mound kiln is covered with an additional layer of soil to the seal it during cooling. The duration of the carbonization is approximately about 50 hours for small kilns (about 10 cubic meters). Cooling can take several days for the biggest kilns.

Picture 3: Traditional mound kiln in Benin (wood cut in the forest)

Picture 4: Traditional mound kiln in RD Congo, Bateke Eucalyptus plantations

The horizontal mound kiln (Picture 5 & Picture 6) is very similar to the traditional mound kiln regarding coverage and the way to conduct it. Its shape is like a half cylinder or a flattened rectangular parallelepiped. The two significant differences from the previous process are as follows;

- Wood is piled horizontally (longitudinally)
- The carbonization front moves from one mound kiln end to the other

In the case of horizontal mound kilns, the wood load is placed transversely over a series of logs placed end to end. They constitute an airflow grid. Sometimes the logs of the wood load are arranged longitudinally. Again, brushwood is used to fill the gaps between the logs.

The process starting point (ignition) occurs on the leeward side of the kiln. In the case of a large-sized mound kilns, already cooked charcoal (at ignition side) may be collected before the carbonization of the all kiln complete. Horizontal Kilns volumes can go up to 100 cubic meters, the complete cycle of carbonization may be more than 3 weeks.

Picture 5: Traditional mound kiln in Cameroon (sawmill residues)

Picture 6: Traditional mound kiln in PRCongo (sawmill residues)

Improved mound kilns (Picture 7 & Picture 8) have been developed to improve, accelerate and facilitate the monitoring and the conduction of the charcoal production process. Among improved mound kiln the Casamance one is probably the one which was the most spread.

The setting up of this mound kiln requires good air circulation (floor vents and floor made of small logs, vents are made by using pipes at the base of the kiln) and a wood logs piling based on the size (small branches at the periphery and large logs at the centre of the kiln). Coverage does not undergo changes over traditional kilns.

However, the main improvement is the use of a chimney made of inexpensive materials (old 200 l drums). It allows a faster carbonization process, easier to conduct thanks to inducing the gas flow direction. In addition, the yields would be improved through the downdraft. A mound kiln of 100 cubic meters requires 3 days carbonization and 4 days cooling.


Picture 7: Improved mound kiln in Madagascar (MATI)


Picture 8: Casamance mound Kiln in Tchad

The mound kilns have the advantage of being mobile, and require no investment because they can be built from local materials. Furthermore, their capacity is adjustable to the needs and to the available raw material.

On the other hand, mound kilns production is highly dependent on charcoal maker skills, they require heavy and permanent workload. Moreover, the production quality is quite variable. In addition, the yields obtained are very variable, from 12 to 25%. Indeed, without ongoing monitoring, the risk of fire is high and thus almost complete destruction of the wood load. These carbonization processes generate emissions typical of incomplete combustion, including CH_4, which is particularly impacting the greenhouse effect.

2.4.2.2 Metal Kilns

A cylindrical metal kiln was optimized by the UK Tropical Products Institute. This work was based on a similar furnace that was used in the UK & Europe since the 30s. This kiln (TPI) was then disseminated in many developing countries. Besides being mobile, metal kilns allow to conduct the charcoal process accurately by using air ducts and metal chimneys that allow efficient control of air access. The observation of smoke escaping from the chimneys makes it possible to identify areas where charring occurs and to control it. It is also possible to direct the incoming air to areas where charring has not yet started. These furnaces generally have a diameter and a height of 2m. They are easy to conduct and their cycle is relatively short (5-6 day) through a cooling phase accelerated by metal walls.


Picture 9: Metal drum (TPI) in Cameroon

Picture 9 illustrates one of these TPI kilns used in Cameroon to make charcoal from sawmill residues.

These kilns however have some disadvantages, notably they generate a lot of smoke, have a limited life time and require equipment and skills to perform the welds needed to make them. Metal kilns have the advantage of short carbonization cycles which are easy to conduct. Production is more homogeneous, both in terms of charcoal quality and yield regularity. The average yield is about 22% (from 12 to 30%). The risk of fire is reduced.

However, the capacity of these kilns is fix and cannot be adjusted. As for the mound kilns carbonization processes, mound kilns generate emissions characteristics of incomplete combustion, including CH_4, which particularly impacts the greenhouse effect.

2.4.2.3 Brick Kilns

Traditional models of brick kilns have been improved over the centuries, but 3 of them must be highlighted for their high use, especially in the Americas: the Brazilian kiln, the hemispherical Argentine kiln, and Missouri kiln in the United States.
The Missouri kiln, was developed in the United States, it is generally made of reinforced concrete or concrete blocks, it has steel doors and a chimney. Its performance is comparable to the Argentine and Brazilian kilns. The large metal doors allow the use of mechanical equipment for loading and unloading. Regarding developing countries, it has two disadvantages: it requires a large amount of steel and cement for its setting up, which is expensive material and usually need to be imported. Moreover, it cools down slower than other ovens. Therefore, its use is more suitable for temperate countries, where the cooler climate allows easier cooling and where the materials and skills needed for concrete and steel building are easier to find.
Argentine and Brazilian hemispherical kilns (see Picture 10 & Picture 11) are completely made of bricks. The brick quality can be moderate (low degree of cooking). The bricks are assembled using clay. These kilns are adjustable in size and sturdy, their lifetime varies from 5 to 8 years and are relatively easy to conduct.
The main drawback of these kilns is to generate a lot of smoke at ground level, which, in addition to the pollution generated, make charcoal makers working conditions very difficult. Brick kilns have the advantage of a limited investment and to be easy to conduct. As for metal kilns, production is more homogeneous, both in terms of charcoal quality and in terms of yield regularity. An average yield of about 22% (from 12 to 30%) may be considered. The risk of fire is reduced.
However, these kilns have a fixed capacity and cannot be adjusted. Their construction requires skilled workers and suitable equipment. As for the mound kilns, carbonization processes generate emissions characteristics of incomplete combustion, including CH_4, which is particularly impacting the greenhouse effect.

Picture 10: Brick Kiln in Cameroon

Picture 11: Brick Kilns also generate a lot of smoke

2.4.3 Retort Kilns

2.4.3.1 Industrial Retort kilns

The principle of operation of a vertical cylindrical retort (illustrated by Picture 12) is to use the heat produced by the combustion of the pyrolysis gases to dry and char the wood load. During the starting phase, a fire is started at the bottom of the retort. Through the vents at the base (which are completely open), a fire is also started in the wood load. Once the fire has started, wood is added through the hopper. When it ignites, the vents are closed. One of the air inlets (usually one located on the side opposite to the wind) is opened, and the hopper is partially closed. The wood feeding takes place gradually until the cell is full. In operation, the trap at the base of the retort is opened every two or three hours, to fill a metal drum with hot charcoal. Once filled the barrels are closed and allowed to cool. A new load of logs is introduced through the hopper after each collection of charcoal, so that the operation of the retort may be continuous.

The principle of retort kilns has experienced many variations in its implementation, most of which were developed by the charcoal producers themselves. Few of them were commercially available and many of these producers are no longer in business, with a consequent loss of knowledge in the implementation of the retort principle. Some names remain: Lambiotte, Martezo, Herreshof ...

Retorts have evolved, some furnaces have now lower capacities and nevertheless allow the combustion of the pyrolysis gases. This is the case of the Ukrainian retort kiln which has been visited at CCF (Cheetah Conservation Fund – Otjiwarongo) during this mission. This furnace consists of two compartment connected to a burner. Each compartment contains three boxes in which wood logs (or wood briquettes, in case of CCF) are loaded. The boxes are heated by the gas combustion of the other compartment. Once carbonization is complete, the sealed boxes are changed by others and allowed to cool.

Retort furnaces have the advantage of a continuous process and homogeneous production of high quality charcoal. In addition, due to the combustion of the pyrolysis gases, this principle of charcoal production is much more environmentally friendly (no CH_4 emissions). The observed yields are high (> 35%). However, the investment required to implement retorts kilns are very high.

Picture 12: Lambiotte Retort Kiln

Picture 13: Ukrainian Retort Kiln at Cheetah conservation found, Otjiwarongo

2.4.3.2 Small scale "retort" kilns

2.4.3.2.1 Plethora of prototypes

About small scale retort furnaces, many prototypes have been developed. Human imagination seems boundless in this area. An Internet search on the subject illustrates the wide variety of designed models (see Picture 14 to Picture 19). Some names among others: Mekko Kiln, Kiln Kohn Tikki, Gallon drum ... However, few of these alternatives are commercially available and when they are, their cost seems high in relation to their volume. The announced yields are seldom confirmed by independent testing and the wood fuel needed to their operation is almost never included in the calculation. Very often the leaking of carbonization chambers imposes the use of water to cool the charcoal which leads to a lower quality (break into small pieces).

Picture 14: Mekko Kiln

Picture 15: Kohn Tikki Kiln

Picture 16: example of "retort" found on internet (1)

Picture 17: example of "retort" found on internet (2)

Picture 18: example of "retort" found on internet (3)

Picture 19: example of "retort" found on internet (4)

2.4.3.2.2 Adam Retort kiln

Adam Retort, named after its inventor, has to be highlighted because it was probably the first brick kiln designed to allow the combustion of methane emitted during the carbonization process. According to the designer, the heat from the methane combustion allows (through a system of canals under the carbonization chamber), to heat to wood load and by that to fulfil the energy needs of the process. It turns out that although the spectacular combustion, the influence of the heat it produces on carbonization performance is marginal. A recent study, however, reported a reduction of 50% CH_4 emissions compared to traditional mound kilns [13]. Construction plans and the user license can be purchased from the inventor of the concept... This type of kiln has been implemented in several countries producing charcoal.

Picture 20: Adam Retort kiln

However, some weak points were identified by users:

- Brick walls and junction with metal lids appear to be porous, preventing airtight cooling, resulting in losses due to wood load combustion and imposes the use of water to stop the process.
- The pyrolysis gas is not burned completely and without heat recovery.

2.4.3.2.3 Green Mad Retort

The Green Mad Retort (GMDR - Picture 21) was developed in Madagascar, to produce charcoal from Eucalyptus wood harvested in plantations located around Antsiranana, North of the island. The GMDR has double walls which ensures its perfect sealing during the cooling phase. Through a thermal gas cleaning system, this brick kiln enables combustion of the methane generated by the pyrolysis. The combustion occurs before methane is released into the atmosphere. Although the heat from this combustion is not yet recovered or used, this system makes GMDR one of the cleanest technologies to produce charcoal: less than 1 kg CH_4 is emitted to produce one ton of charcoal [15]. In comparison the production of one ton charcoal in traditional mound kiln generates around 40 kg of CH_4 and the production of one ton of charcoal with a Adam kiln generates 20 kg [13] [14]. Moreover, this carbonization technique leads to high mass yields: about 40% was measured.
As shown in Figure 2 & Figure 3, the GMDR consists of 3 parts: an external combustion chamber, where lower wood quality or other biomass may be used, a charcoal chamber and a chimney at the basis of which a simple system allows the post-combustion of the gases generated by the carbonization.

Picture 21: Green Mad Retort

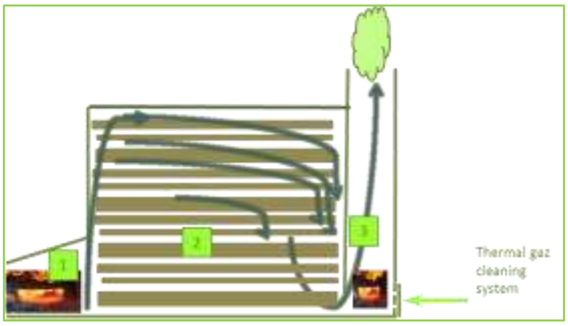


Figure 2: Green Mad Retort - Principle

Picture 22: Green Mad Retort, gas cleaning

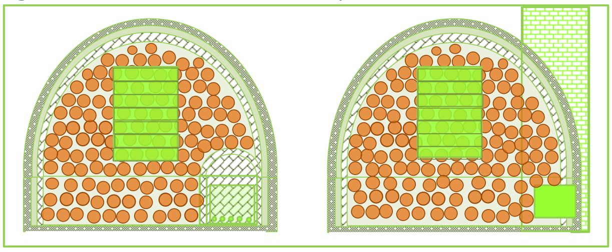


Figure 3: Green Mad Retorts, side views

2.4.3.2.4 Mindourou Kiln

The Mindourou kiln is also a brick oven. It was developed to produce charcoal from sawmill residues in Eastern Cameroon. Here, the sealing problems have been solved by placing the kiln in a pit. The wood load is placed in the carbonisation chamber and covered by metal lids. Sawmill residues are often large, consequently this oven was sized to allow the use of these wood piece without requiring previous cuttings. The length of a furnace module is 6 meters, width of 1.8 m and depth of 2m. As GMDR, the Mindourou kiln is equipped with an external combustion chamber. Even if this has not yet been achieved, the Mindourou kiln may be equipped with a thermal gas cleaning system like that used on the GMDR. In addition, Mindourou kilns are designed to use the heat generated by the combustion of one module to supply the combustion chamber of the next one. This concept, which remains to be implemented, is shown in Figure 4. Although it is still in development, the Mindourou furnace already reached high mass yields of around 40%. Charcoal product is also of very good quality.

Picture 23: Mindourou Kiln – Filling operation

Picture 24: Mindourou Kiln – metal lids

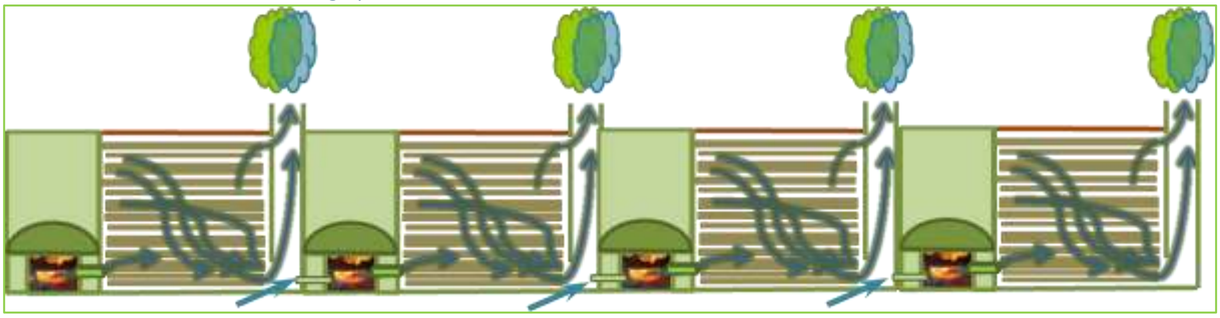


Figure 4: Mindourou – combination principle

2.4.4 Summary

Analysis of Table 1 shows the very high variability of carbonization mass yields in the literature, regardless the technique used. Factors that influence the carbonization have been described above (§2.2). According to [6] the following yields are most commonly obtained: mound kilns: 20 to 30%, brick kilns: 25%, Metal Kilns 25%. The mass yields that can be obtained by using retort kilns are slightly higher, of the order of 30% [8]

Besides the yield (mass or energy) and its strong implications on pollutant emissions, carbonization time must also be considered. The time required for a cycle has consequences at the logistic and organizational level of the site. For mound kilns, cycles time needs can vary from 4 to 45 days, according the information contained in [6]. Here, the Casamance kiln shows an advantage over the traditional mound kilns, the first showing a much shorter carbonization cycle (9 to 14 days as against 43 to 45 days depending on the volume of the load).

New developments in "retort" kilns, small, built of brick, allow the production of charcoal at high mass yields and the elimination of methane before its release into the atmosphere. Green Mad Retort emits less than 1 kg methane to produce one ton of charcoal, the yield is around 40%. Similar yields were obtained with the Mindourou kiln.

Table 1: Charcoal production technics, references summary of announced pro & cons

Technic	Advantages [7]	drawbacks [7]	Yiels RMba (%)	source
Partly combusted wood load processes				
Mound Kilns	Mobile (off road) No skid Local Materials No Investment No splitting needs Adjustable Capacity Use of biomass residues	Demanding regarding operator skills Requires a lot of manpower (permanent) Sensitive to climatic variations Coal of varying quality and soils contamination by the cover low energy efficiency significant pollution	***Traditional*** 12 to 34 26 15-30 ***Improved*** 19-42 27 ***Casamance*** 19 to34 25 37 15-30	 [6] [5] [1] [6] [9] [6] [5] [9] [1]
Pits	Mobility Skidding on small areas local materials very low to zero investment Charcoal production from large wood logs possible, without slitting adjustable capacity Use of biomass residues	Demanding regarding operator skills Requires a lot of manpower (permanent) Sensitive to climatic variations Requires a deep and cohesive soil low energy efficiency significant pollution	***Subri*** 22 – 36 30	 [6] [8]
Brick kilns	local materials easy to conduct homogeneous and clean coal Good thermal insulation Little sensitive to climatic variations Long life expectancy	Construction requires a competent mason Splitting of large timber needed Fixed capacity Load factor problem Labour intensive dust fixed installations Skidding costs slow cooling	***Semi-sphere*** : 20 13-32 ***Mineirinho*** : 25 22-31 ***Missouri :*** 30 ***Non spécifié***	 [10] [6] [10] [6] [10]

		♪ significant pollution (smoke)	27-30	[8]
Metal Kilns	♪ Mobility ♪ Skidding on small area ♪ easy to conduct ♪ homogeneous and clean coal ♪ short cycle by rapid cooling	♪ Splitting needs for large timber ♪ fixed capacity ♪ load factor problem ♪ Short life span - sensitive to weather (following operators and quality of materials) ♪ average fuel efficiency ♪ significant pollution (smoke)	***Mark V*** 12 -32 ***Magnien*** 25 ***Non spécifié*** 21 28	 [6] [5] [8] [8]
Retort Kiln				
Metal	♪ controlled and constant quality ♪ high mass yield ♪ High energy efficiency ♪ low pollution to zero	♪ Medium investment ♪ average technicality ♪ fixed Installation	23-32	[8]
Continuous processes – industrial retorts	♪ controlled and constant quality ♪ high mass yield ♪ High energy efficiency ♪ low pollution to zero ♪ automatization	♪ considerable investment ♪ high tech ♪ expanded area of supply ♪ Wood transport ♪ Splitting and wood preparation	26-35	[8] [8] [8] [8]
Mindourou Kiln	♪ controlled and constant quality ♪ high mass yield ♪ High energy efficiency ♪ low pollution to zero	♪ Medium investment ♪ average technicality ♪ fixed Installation	38%	[13]
GMDR	♪ controlled and constant quality ♪ high mass yield ♪ High energy efficiency ♪ low pollution to zero	♪ Medium investment ♪ average technicality ♪ fixed Installation	38%	[13]

2.5 Polluting emission due to charcoal production

After a life-cycle assessment of different charcoal supply chains of the Brazilian steel industry, it appears that among the fuel production steps, the carbonization has the heaviest environmental impact. Nevertheless, replacing the traditional brick kiln by an industrial retort kiln provides a significant reduction of the environmental impact of carbonization [10].

These results confirm previous studies, although they are few [7]. The emissions to be considered during the carbonization process are: the non-condensable gases (CO_2, CO, CH_4, H_2, C_2H_4, C_2H_6), the condensable gases and / or their condensates and fine particles. The proportions in which these gases are emitted depend mainly on the carbonization temperature (indication: CO_2: 32 to 36%, CO: 29-55% CH_4: up to 15%, but in but in small scale production, the value of 2, 5% may be admitted).

Table 2 compares the emission (per ton of charcoal) generated by two different carbonization processes: the first one is a party combusted wood load process, the second is a retort type kiln and allows complete combustion of the carbonisation gases.

Table 2: Charcoal production environmental impact, main atmosphere pollutants for two production processes, in kg/ton charcoal [7]

	Partly combusted wood load kiln	Industrial Retort Kiln
Dust	*32*	*3*
CO	*340*	*12*
VOC (excl. methane)	*100*	*9,5*
HCT (excl methane)	*40*	*0*
Methane	*40*	*0*
Phenols	*0,6*	*0,2*
Acetic acid	*48*	*4,5*
Methanol	*8*	*0,75*
Formic acid	*10*	*0,85*
Propionic acid	*4*	*0,15*
Furfural	*5*	*0,5*
HAP	*1,35*	*0*

VOC : Volatile organic compound, **HCT** : Total Hydrocarbonates, **HAP** : Polycyclic aromatic hydrocarbonates

The environmental impact of carbonization gas is threefold: indeed, a gas such as CO is toxic and therefore has a direct effect on human health. Acid emissions (acetic, formic, propionic ...) and polycyclic aromatic have effects at the environmental local scale (acid deposition, for example). Picture 25 to Picture 28 illustrate the impact of smoke on a local scale and on the working conditions of charcoal makers. Gases such as CO_2 and CH_4 are known for their impact on the greenhouse effect. CH_4 has an impact on the greenhouse effect 21 times that of CO_2 [11].

Picture 25: smoke emission due to charcoal production (1)

Picture 26: smoke emission due to charcoal production (2)

Picture 27: smoke emission at human high due to charcoal production (1)

Picture 28: smoke emission at human high due to charcoal production (2)

In a first approach, GHG emissions will be estimated on a mass yield basis. The method of calculating carbon emissions is mainly based on the method presented by Girard in [4]. This method estimates the minimum potential gain in carbon emissions (Ton equivalent CO_2 - T_{eq} CO_2) for enhanced performance of the used carbonization kiln. This method considers as reference a carbonization technic having a mass yield (RMBA) of 12%. This yield, very low but plausible, is the lowest yield observed by [6] and from published literature. It will be compared to different methods of carbonization whose yields are presented in Table 1. The results of this analysis are presented in Table 3. The evolution of the number of T_{eq} CO_2 avoided by improving carbonization yield is also illustrated in Figure 5.

Table 3: Avoided Téq CO2 / ton of produced charcoal by improving the charcoal process yield,

Environmental impact of charcoal processes								
				Charcoal				
Material (MP) / Product (P)	Unités	Coef						
Carbonization Process			Traditional Mound Kiln	Traditional Moun	Metal drum Kiln	Brick Kiln	Retort Kiln	Retort Kiln
Carbonisation characteristic			Low Yield	Improved			Industrial	Small Scale
Proportion of C released under Methane form	% of charcoal ton		2,5	2,50	2,5	2,5	0,0	0,2
Proportion of C released under CO2 form or equivalent	% of charcoal ton		97,5	97,5	97,5	97,5	100	99,8
Anhydrous load wood mass (MP)	kg		1000	1000	1000	1000	1000	1000
Carbon proportion in MP	%		50	50	50	50	50	50
MP Carbon Mass	kg		500	500	500	500	500	500
Carbonisation yield	%		12	20	25	25	38	38
Charcoal Mass	kg		120	200	250	250	380	380
Fixed Carbon proportion in Charcoal	%		78	78	78	78	85	78
Carbon mass in charcoal	kg		94	156	195	195	323	296
Carbon emission due to charcoal production	kg		406	344	305	305	177	204
Spécific emissions	kg C/T Pd		3387	1720	1220	1220	466	536
Avoided emissions	kg C/T Pd		0	1667	2167	2167	2921	2851
Minimum GHG reduction per ton Charcoal compared to	T Eq CO2/T Pd		0	6,11	7,94	7,94	10,70	10,45
Form under wihich C is emitted / ton charcoal								
Emissions carbon CH4	kg/ton Charcoal		85	43	31	31	0	1
Emission carbone CO2	kg/ton Charcoal		3302	1677	1190	1190	466	535
Equivalent CO2 mass of C emitted under CH4 form	kg/ton Charcoal		6515	3309	2347	2347	0	82
Equivalent CO2 mass of C emitted under CO2 form	kg/ton Charcoal		12099	6145	4358	4358	1707	1959
Total CO2 equivalent due to carbonization	kg/ton Charcoal		18613	9453	6705	6705	1707	2042
Gain CO2 par rapport à la méthode traditionelle	T éq CO2/ton charcoal		0	9,16	11,91	11,91	16,91	16,57
Rapport CO2/C	*kg/kg*	*3,66*						
Rapport CH4/C	*kg/kg*	*76,9*						

The results presented in the upper part of Table 3 & in Figure 5 clearly show the environmental benefits of using improved carbonization techniques. Thus, compared to a low yield carbonization, the use of a partly combusted wood load process (brick or metal) having a mass yield of 25% will avoid the emission of at least 7,94 tons T_{eq} CO_2 per produced ton of charcoal. It would be between 10,4 & 10,7 tonnes for industrial carbonization system (38% mass yield). CO_2 Carbon conversion factor is 3.66.

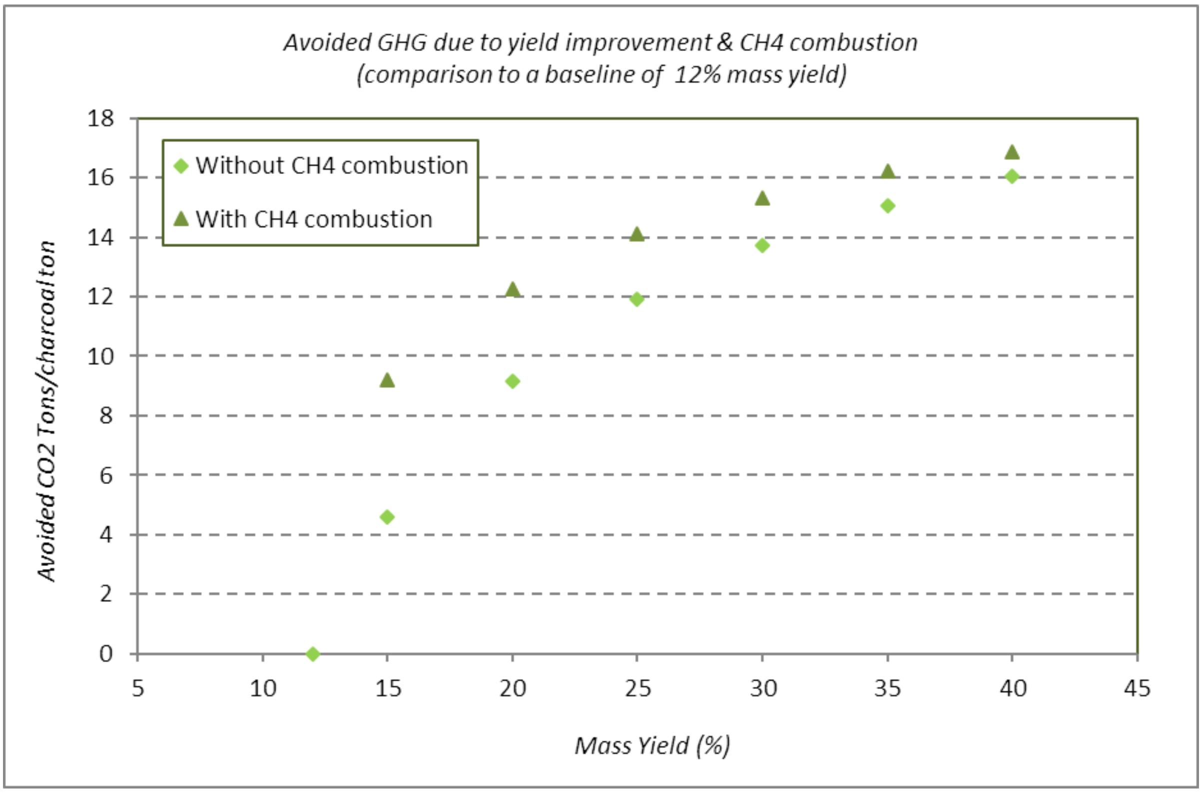


Figure 5: Equivalent CO_2 tons avoided due to charcoal production yield improvement, with & without CH4 combustion

The calculation method, however, is only based on the mass yield and do not consider the quality of the emitted gases. But this carbon is emitted in several forms, for simplification only CO_2 and CH_4 will be considered here. CO_2 is emitted by all the considered carbonization techniques, whereas CH_4 is emitted only by the partly combusted wood load processes. Indeed, the retort techniques does not emit CH_4 or very few. The results shown in the lower part of Table 2 and Figure 5 clearly demonstrate the environmental benefits of burning CH_4. Thus, considering the impact of CH_4 and compared to a low carbonization yield (12%), using a partly combusted wood load process (brick or metal - 25% yield) avoid the emission of 11,91 tonnes of CO_2 equivalent per ton of charcoal produced. It would be between 16,6 and 16,9 tonnes for a carbonization system transforming CO_2 into CH_4.
CH_4 carbon conversion factor is 76,9.

3 The situation in Namibia

3.1 General data about the bush

The areas concerned by the bush encroachment in Namibia (see Picture 29) are about 300 000 km² [16]. These species compete with herbaceous vegetation that constitutes the feed of livestock on such surfaces (see Picture 30). This competition is such, especially during drought periods, that the farms productivity has fallen drastically in recent years. The elimination of this vegetation to facilitate regrowth of the grass is the main reason for the de-bushing operation by farmers. Until the recent ban on the practice, the elimination of the bush using herbicides was still widespread.

For farmers, production of charcoal is primarily a way to reduce costs related to the elimination of the bush. Unlike chemical removal, mechanical operation requires monitoring because regrowth although appreciated by game and livestock is often denser than was the original bush. On the other hand, it seems that the branches left after harvesting facilitate regrowth of grass (protection against the sun, against livestock, runoff avoidance by water retention?)

Above ground biomass per hectare has been be estimated at 30 tonnes of dry matter, from which 10 tons can be harvested sustainably [16]. The species in the bush are characterized by a high wood particle density (an average of 770 kg / m³ will be considered later in this document) and a high ash content. Weather conditions in Namibia (usually high temperature and very low air relative humidity), are favourable to wood drying, which can reach lower humidity values than 15%. However, it was observed that the timber undergoes only a very short drying period (several days maximum) between the cutting and carbonization.

Picture 29: General view of the bush

Picture 30: Bush harvesting helps to grass regrow – on the left with harvesting – on the right without harvesting

3.2 *Charcoal chain*

The charcoal value chain is well organized in Namibia. The owner of a farm operates by itself or delegates to a manager, the operator recruits charcoal makers, buys their production, transport it in a place accessible to processors trucks, processors buy and transport the charcoal to their calibration plants where charcoal is sorted and divided into quality classes before being, for the most part, exported.

3.2.1 Producers

The farmer hires charcoal makers and facilitates the production of charcoal by providing the carbonization kilns. He also organizes the lumbering, sometimes providing machine to mechanize a part of the harvesting (See Picture 32). However, it has to be highlighted that charcoal production is not widespread in all farms, some farmers burn the wood in the open air after cutting to promote regrowth of grass (Picture 33).

For charcoal production, the area of the farm is generally divided into "camps" which is an area that will be fully harvested before moving to the next one. The cutting planning of some farms could be improved, indeed without instructions given to charcoal makers, the trees are usually harvested in a disordered way. But, for organization and control reasons, some operators have established transects systems which also facilitate the collection of charcoal and reduces the risk of fire (Picture 33 to Picture 37). It has to be highlighted that some tree species are protected and that the trees having a diameter over 18 cm cannot be cut.

Picture 31: bush manual harvesting

Charcoal makers are responsible for the trees cutting and logging they also produce the charcoal and put it in bags. The farmer buys the charcoal bags after being weighed. The price is 750 N $ per ton charcoal.

A harvesting productivity test was conducted during this mission (Picture 31). Based on the amount of timber felled & chopped by two men within two hours, it can be estimated that an experienced charcoal maker may cut 150 kg of wood reported in the anhydrous mass within one hour.

The charcoal is then transported to the collection point (Picture 39 & Picture 40) to be transported to calibration plant that buy it to N $ 1500/ton, in bulk.

Several producers have started the process to obtain the FSC label (Picture 38). In this case, evidence must be made that the bush is managed sustainably, which is sometimes contradictory to the goal of eliminating the bush and replace it by grass. However, according to some producers, *it seems possible to ensure sustainable production of charcoal while increasing agricultural productivity of the farm*. In addition to a sustainable management, efforts must also be undertaken in the field of training and welfare of charcoal makers.

Picture 32: Partly mechanised harvesting

Picture 33: some farmers clean their fields without recovering the wood energy

Picture 34: harvesting transect in a camp (year 2)

Picture 35: harvesting transect (year 1)

Picture 36: harvesting transect identification (& numbering)

Picture 37: Harvesting transect, the wood is moved to the place where it will be transformed in charcoal

Picture 38: FSC charcoal

Picture 39: Charcoal stock at producer

Picture 40: Charcoal stock at producer, along the road to be loaded on trucks

3.2.2 Processors

The charcoal is transported from its production site to a sorting plant. Namibia has a dozen such processors. These processors basically all operate in a similar way (Picture 41 to Picture 48). After receiving the charcoal bags (and sometime having taken a sample for quality analysis – e.g. moisture), the bags are dumped into the hopper of a mechanical screen (rotating or vibrating). This sieve sort bulk charcoal in different categories having different values. Fractions for export are then bagged according to customer demand (charcoal dimensions, mass bags, logos ...). Finally, they are placed on pallets to be exported.

A note must be made about the working conditions in these factories sorting charcoal. Handling charcoal generates large amounts of dust which is suspended in the air and are inhaled by the workers. Masks are usually provided to the staff, but this individual protective equipment should be complemented by vacuum and air filtration systems.

Picture 41: Charcoal delivery

Picture 42: Bulk Charcoal may contain high share of fines

Picture 43: Mechanised sorting by sieving (drum sieving)

Picture 44: Charcoal sieving (drum sieving)

Picture 45: Charcoal sorting: sieve output (vibrating screen)

Picture 46: charcoal size classes after sorting

Picture 47: Charcoal bagging

Picture 48: Charcoal bags prepare for exportation

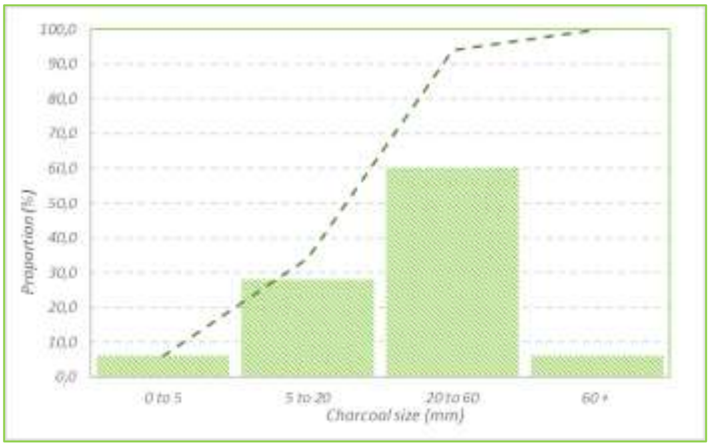


Figure 6: Charcoal sizes proportions, based on data provided by Carbo Namibia & Makara Bush Products

Generally, four fractions are separated by the processors, dimensions may be somewhat different from one operator to another. Figure 6 is based on information gathered from two processors, it illustrates the average charcoal particle size distribution. These fractions have different destinations and different prices. To recap, the charcoal is typically purchased at N$ 1500 in bulk. The fraction "Sand & Ash" has no use (if it is a field application to improve soil fertility), it has no value neither. The fraction "5 to 20 mm" is intended to produce briquettes or to be exported to South Africa, its price is N$ 750 / tonne. The third fraction "20 to 60 mm" is intended for export to the Northern hemisphere, its price is N$ 1850 / ton. The best quality of charcoal consists of the fraction "60 +" also known as "restaurant quality", this fraction has a value of N$ 3000 / ton.

3.2.3 Briquettes

The "5-20 mm" fraction is exported to South Africa where it is pressed into briquettes, the pressing is sometimes made by the processor himself. Indeed, some processors have the required equipment for briquetting production (Picture 49 to Picture 51). Scale of production depends on the producer. Generally, corn starch is used as binder. The air drying does not seem to always be fast enough, especially in the rainy season, thermal drying alternatives have therefore been tried.

Picture 49: Starch is used as binder for briquette agglomeration

Picture 50: Small scale briquette production plant

Picture 51: briquettes sun drying

3.3 Kilns

3.3.1 Namibian traditional Kiln

3.3.1.1 principle

The most used charcoal production technic in Namibia is the metal kiln. This kiln is made of a bottomless metal drum. Even if there are variants (including square barrels), the most common dimensions of this kiln are dictated by the standard dimensions of the metal sheets of 1.6 mm thick (3.65 m x 1.225 m). The sheets are bent along their length and the two ends welded together. The result is a cylindrical drum 1,16 m in diameter and 1,225 m height. A metal plate is welded on the top (easy to see on Picture 52), a rectangular opening is made to introduce the wood load. This opening is sealed with a lid for the cooling step. Drums have a price of N$ 2000, they are mobile and their use is well known by charcoal makers. The carbonization cycle takes 5 to 6 days.

The operating principle is quite simple, and is illustrated by Picture 52 to Picture 66 . Two alternatives were observed to start the process. The first is to light a fire with brushwood at the bottom of the drum. Afterwards the drum is progressively filled by wood until the upper level is reached. The second alternative is to fill the kiln first, then start the fire. The next step is the same in both cases. The air access at the bottom of the kiln is reduce to control the load combustion and avoid the fire reaches too high temperatures. Because of combustion, the wood at the bottom of the kiln decrease in volume and strength, consequently the charge collapses. The charcoal makers promote this collapse by exerting pressure on the top of the load. Free space at the top is reloaded with additional wood. They are therefore in contact with the gases from the combustion which takes place at the base of the load, which favours their temperature increase and drying.

Reloading will be made after every collapse, about every hour. The process is complete when the kiln is completely full of embers. Then, air access is blocked and the lid placed on top of the kiln. The tightness of the base is secured by dry ground and sand, while the cover is clogged with mud. The charring phase has a duration of 2 to 3 days, which must be added 2 to 3 days for cooling. Charcoal may then be taken out the kiln and bagged after a while.

This carbonisation process, despite its many advantages (low cost, wide distribution, high productivity, good knowledge of technology by charcoal makers...) does not have a good image, mainly because the smoke it generates are abundant and disturbing. In addition, the charcoal it produces generally has a medium quality.

3.3.1.2 Namibian traditional kilns mains characteristics, in brief

- Mobile
- Cheap (2 000 N$)
- *Long lifetime (10 years & more)*
- <u>Supposed</u> low yield
- *Generates a lot of smoke*
- Charcoal contains a high share of Sand & ash & small pieces
- Unstable production (sometime very good, sometimes very poor charcoal)
- After ignition, the kiln is filled up to be full of charcoal (3+3-day process)
- Quality & yield seems “charcoal makers skills dependent”

Picture 52: surface cleaning before kiln placement

Picture 53: Wood is moved on a short distance to the kiln

Picture 54: necessary wood to a carbonisation cycle is placed next to the kiln

Picture 55: a fire is lightened at the bottom of the kiln

Picture 56: progressively the kiln is filled with wood on top of the fire

Picture 57: progressively the kiln is filled with wood on top of the fire

Picture 58: progressively the kiln is filled with wood on top of the fire

Picture 59: when no wood can be added, the kiln is ready to be sealed

Picture 60: smokes can be seen from far away

Picture 61: Some charcoal maker fill the kiln before lighten the fire underneath

Picture 62: the kiln is sealed and let down to cool

Picture 63: some kiln have a rectangular shape

Picture 64: after cooling the drum can be open

Picture 65: the charcoal produced contains burned wood & ashes

Picture 66: charcoal is placed in bags

3.3.2 Namibian Retort

3.3.2.1 *Principle*

Some individuals have developed retort types kilns, to increase the productivity of their charcoal production. The operating principle of this retort kiln is shown in Figure 7. The different steps of the method are illustrated by the Picture 67 à Picture 78

The Namibian retort consists of a metal cylindrical enclosure inside which is fixed the retort, also of cylindrical shape. The retort is filled by wood logs before being sealed and heated by a fire underneath. The hot combustion gases escape along the walls of the retort which allows to increase the temperature of the inside wood. After some time, the water in the wood turns to steam and the pressure in the chamber increases, a gas stream is then generated to the chimney of the retort. When the wood is dry, all water being removed, pyrolysis begins and fuel gases are produced. When they come out of the chimney, they encounter the air and start to burn. The information given by the designers of this retort indicate that the combustion of these gases should take place in the chimney which has an air access at its base. The heat released by this combustion is supposed to provide enough energy to maintain the pyrolysis. Several observations indicate that this is probably not the case: the burning of gas takes place only a few centimetres above the chimney output, flue gases coming through the orifice at the base of the chimney probably contain too few oxygen as they come from the combustion chamber ... Finally, when the fire under the retort is no powerful enough, the carbonization process in the retort stops, without all the wood is carbonized.

To improve the drying conditions in the retort and decrease the duration of this phase, junctions between the inside of the retort and the outside air have been arranged at the base of the retort. The objective is to enable the creation of a drying flow in the retort and to more rapidly reach the pyrolysis conditions.

This Namibian Retort has a good image among users: high productivity and high-quality charcoal product are two of its advantages over traditional kiln. Moreover, this alternative is movable.

3.3.2.2 *Namibian retort, in brief*

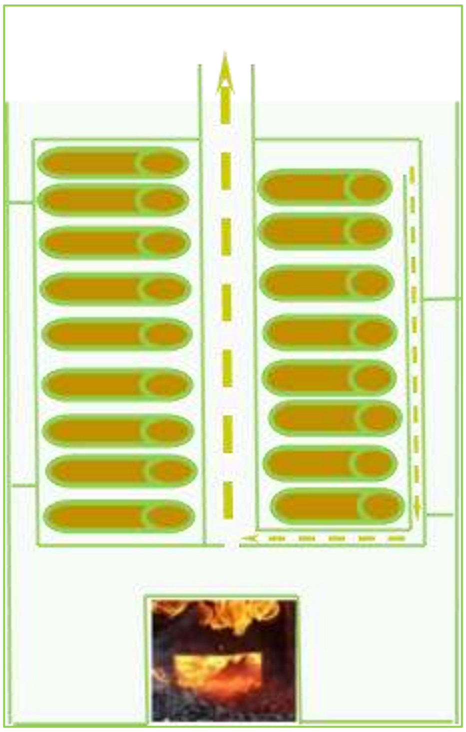


Figure 7: Namibian retort principle

- Mobile
- Less Cheap (7 000 N$)
- Shorter *lifetime (unknown but less of 1 year for the bottom metal plate)*
- Supposed high yield
- *Generates less smoke but still*
- Charcoal contains no Sand & ash
- Stable production (very good charcoal)
- Quality & yield less depend on "charcoal makers skills"
- *Needs* fuel *wood*
- One day process

Picture 67: after being loaded, the pot is sealed

Picture 68: the wood contained in the retort is heated

Picture 69: Heating phase

Picture 70: water steam start to go out the retort pot

Picture 71: steam flow is increasing

Picture 72: steam flow start to be mixed with pyrolysis gas

Picture 73: the gas going out the retort in flammable enough to burn

Picture 74: exhaust gas burns in contact with air

Picture 75: the retort needs to be fuelled permanently

Picture 76: after cooling the charcoal is of very good quality

Picture 77: 120 kg charcoal has been produced in 24 h

Picture 78: except in drying phase, the retort kiln leads to less smoke than traditional drum

3.3.1 Other kilns

During this mission, other carbonization kilns were observed. A very large retort oven which is no longer in use (Picture 79), this oven was part of a set of 4 which were spread in different farms across Namibia, none of them is still active. In Otjiwarango, a Ukrainian retort oven is being assembled, it was purchased by the Cheetah Conservation Fund and is intended for carbonization of densified bush briquette already produced by this organization (Picture 80 & Picture 81).
There is also one (or more) brick furnace in the Otjiwarongo area. However, these have not been visited. According to information obtained, it could be a hemispherical Brazilian kiln.

Picture 79: Unused big retort kiln

Picture 80: Ukrainian retort kiln (CCF)

Picture 81: Ukrainian retort kiln (CCF)

3.3.2 Stakeholders expectations regarding a new charcoal production technique

Meetings and discussions with the charcoal industry stakeholder together with field observations have highlighted the following aspects to be considered when designing a new charcoal production system:

- Expectations
  - A cleaner system that generates less smoke
  - Mobile or semi-mobile
  - small scale
  - faster carbonization process (1 day)
  - Improved charcoal quality
  - Improved charcoal resistance to transport
  - Reuse of existing equipment
  - Reduced fire risk
- Constraints
  - The lifetime of current furnaces is from 10 to 15 years
  - Drying leads to higher yields of carbonization but is impractical on mobile sites
  - The productivity of a drum is 200 - 250 kg / week
  - N$ 2000 Investment for one kiln

3.4 Namibian wood & charcoal characteristics

3.4.1 Wood moisture content

The high temperatures during daytime, the low relative air humidity and the strong winds offer favourable drying conditions. According to collected information, the harvested wood can therefore reach an equilibrium moisture content of 15% or less. It seems that for medium size wood this moisture level may be achieved within 3 to 4 months. However, this estimated time should be confirmed by measurements and drawings of the wood drying curves.

According to data measured during this mission, the wood moisture content at harvesting is higher than 42%, which is the maximum limit of detection of the used hygrometer. This range of value is not surprising, wood moisture just after harvesting is generally around 50%.

A high proportion of harvested wood is made up of branches or dead trees. In addition, it takes several days between the time of harvesting and carbonization, under very favourable conditions air drying. Accordingly, the wood initial moisture content prior to carbonization has been estimated to be 30%. This value must be confirmed by more measurements to be conducted in a drying cabinet.

3.4.2 Wood ash content

The pure wood ash content wood is generally very low (about 0,5%). The bark ash content is higher and may reach 5%. The origin of these ashes is twofold: the minerals contained in the bark and the external particles that adhere to bark during the tree growth and its harvesting. In Namibia wood are not debarked, are of small diameter, the ground is dry and often sandy, leading to high levels of ash in the harvested wood. Ash content of 6 to 7% or more were mentioned for wood. It should nevertheless be noted that these values are in contradiction with the ash content of charcoal mentioned in the analyses reports provided by processors (Table 4). The average value mentioned in the analysis reports is 6.2%, and charcoal has a higher ash content than the wood from it is made of.

3.4.3 The logs bulk densities

Bush invasive species (Dichrostachys cinerea, Acacia mellifera Acacia reficiens, prunoides Terminalia, Combretum apiculatum, mopane Combretum, Acacia senegalensis ...) have very high particle densities. Although it is difficult to find accurate data on this subject.

By default, in this report, the value considered for particle density will be 770 kg / m³ dry. If logs are piled in 1 m long pieces, given the rough and tortuous nature of these species bark, and the average diameter of the branches, it seems realistic to consider a piling factor of 0,6. Thus, one cubic meter of piled logs contain 462 kg of dry wood. The piling factor will be 0,3 for the filling of a cylindrical carbonization kiln. A kiln having a volume of one cubic meter will only contain 231 kg of dry wood.

3.4.4 Charcoal Moisture Content

Such as wood, the charcoal moisture content find an equilibrium with the air moisture content. However charcoal reaches lower moisture content than wood. According to data provided by the processors, charcoal moisture content at equilibrium would be 1%. (Table 4).

3.4.5 Charcoal ash content

The traditional method of making the charcoal in Namibia generates a lot of ash: wood logs are burned one above the other and charcoal lays on sand. Charcoal in the bottom of the kiln is soiled by sand (Table 4).

3.4.6 Charcoal density

Table 4: Charcoal & briquettes characteristics, based on data provided by Carbo Namibia & Makara Bush Products

	M C	*Ash C (1)*	*Vol Mat (2)*	*Fix Carb (3)*	*Total*
Lumpy Charcoal					*1 + 2 + 3*
HC 2078	0,82	7,8	18,05	74,15	100
HC2080	1,28	6,42	14,28	79,29	100
HC2079	1,15	7,88	23,1	69,02	100
HC2036	1,27	4,74	7,31	87,95	100
HC2258	1,22	6,95	16,12	76,93	100
HC2233	0,97	1,87	8,32	89,81	100
HC2268	0,47	7,43	19,31	73,25	100
Mean	*1,0*	*6,2*	*15,2*	*78,6*	
Std	0,3	2,2	5,8	7,7	
CV	*29,0*	*35,3*	*37,8*	*9,8*	
Briquettes					
HC2207	2,2	12,9	27,0	60,2	100

The charcoal particle density depends on the wood density from which it was produced. Forest species of Namibia are characterized by high density; it is the same for the charcoal (Table 4).

3.4.7 Charcoal size classes & prices

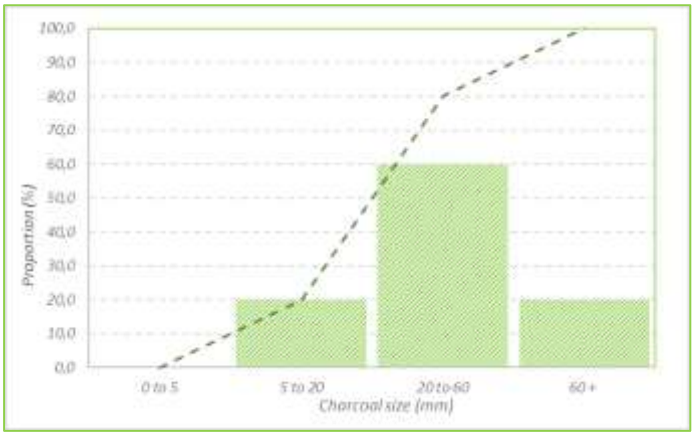


Figure 8: expected size classes for retort charcoal

The charcoal classes after sorting were presented at §3.2.2. It gives an indication about the current situation. As retort charcoal has no contact with the soil, as it undergoes no combustion and no settlement during production, retort charcoal pieces will be of larger dimension and free of the "Sand & Ash" fraction. In consequence, the different classes proportions are modified, the data presented in Figure 6 were therefore recalculated accordingly and are presented in Figure 8.

Consequently, the charcoal bulk price is changed. The current price structure is shown in Table 5.

Table 6 & Table 7 present two hypotheses for the charcoal price evolution, depending on the quality: the first option maintains the same price levels for different classes, but allows for redistribution, in this case the price of coal in bulk will be N $ 1860 / ton. This assumption is deemed too pessimistic by many stakeholders who considered the two best charcoal classes will reach a price of N$ 3000 / ton. In this case the price of charcoal in bulk will be N$ 2550 / ton.

Table 5: actual shares & prices for charcoal size categories

Information from processors					
Classes	Central point	%	Cumulated	Price	
0 to 5	2,5	6,0	6,0	0	N$/Ton
5 to 20	12,5	28,0	34,0	750	N$/Ton
20 to 60	40	60,0	94,0	1850	N$/Ton
60 +	75	6,0	100,0	3000	N$/Ton
Total		100,0			
Bulk price				1500	N$/Ton

Table 6: expected shares & prices for retort charcoal size categories – Hypothesis 1

Expected size distribution from retorts				Price	
Classes	Central point	%	Cumulated	Price	
0 to 5	2,5	0,0	0,0	0	N$/Ton
5 to 20	12,5	20,0	20,0	750	N$/Ton
20 to 60	40	60,0	80,0	1850	N$/Ton
60 +	75	20,0	100,0	3000	N$/Ton
Total		100,0			
Bulk price				1860	N$/Ton

Table 7: expected shares & prices for retort charcoal size categories – Hypothesis 2

Expected size distribution from retorts				Price	
Classes	Central point	%	Cumulated	Price	
0 to 5	2,5	0,0	0,0	0	N$/Ton
5 to 20	12,5	20,0	20,0	750	N$/Ton
20 to 60	40	60,0	80,0	3000	N$/Ton
60 +	75	20,0	100,0	3000	N$/Ton
Total		100,0			
Bulk price				2550	N$/Ton

4 Kiln testing

4.1 Test description

.

Picture 82: Wood load weighing for one traditional kiln at producer 1

Picture 83: Wood load weighing at producer 2

During this mission 5 yields tests were performed on the Namibian retort kiln. These tests were performed at two different charcoal producers. In addition, 6 tests were performed on Namibian traditional kiln, also at two different producers. These tests are illustrated by Picture 82 to Picture 88. The method used to determine the mass of wood used by each carbonization consist in weighing many logs which is a priori much higher than the amount needed. The remaining wood is weighed after the kiln is closed. This procedure makes it possible, once the weighing work is finished, to let charcoal makers work as they usually do, without interfering. The method was used for both tests on traditional kilns as the retorts kilns

Moisture content measurements were performed with a portable electric hygrometer. Based on these measurements, the initial moisture of the batch was estimated to be 30%. The moisture content should be confirmed by a larger number of measurement, a more rigorous sampling and a moisture content measurement in a drying cabinet. The duration of the mission did not allow it. When carbonization is complete and the kiln is cooled, kiln is made empty, charcoal is bagged and bags are weighed. The considered moisture content for charcoal is 1%. The mass yield is calculated using the formula presented at. § 2.3

Picture 84: Traditional drum testing

Picture 85: Retort Kiln testing

Picture 86: wood left after kiln has been closed

Picture 87: charcoal production before weighing

Picture 88: Retort charcoal of good quality

4.2 Results & discussion

4.2.1 Measured values & yields

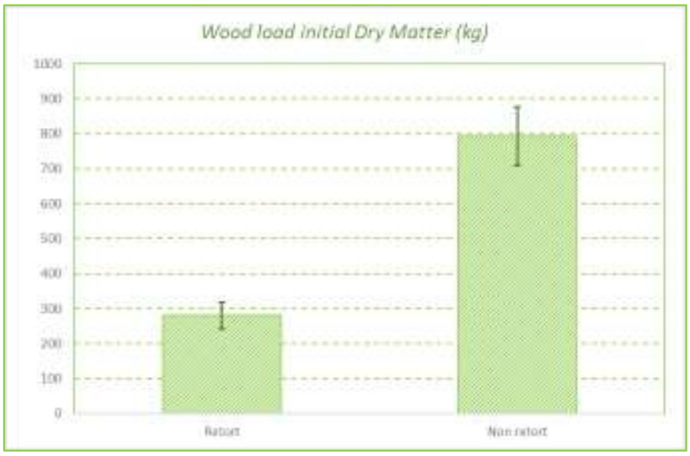


Figure 9: comparison between retort & non retort kilns regarding dry matter wood load

Figure 9 shows the mass of the initial wood load for traditional and retort kilns. A carbonization cycle with the traditional kiln requires 792 kg of dry wood. The cycle lasts 6 days. The needs of the retort kiln are 281 kg per cycle, but this cycle is of 24 hours. A retort oven thus needs 1 686 kg wood within 6 days. Almost 2 times more than the traditional kiln. The amount of fuel wood needed for combustion (246 kg / cycle on average) has to be added and is about 1476 kg wood every 6 days. Total needs by retort kiln is about 3,5 ton of wood per week.

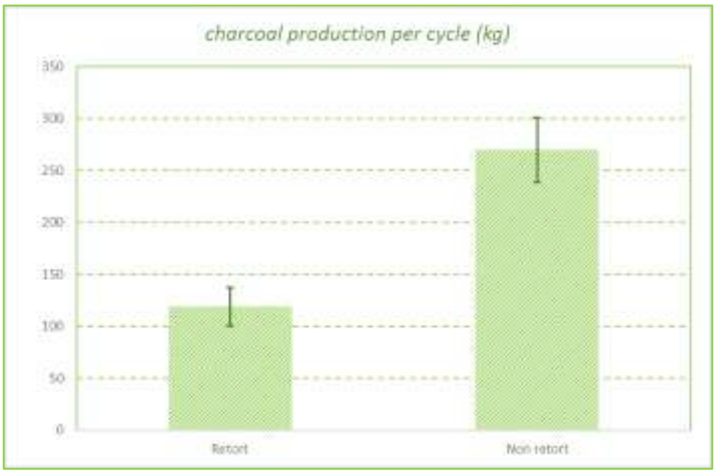


Figure 10: comparison between retort & non retort kilns regarding charcoal production per cycle

Figure 10 illustrates the amount of charcoal produced per cycle. Traditional kilns produce 270 kg charcoal on average every 6 days, while the retort kilns produce 119 kg per day, or 714 kg charcoal every 6 days. Therefore, the productivity of retort furnaces is 2,6 times higher than that of traditional kilns.

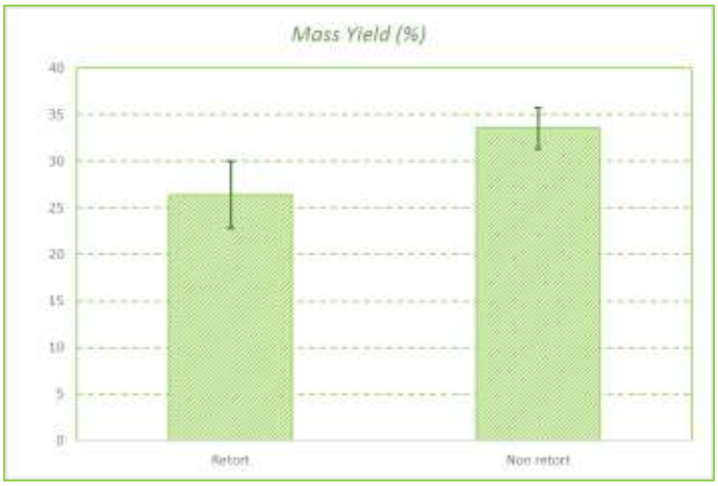


Figure 11: comparison between retort & non retort kilns regarding Mass yield

Figure 11 shows the calculated mass yields based on data collected in the field. About the retort kilns mass yield, it should be noted that the wood fuel has been considered in the calculation.

Based on the 6 tests performed, the calculated yield for the traditional kiln is 33,5%. The yield of retort kilns (based on 5 tests) was 26,4%. The results are highly variable. If the fuel wood is not considered, the retort mass yield is 42%.

It should be noted that the measured yield for traditional kiln is very surprising and is far above yields usually admitted with this type of kilns. This is quite difficult to explain. A limit to the test should be reported: wood load moisture content, which was considered to be equal to 30%, according to measurements and information collected on the field. Overestimation of the moisture also lead to an overestimation of yield. But the impact of this potential source of error is limited. Similarly, a low fixed carbon content may partially explain the high yield. Samples were taken for analysis of the fixed carbon content. Reloading process, during carbonization may also affect performance, but it is difficult to quantify this impact. Also, the influence of the high particle densities of the carbonized species on mass yield should be evaluated.

4.2.2 Environmental impact

It was shown at § 2.5 that emissions related to carbonization are depending on the yield. Applying the same calculation method, but considering the Namibian traditional kiln as the reference, the results are different. The Table 8 shows the calculation of these emissions considering that for the Namibian traditional kiln 2,5 % of the carbon is emitted in the form of methane, and the remaining carbon is emitted as CO_2. For GMDR & Mindourou kilns, it is considered that only 0,2% of the Carbon emitted is methane. In this case the use of a GMDR saves 1,75 tonnes of CO_2 equivalent per produced ton of charcoal while the Mindourou kiln leads to avoid the emission of 1,62 ton CO_2 equivalent.

The low overall yield (including fuel wood) of the Namibian retort furnace leads (if it is considered that 0,75% of the emitted carbon is CH_4) to emit more CO_2 equivalent in the atmosphere than the traditional kiln emits. Indeed, the production of one ton charcoal with the Namibian retort kiln release 1,02 ton CO_2 equivalent more than if it had been produced with the traditional kiln.

It must be noted that the methane amount contained in the gases emitted by the Namibian retort was set at 0,75% by hypothesis, based on qualitative field observations. In future, this aspect will need to be confirmed by measurements to accurately determine the environmental impact of this retort. Particularly if a development is undertaken to improve its performance.

For information, in the current state of performance of the Namibian retort kiln, although all the methane is considered as burned (0% CH4 in gas escaping from the kiln), this alternative still would emit 0,39 tonnes equivalent CO_2 more than traditional kilns, per ton of charcoal produced. If the CH_4 concentration was 1 or 2% extra emissions are respectively 1,23 & 2,45 T_{eq} CO_2 per tonne of produced charcoal.

Table 8: Emissions saving compared to Namibian Traditional drum for the Namibian retort, the GMDR & the Mindourou kiln.

Environmental impact of charcoal processes						
				Charbon de bois		
Material (MP) / Product (P)	Unités	Coef				
Carbonization Process			Namibian drum	Namibian Retort	GMDR	Mindourou
Carbonisation characteristic			load partly combusted	CH4 combustion	CH4 combustion	CH4 combustion
Proportion of C released under Methane form	% of charcoal ton		2,5	0,75	0,2	0,2
Proportion of C released under CO2 form or equivalent	% of charcoal ton		97,5	99,25	99,8	99,8
Anhydrous load wood mass (MP)	kg		1000	1000	1000	1000
Carbon proportion in MP	%		50	50	50	50
MP Carbon Mass	kg		500	500	500	500
Carbonisation yield	%		34	26	38	37
Charcoal Mass	kg		340	260	380	370
Fixed Carbon proportion in Charcoal	%		78	78	78	78
Carbon mass in charcoal	kg		265	203	296	289
Carbon emission due to charcoal production	kg		235	297	204	211
Spécific emissions	kg C/T Pd		691	1143	536	571
Avoided emissions	kg C/T Pd		0	-452	155	119
Minimum GHG reduction per ton Charcoal compared t	T Eq CO2/T Pd		0	-1,66	0,57	0,44
Form under wihich C is emitted / ton charcoal						
Emissions carbon CH4	kg/ton Charcoal		17	9	1	1
Emission carbone CO2	kg/ton Charcoal		673	1135	535	570
Equivalent CO2 mass of C emitted under CH4 form	kg/ton Charcoal		1328	660	82	88
Equivalent CO2 mass of C emitted under CO2 form	kg/ton Charcoal		2467	4157	1959	2089
Total CO2 equivalent due to carbonization	kg/ton Charcoal		3795	4816	2042	2177
Gain CO2 par rapport à la méthode traditionelle	T éq CO2/ton charcoal		0	-1,02	1,75	1,62
Rapport CO2/C	*kg/kg*	*3,66*				
Rapport CH4/C	*kg/kg*	*76,9*				

4.2.3 Financial evaluation

Table 9 summarizes the main characteristics of the considered alternatives for replication by a pilot. This data is used in Table 10 to estimate the generated incomes by the selected kilns. For this first analysis, it was considered that the increased quality of produced charcoal would lead to an increase in its price. A discussion with stakeholders has led to an estimated N $ 2 550 per tonne. The influence of the bulk coal sales prices will be discussed in §4.2.4

Given the carbonization chamber volume, the mass which it may contain, the carbonization yield and the carbonisation cycle time, it is possible to calculate the daily charcoal productivity, for each alternative. They are of 43 kg, 119 kg, 208 kg & 322 kg for the Namibian traditional kiln, the Namibian retort, the GMDR and the Mindourou kiln, respectively.

However, the investments related to charcoal production alternatives are different. If productivities are compared on an equivalent investment basis (the one for Namibian traditional kiln), the trend reverses. Thus, an investment of N $ 2000 daily generates 43 kg, 34 kg, 22 kg & 24 kg for the Namibian traditional kiln, the Namibian retort, the GMDR and the Mindourou kiln, respectively. It appears that the productivity increase of alternativess to Namibian retort don't compensate the increased investment they impose.

But if the price difference between the charcoal qualities is considered, incomes generated by an investment of N $ 2000, are 65, 87, 56 & 62 N $ / day for the Namibian traditional kiln, the Namibian retort, the GMDR and the Mindourou kiln, respectively. In this case, the Namibian retort is ranked at the top because it generates $ 87 N / day.

Environmental impact must also be considered. Indeed, compared to Namibian traditional kiln, the Namibian retort emits more,1,02 tons of CO_2 equivalent more, for each ton of produced charcoal. On the other hand, the GMDR avoids the emission of 1,75 tons of CO_2 equivalent and the Mindourou kiln 1,62 ton.
If the emissions could be valued on a carbon market, currently a CO_2 ton could be traded at around € 8, this aspect does not change the ranking of revenues generated by the different alternatives. The Namibian retort is, given assumption made about charcoal prices, the most productive solution. However, its negative impact on the environment prevents promote this alternative at its current stage of development.

Table 9: main characteristics of the considered kilns

	Traditional Kiln	Namibian Retort	Green Mad Retort	Mindourou kiln
Volume	1,3 m³	1 m³	13,8 m³	14,4 m³
Mass Yield	34%	26%	38%	37%
Charcoal quality	Low to Medium	High	High	High
Charcoal price in bulk	1500	2 550	2 550	2 550
Environmental impact	Baseline	+ 1,2 TCO2Eq / ton charcoal	-1,75 TCO2Eq / ton charcoal	-1,62 TCO2Eq / ton charcoal
Cycle duration	6 days	1 day	5 days	5 days
Production per cycle	260 kg Charcoal	119 kg Charcoal	1040 kg Charcoal	1610 kg Charcoal
Price	2 000 N$	7 000 N$	19 000 N$	26 410 N$

Table 10: Estimation of incomes generated by the selected alternatives

	Units	Namibian Drum	Namibian Retort	Green Mad Retort	Mindourou Kiln
Kiln caracteritics					
Mobility		Yes	Yes	No	No
Material		Metal	Metal	Bricks	Bricks & metal
yield with fuel	%	34	26	38	37
Volume	m³	1,30	1,0	13,8	14,4
Productivity					
carbonisation time	Days	6	1	5	5
Estimate with Namibian species					
Wood load	kg anhydrous wood	766,5	281	2695	4241
Yield without fuel	%	34	42	39	38
Charcoal production per cycle	kg/cycle	260	119	1040	1610
Charcoal production per day	kg/day	43	119	208	322
Price					
Total	N$	2000	7000	19000	26410
Investment related production	kg/day 2000 $ invest	43	34	22	24
Quality					
Expected price due to quality increase	N$/kg	1,5	2,55	2,55	2,55
Incomes generated by a 2000 N$ invest	N$/day	65	87	56	62
Environment					
Avoided CO2	CO2 teq/ charcoal ton	0	-1,02	1,75	1,62
CO2 price	N$/ton	123,2	123,2	123,2	123,2
Added value/Charcoal kg	N$/kg	0	-0,13	0,22	0,20
Charcoal price	N$/kg	1,5	2,4	2,8	2,7
Income generated/ day & 2000 N$ invest	N$ /day & 2000 $ invest	65	82	61	67

4.2.4 Sensitivity analysis

The main factors for improving the Namibian retort competitiveness, which will make it suitable for implementation and promotion by a pilot project are: the global mass yield, the sales price of charcoal bulk and the concentration methane gases emitted. Table 11 presents projections of generated incomes by a retort kiln for increasing yields assumptions. Emissions from these yields are calculated and presented in Table 11 as well. Two assumptions for flue gas methane concentration are considered (0,2% & 0,75%)
The Table 11 left-hand side shows the results for the Namibian traditional kiln, the GMDR and the Mindourou kiln. The right-hand side shows calculations for the four yield assumptions of the Namibian retort. These assumptions are the current situation (26%), a 30% yield which probably corresponds to the level of performance that can be expected by improving the current single retort kiln (see recommendation at § 6.1). The latter two assumptions (35 & 40% yields) match the performance levels that can be expected if further development is performed (several kilns heating each other).

The first observation is about the overall yield increase (including fuel) which does not affect the Namibian retort productivity, because it depends on the off-fuel yield that is currently 42% and will likely not be increased. But, the global yield greatly influences the environmental impact. The increase from 26% to a 30% yield would place the Namibian retort to comparable emission levels than those emitted by the traditional kiln, while having a higher productivity. Two assumption about flue gas methane concentration were considered (0.75% this estimation is based on qualitative field observation and 0.2% which seems a realistic target for a series of connected retort kiln).
In the case of a 0.2% methane concentration, a yield of 35% would avoid the emission of 1.32 tonne of CO_2 equivalent per produced ton of charcoal. Under these conditions a yield of 40% would avoid 2 tons of CO_2 equivalent.
About charcoal sale price in bulk, 4 assumptions were considered: 1850 N $ / tonne (which is just the redistribution of Sand & Ash fraction on the other fractions) and three other levels that consider a price increase due charcoal quality increase: It appears that the Namibian retort is competitive with the traditional kiln from N $ 1900 / ton. However, it is likely that charcoal quality allows to sell the production at higher prices, about 2 250-2 500 N $ / ton. Incomes generated by N$ 2000 investment are of N$ 65, N$ 77, N$ 85 if the bulk price are 1900, 2250 & 2500 N $ / ton, respectively.

Table 11: Incomes generated per day by 2000 N$ investment in NTK (Namibian Traditional Drum), GMDR (Green Mad Retort), MK (Mindourou Kiln) & NRK (Namibian Retort Kiln) & related CO_2 equivalent emission or savings (ton Eq CO_2/ ton charcoal). NTK being the baseline.

Mass yield (%)	34	38	37	26	30	35	40
Charcoal Bulk price (N$/ton)	NTK	GMDR	MK	NRK	NRK	NRK	NRK
1850	65	40	45	63	63	63	63
1900	65	42	46	65	65	65	65
2250	65	49	55	77	77	77	77
2500	65	55	61	85	85	85	85
Avoided CO2 (0,75% CH4)	0	1,75	1,62	-1,02	0,06	1,06	1,82
Avoided CO2 (0,2% CH4)	0	1,75	1,62	-0,56	0,42	1,32	2,00

5 Conclusions

- The good mass yield (34%) of the **Traditional Namibian Kiln** has been a surprised
  - It is over what is expected for this group of kilns
  - Its low cost and long life time makes it a highly competitive alternative
  - But its use leads to pollution (even if emissions should be measured)
  - But it produces a charcoal that could be easily improved
- The high *Quality* of the **Namibian Retort Kiln** charcoal and its short production cycle (1 day) makes this alternative more profitable than the Namibian traditional Kilns
  - But it has a far lower global mass yield
  - Leads to higher emissions as well
  - These 2 weak points make difficult to promote de Namibian Retort Kiln at the stage it is now
- Among the alternatives selected, the only proven technology that has a better impact on the environment is the GMDR
  - But it is the less profitable solution
  - But it is a fix alternative (which has many advantages but is not what the main share of charcoal producers are waiting for)
  - Anyway, there is a demand for brick kilns and this alternative should be demonstrated in a pilot project
- Finally, the main improvement of the Namibian Charcoal production chain will come from the Namibian Retort Kiln development
  - An improvement of 10% of its global yield would makes this alternative more environmental friendly than the traditional kiln
    - These developments are currently tested and the results should be known in the coming weeks
  - The combination of a few Namibian Retort Kilns would allow to use the heat generated by the combustion of the pyrolysis gases of one retort to heat the next one
    - Retort should be developed as modules that could be used alone or as a combination of two or more kilns, without maximum limit
    - This improvement will lead to avoid or drastically reduce the use of fuel wood which is responsible of the low yield of this alternative
    - This will place the Namibian Retort Kiln among the cleanest technologies for producing charcoal (high yield, emission burning, high quality charcoal)
    - Moreover, it would fulfill some of the producer requirements
      - Semi-mobility
      - Cleaner production
      - Higher quality
      - Affordable investments
      - Reuse of existing equipment…
- In consequence, a pilot project should concentrate on:
  - Characterize the baseline (Namibian Traditional Drum)
    - CH_4 emissions
    - Yield confirmation (and accurate moisture content determination, carbon content)
  - Proposing alternatives
    - Namibian retort kiln development
      - As a single kiln, will probably, at the best reach the environmental efficiency than the Traditional kiln
      - As series of kilns, which could lead to one of the cheapest and cleanest technologies for charcoal production
    - Implement a GMDR demonstration unit, to

- Confirm the implementing costs in Namibia
- Fulfil the demand of brick kiln of some producers
- Evaluate the yield of this alternatives with Namibian species
- Compare the environmental efficiency to the other alternative
- Determine the pro & cons of a fix alternative…

- For both alternatives, efforts should concentrate on:
  - Global yield improvement
  - Emission measurements
  - Wearing costs determination
  - Evaluate pro & cons of mobile & semi-mobile alternative…

6 Recommandations

6.1 Recommendation 1: Namibian retort improvement – Experimental planning proposal

6.1.1 Activities

- These tests are designed to calculate the Namibian mass yield improvement due to light and simple modifications.
- The tests will be made on modified retorts equipped with pipes of a 7-cm diameter
- 3 variation factors will be tested
  - Pipes usefulness and time prior closing influence
  - Heating power
  - Drying time
- By participating producer, these tests require 3 Namibian retorts equipped with 7cm diameter pipes.
- 1 to 3 participating producers
- Experimental Procedures
  - A data collection sheet for each participating producer is included in Annex 1 (the Excel file will be provided as well)
  - The first step is the wood harvesting
    - 8 tons must be harvested each day on a 6 days' period
      - 2 tons have to be processed to day after
      - 2 tons must be dried for 1 week before being processed
      - 2 tons must be dried for 1 month before being processed
      - 2 tons must be dried for 2 month before being processed
    - Wood piles for drying must be clearly identified
  - The second step is to process the wood according to table in Annex 1
    - The same treatment is applied to the three retorts tested at the same time (3 repetitions per treatment)
    - Treatments are:
      - Load moisture content modified by drying time of:
        - 1 day
        - 1 week
        - 1 month
        - 2 month
      - Heat power during retort drying phase
        - Low: around 10 kg wood per hour
        - Around 30 kg wood/hour
        - Warning! as soon as the retort is closed heat power must be high (about 30 kg per hour)
        - The values of 10 or 30 kg of wood per hour may be adjusted if necessary based on field observations, but once established they must be kept for other tests
      - Time before closing airpipes and lid
        - 0 hours (this treatment actual situation without air pipes, in this case the lid is closed as well)
        - 1 hour (for 1 hour air pipes & lid are left open)
        - 3 hours (for 3 hours, pipes & the lids are left open). If it appears that the 3 hours causes an excessive burning of the load, this period may be reduced and brought back to 2 hours.

Please note this will then be made for all tests (including low heat power)

- Recorded data are:
    - The initial wood mass in the retort pot
        - Warning, the wood load may not include dead wood
        - To estimate the initial wood mass of the load, the same procedure as that applied during the mission will be repeated: several logs over what is needed is weighed prior to loading and after loading. The mass of wood constituting the charge is obtained by difference.
    - Initial wood load moisture content
        - Measurement are made using an electric hygrometer or ideally samples are taken to be measure in a drying cabinet
    - The wood fuel mass
        - Wood fuel may include dead wood
        - Dead wood proportion has to be estimated
        - To estimate the wood fuel mass, the same procedure as that applied during the mission will be repeated: an amount of logs over what is needed is weighed prior and after burning (remaining wood). The mass of needed fuelwood is obtained by difference.
    - Amount of produced charcoal
    - Unburnt mass
    - Ideally a charcoal sample is taken for fixed carbon content analysis
- At the end of the first week, the data can be sent to mike.temmerman@eco-consult.com for first analysis & confirmation of the further experimental planning with or without modifications.

6.1.2 Implementation

- Harvest 8 tons of wood per day will require to hire about 5 experienced charcoal makers. These charcoal makers may have to be paid, because only a portion of the harvested wood (1/4) will be processed directly, the rest will undergo a drying period. For the last pile, the charcoal will be produced as 2 months later.
- 3 modified retort / participating producers
- NCA follow up
    - Explanations and implementation of experimental design to participating producers
    - Contact & discussion with ECO
    - 2-man month needed

6.2 Recommendation 2: Namibian retorts combination

6.2.1 Activities

This development will propose a concept of optimized Namibian retort regarding productivity & environmental impact, to do this, the following steps need to be implemented:

- Accurate base line characterization
    -
    - Yield confirmation for traditional Namibian kiln
        - accurate moisture content measurement (& sample)
        - wood logs diameter influence determination
        - Attempt to explain high values
            - Determination of carbonisation temperature profile
            - Tests with species of different densities...
    - traditional Namibian Emission measurement

- Estimated number of kilns in Namibia
- Design of effective modular retort system
  - In collaboration with a local workshop and based on the development results described in recommendation 1 a system will be designed which uses the heat from the gas combustion of a retort to power the following
  - This system must be modular: able to work as a single kiln but with the possibility to combine more than one kiln to improve the global efficiency & yield
  - The influencing factors are further investigated
    - Initial moisture content of wood load
    - logs diameter
    - wood species particle densities
    - ...
- When the modular system is developed, its use is optimized
  - Influence of the carbonization time on the charcoal quality and transport resistance
  - Determination of the number of modules required for continuous operation
  - Depending on the wood initial moisture content, determine the minimum flame phase duration to carbonize the whole amount of wood (without unburnt)
  - Determine the influence of the carbonization time (heating) on the fixed carbon content
  - Determine the fixed carbon content providing the best balance quality / weight loss
- To better understand the Namibian retort kiln carbonization, process the following profiles will be established:
  - Temperature (progression of the pyrolysis front)
  - fixed carbon content at the end of process
- After system optimization
  - Overall yield calculation, depending on the number of retort included in the system
  - Emission calculation
  - environmental benefit calculation when replacing the traditional system by optimized retort system
  - financial & economic evaluation
  - Next step planning proposal for a large-scale distribution
- Long-term follow-up (one year) to confirm the data about
  - Wearing cost
  - charcoal price evolution regarding the improved quality

6.2.2 Implementation

- International Expertise: 3-man month
- NCA involvement: 3 month
- NCA Follow up: 1 year
- Equipment and workshop: about 25 000€

6.3 Recommendation 3: GMDR Set up and training for use

The GMDR is now proven technology that offers the best environmental performance, among the considered solutions. Although the level of investment it requires makes it uncompetitive compared to Namibian traditional kilns, it can however advantageously be used in the same conditions as brick kilns already being used in Namibia (Partly combusted wood load brick kilns)

The implementation of a demonstration GMDR will allow:

- To clarify its construction costs under the Namibian conditions
- Assess the pro & cons of a centralized & fixed charcoal production alternative
- To evaluate the environmental benefit of this alternative & the productivity increase compared:
  - to brick kiln which are used for time being
  - To traditional drums

6.4 Sound selection of the charcoal process to promote

The analysis of information collected from §6.1 to 6.3 will lead to the proposal on sound clean & Namibian context adapted technical charcoal production technique. This alternative will be described in a promotional brochure which will put forward the following:

- productivity increase
- Quality improvement & sale price increase
- Environmental improvement
- Design assistance possibility at NCA about carbonization equipment needs
- NCA possibility of assistance for bush harvesting planning & management in a perspective of charcoal production
- …

7 References

[1] Sanogo C.A., Elhadji Mahamane M. L., Khennas S., Konadji H., Van der plas J.R., Girard P., 2006, Techniques améliorées de carbonisation au Sahel, Collection : Les guides techniques du predas, Predas, Predas, Ouagadougou

[2] Doat J., Petroff G, 1975, La carbonisation des bois tropicaux, Bois et Forêts des Tropiques, n°159, Janvier-Février 1975, Centre Technique Forestier Tropical

[3] Benabdallah B., Carré J., Khennas S., Vergnet L.F., Ossoukaii P, 1994, Guide Biomasse Energie, IEPF

[4] Schenkel Y., Temmerman M., 2005, Les caractéristiques physico-chimiques des matières lignocellulosiques, Guide Biomasse Energie deuxième édition, Schenkel Y., Benabdallah B., les publications de l'IEPF

[5] Girard P, 1992, Techniques et matériels de carbonisation contrôle de performance, Bois et Forêts des Tropiques, n°232, 2° trimestre 1992, CTFT, Paris

[6] Schenkel Y., Bertaux P., Vanwijnsberghe S., Carré J, 1997, Une évaluation de la technique de carbonisation en meule, Biotechnol. Agron. Soc. Environ. 1997 1 (2), 113-124

[7] Schenkel Y., 1999, Modélisation des flux massiques et énergétiques dans la carbonisation du bois en four cornue, Thèse de doctorat en sciences agronomiques et ingénierie biologique, Faculté des sciences agronomiques de Gembloux, 328 p

[8] Schenkel Y., Temmerman M., Van Belle JF., Vankerkove R , 1999, New Indicator for Evaluation of the wood carbonization process, Energy sources, 21: 935-943, 1999, TayloretFrancis

[9] Mundhenk P., Gomis O., Sy C, 2010, Comparaison des rendements de production de charbon de bois entre la meule traditionnelle et la meule Casamance dans la forê communautaire de Sambandé, Peracod GTZ Août 2010, Eco consult, Peracod, Dakar

[10] Piketty M.G., Fonseca Morello T., Bouillet JP., Laclau JP., Behling M., Caldeira Pires A., Rousset P., Olivera Rodrigues T., Dufour T., Durieux L., Sist P., Viera P., 2011, Charbon de bois et sidérurgie en Amazonie brésilienne: quelles pistes d'améliorations environnementales? L'exemple du pôle de Carajas, document de travail 112, Agence Française de développement, 87 p

[11] IPCC Third assessment report – Climate change 2001 - Website : http//www.grida.no/publications – consulté le 03/06/2012

[12] EN 14774-2:2009 - Solid biofuels - Methods for determination of moisture content - Oven dry method - Part 2: Total moisture - Simplified method,

[13] Sparrevik M., Adam C., Martinsen V., Jubaedah, Cornelissen G.,2015, Emissions of gases and particles from charcoal/biochar production in rural areas using mediumsized traditional and improved “retort” kilns, Biomass & Bioenergy 72 (2015)

[14] Pennise D.M., Slith K.R., Kithinji J.P., Rezende M.E., Raad T.J., Zhang J. Fan C., 2001, Emission of grenhouse gases and other airborne pollutants fromcharcoal making in Kenya and Brasil, Journal of Geophysical Research, Vol 106, NO D20, Pages 24, 143-24, 155, 2001

[15] Temmerman M., 2016, Rapport de mission Madagascar

[16] Smit G.N., de Klerk J.N., Schneider M.B., van Eck J., 2015, Quantifying Harvestable Encroacher Bush, 32 p, GIZ, http://www.dasnamibia.org/download/brochures/Brochure_Debushing_Resource-Assessment-2015.pdf downloaded on 2016 10 26

[17] de Wet M.J., 2016, Harvesting Namibian Encroacher Bush, 40 p, GIZ, http://www.dasnamibia.org/download/studies/STUDY-Harvesting-Final.pdf downloaded on 2016 10 26

[18] Development Consultants for Southern Africa , 2015, Adding Value to Namibian Encroacher Bush, 32p, GIZ, http://www.dasnamibia.org/download/brochures/Brochure_Debushing_Value-Chains-2015.pdf downloaded on 2016 10 26

Annex 1: proposed experimental planning for the first phase

Day	Wood drying time	Fuel Power (kg/h)	Pipe closing time (hours)	Retort number	Wet Wood mass (kg)	Estimated MC (%)	Charcoal mass (kg)	Uncooked wood mass (kg)	Fixed carbon content (%)
1	1 day	30	0	1					
1	1 day	30	0	2					
1	1 day	30	0	3					
2	1 day	30	1	1					
2	1 day	30	1	2					
2	1 day	30	1	3					
3	1 day	30	3	1					
3	1 day	30	3	2					
3	1 day	30	3	3					
4	1 day	10	0	1					
4	1 day	10	0	2					
4	1 day	10	0	3					
5	1 day	10	1	1					
5	1 day	10	1	2					
5	1 day	10	1	3					
6	1 day	10	3	1					
6	1 day	10	3	2					
6	1 day	10	3	3					
7	1 week	30	0	1					
7	1 week	30	0	2					
7	1 week	30	0	3					
8	1 week	30	1	1					
8	1 week	30	1	2					
8	1 week	30	1	3					
9	1 week	30	3	1					
9	1 week	30	3	2					
9	1 week	30	3	3					
10	1 week	10	0	1					
10	1 week	10	0	2					
10	1 week	10	0	3					
11	1 week	10	1	1					
11	1 week	10	1	2					
11	1 week	10	1	3					
12	1 week	10	3	1					
12	1 week	10	3	2					
12	1 week	10	3	3					
30	1 month	30	0	1					
30	1 month	30	0	2					
30	1 month	30	0	3					
31	1 month	30	1	1					
31	1 month	30	1	2					
31	1 month	30	1	3					
32	1 month	30	3	1					
32	1 month	30	3	2					
32	1 month	30	3	3					
33	1 month	10	0	1					
33	1 month	10	0	2					
33	1 month	10	0	3					
34	1 month	10	1	1					
34	1 month	10	1	2					
34	1 month	10	1	3					
35	1 month	10	3	1					
35	1 month	10	3	2					
35	1 month	10	3	3					
60	2 month	30	0	1					
60	2 month	30	0	2					
60	2 month	30	0	3					
61	2 month	30	1	1					
61	2 month	30	1	2					
61	2 month	30	1	3					
62	2 month	30	3	1					
62	2 month	30	3	2					
62	2 month	30	3	3					
63	2 month	10	0	1					
63	2 month	10	0	2					
63	2 month	10	0	3					
64	2 month	10	1	1					
64	2 month	10	1	2					
64	2 month	10	1	3					
65	2 month	10	3	1					
65	2 month	10	3	2					
65	2 month	10	3	3					