People in Need

BAMBOO-BASED FUEL FOR COOKING

Case study of Karhongo Grouping and Bukavu

August 2024

EXECUTIVE SUMMARY

The aim of this study was to assess the technical and economic feasibility of replacement of wood charcoal by bamboo charcoal as a means of protecting the forest resources from deforestation and degradation while giving an alternative to charcoal value chain actors.

Another objective was to carry out profitability and a market systems analysis to assess the bamboo charcoal market in Karhongo grouping, especially in Nyangezi, Kwabakaja, Mushenyi and in Bukavu City which is the largest charcoal market in South Kivu.

To achieve this, a technical study of the various bamboo charcoal production processes was conducted, followed by a comparative analysis between bamboo-based fuels produced by different kilns with hardwood charcoal and waste-based briquettes. After that a bamboo charcoal market systems study and profitability analysis of charcoal value chain actors was done. Species used for bamboo charcoal and hardwood charcoal production are respectively giant bamboo (especially *Dendrocalamus giganteus*) and *Eucalyptus grandis*.

The results of this study showed that carbonization in the earth mound kiln gave the highest yield (18.48%) of charcoal compared to the raw material used, producing the highest quality bamboo charcoal (calorific value: 29.85 - 30.68 MJ/Kg) which is 6% higher than the calorific value of wood charcoal (27.5 - 29.4 MJ/Kg). Bamboo briquettes and those made from waste have a respective calorific value respectively of 21% and 25% lower than that of bamboo charcoal (23.8 and 22.7 MJ/Kg), producing 578% and 790% more ashes during cooking than hardwood charcoal. Bamboo charcoal produced in the masonry kiln has a higher ash content (47% to 180% more than charcoal), and a calorific value 15.3% lower than that of bamboo charcoal produced in the earth mound kiln. Furthermore, despite its lower density, which makes it less attractive to users, the energy yield of bamboo charcoal obtained through the water boiling Test (WBT) is the highest. Briquettes have a higher density than wood and bamboo charcoal (2 times higher).

The overall profit margin of bamboo charcoal carbonized in masonry kiln is negative (-261.3 CDF/Kg). Bamboo charcoal produced in the earth mound kiln, bamboo briquettes, and hardwood charcoal (from eucalyptus) have positive overall profit margins respectively of 527.5 CDF/kg, 336.71 CDF/kg and 459.5 CDF/kg. The profit margin is distributed between charcoal producers (37%), wholesalers (38%) and retailers (25%). Bamboo charcoal is profitable for producers at an optimum selling price of 32,500 CDF for a 65-70 kg bag, with a profit of 125-140 CDF/kg. *Dendrocalamus giganteus* can have an annual yield of 20 to 30 tons of biomass per hectare, with a harvesting cycle of 3-4 years for bamboo charcoal purposes. Eucalyptus grandis have an annual yield ranging between 4-15 dry tonnes per hectare with a rotation of 3-7 years. Over a 10-year period, one hectare of bamboo planted for charcoal production can protect 1.3 to 1,875 hectares of forest from degradation and deforestation caused by charcoal production, while producing around 1,700 MJ of heat from 50 tonnes of charcoal (with a carbonization efficiency of 25%). With improved carbonization, 10% to 20 % more of forest area can be protected.

Exchange rate used : 1USD = 2800 CDF

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ACRONYMS

GCV: Gross calorific value

HCV: High Calorific value

NCV: Net calorific value

LCV: Low calorific value

MJ: megajoules

Kcal: kilocalories

PIN: People in Need

FAO: Food and Agriculture organization of the United Nations

UNDP: United Nations development Program

INBAR: International Bamboo and Rattan Organization

GIZ: German Agency for International Cooperation

USAID: United States Agency for international Development

CIRAD: Center for International Cooperation in Agronomic Research for Development

VSLA: Village Savings and Loan Association

EMK: Earth Mound Kiln

INTRODUCTION

South Kivu is part of Congo Basin, the second largest rainforest in the world. The preservation of the Congo Basin is critical to the global climate crisis but also to the biodiversity conservation, and ecosystemic services it provides especially for indigenous and local populations livelihoods. The global climate and environmental degradation crisis are complex and multifaceted, to focus on one tangible, local aspect, namely deforestation. In this part of the DRC and of the Congo Basin, there is little big-scale, industrial cutting of the forest, and the deforestation is small-scale and slow, and caused by household consumption of hardwood charcoal, wood exploitation, shifting agriculture and cutting of forests for agricultural purposes.

Most of the population in eastern DRC rely on hardwood charcoal and firewood for cooking, even in urban areas where alternatives, such as petroleum or gas, are available. Forest is being cut down to produce hardwood charcoal for household consumption all over the province. Bukavu is a city of more than a million inhabitants, and the province had an estimated population of 5.8 million in 2015. Around 90% of households in Bukavu use hardwood charcoal for cooking. This high consumption of wood fuel has a direct impact on the region's forest and provides an income for many people involved in the production, transport and marketing of charcoal and firewood. This causes a continuous deforestation, and over time the effects are devastating. The average daily consumption of wood fuel by a resident of Bukavu is 0.31 kg of charcoal and 0.05 kg of wood, i.e. 2.55 kg of wood equivalent. Thus, the city of Bukavu's annual domestic consumption of wood-energy amounts to 0.917 million tons of wood equivalent for a population estimated at 1 million inhabitants, broken down into 111,460 tons of charcoal (12.4% carbonization efficiency) and 17,977 tons of firewood.[1]

Charcoal-related activities generate a total value added (VA) of around 16.5 million US dollars (USD). This sector is unbalanced, with 67% of VA going to producers and 33% to traders.[2]

Replacing biomass fuel (e.g. charcoal) with renewable energy sources like GPL, biogas, hydroelectricity or solar energy to meet household needs in the immediate short term is hardly realistic in the South Kivu context. A solution that is practically and financially feasible is to replace hardwood charcoal with renewable biomass energy, namely charcoal from bamboo. We will give priority to something that is sustainable, not only environmentally but also practically, and ensure we use technology that is suited to the local context and that the local population can continue using it without external support.

Charcoal and briquettes assessed in this study were produced using the brick kiln and metallic barrel kiln. Some trials are made with traditional earth mound. Bamboo briquettes are produced by Briquette du Kivu, a local partner company.

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[1] Imani G., Dubiez E., Péroches A. & Gazull L (2021). Rapport d'étude de la filière bois énergie dans la ville de Bukavu ;Préparé par CIRAD, financé par PNUD pour le compte du Programme de consommation durable et substitution partielle au bois-énergie, 53p

[2] Laurent Gazull, Emilien Dubiez, Gérard Imani & Adrien Péroches (2020). *Rapport d'étude de la consommation en énergies* domestiques des ménages de la ville de Bukavu. ;Préparé par CIRAD, financé par PNUD pour le compte du Programme de consommation durable et substitution partielle au bois-énergie, 47p

A comparative analysis of kilns' efficiencies and physicochemical characteristics of bamboo charcoal produced from different kilns, bamboo briquettes, hardwood charcoal and Eco briquettes made from waste is done to assess and compare different types of charcoal. This is followed by the market systems analysis of bamboo charcoal, including all stakeholders of the charcoal value chain in Mushenyi, Kwabakaja, Nyangezi and Bukavu, to determine the economic rentability of the bamboo charcoal and the viability of a community-based bamboo charcoal business as an income generative activity.

SCOPE AND OBJECTIVES

The aim of this study was to assess the technical and economic feasibility of replacing wood charcoal by bamboo charcoal as a means of protecting forest resources from deforestation while giving an alternative to charcoal value chain actors. Another objective was to carry out profitability and a market systems analysis to assess the market of the bamboo charcoal in Nyangezi grouping, at Kwabakaja and Mushenyi and in Bukavu which is the largest charcoal market in South Kivu.

To this end, the study had the following objectives:

- ✓ Conduct a technical study of the various bamboo charcoal production processes.
- ✓ Carry out a comparative analysis between bamboo charcoal produced by different processes, wood charcoal, bamboo briquettes and briquettes produced from waste.
- ✓ Conduct a study of bamboo charcoal market systems, comparing them with those of charcoal.
- ✓ Carry out a study of the economic profitability of bamboo charcoal.
- ✓ Identify challenges, opportunities and lessons learned.

I. BACKGROUND AND CONTEXT

This section will focus on the contextual choice of bamboo, its usefulness, the characteristics and advantages of bamboo charcoal, and the value chain for wood charcoal and bamboo charcoal, based on the literature review.

I.1. Why Bamboo?

Bamboo is a group of the most beautiful and useful woody plants belonging taxonomically to the subfamily Bambusoideae under the family of *Gramineae*. These are known to be the fastest growing woody plants with a growth rate ranging from 30 – 100 cm per day in growing seasons. It can grow up to a maximum height of more than 36 m with a diameter of 1 – 30 cm. The culm can reach its full height in a matter of two to three months. It also has the fastest growing canopy for the regreening of degraded areas. Bamboo is not only an ideal economic investment that can be utilized in many different manners but also has enormous potential for alleviating many problems. The increasing rate of tropical deforestation makes the search for alternative natural resources important. Immensely important also are the concept of multiple use of land with multipurpose tree species and increasing the desired level (33%) of tree cover.

Bamboo is the fastest growing plant on this planet, it is a critical element in the balance of oxygen and carbon dioxide in the atmosphere. Bamboo is a viable replacement for wood, an enduring natural resource, versatile with a 105-day growth cycle and a renewable resource for agroforestry production. Over 2.2 billion people rely on bamboo as a source of income. There are more than 1,600 species of bamboo comprising 75–107 subfamilies growing across the world. They are substantially set up in Asia, Africa, and Latin America and cover a total area of 37 million hectares, which accounts for 1% of the global timber area[3].

Additionally, quality of strength, light weight and flexibility make bamboo a viable alternative to tropical timbers which are also in short supply for furniture and building material industries:

- ✓ Bamboo is 17% Stronger in tensile strength than steel
- ✓ Bamboo is 27% stronger than Red Oak
- ✓ Bamboo is 13% harder than hard Maple
- ✓ Everything in wood can be produced from bamboo

I.2. Utility of Bamboo

Due to their strength, straightness, lightness combined with extraordinary hardness, range of size, abundance, and short period in which they attain maturity, bamboo is suitable for a variety of purposes and uses. There are more than 1,500 documented uses of bamboo.

Global bamboo products and consumption is valued at 60 billion USD, with a transnational trade of 2.5 billion USD per annum, supporting 1.5 billion people[4].

I.3. Environmental benefits of bamboo

Bamboo is a highly versatile plant in its adaptability and utility with a great potential for economic development, wealth creation, and environmental resilience, providing opportunity to rural communities to strengthen their livelihood, food security, and environmental resilience efforts[5].

The characteristics of bamboo make it a perfect solution for the environment and social consequences of tropical deforestation. Its biological characteristics make it a perfect tool for solving many environmental problems such as erosion control and CO_2 sequestration. Due to extensive rhizome-root system and accumulation of leaf mulch, bamboo is an efficient agent in preventing soil erosion, conserving moisture reinforcement of embankments and drainage channels etc[6].

I.4. Bamboo charcoal production

Traditional kilns

Much charcoal for domestic consumption in developing countries is produced in pit kilns (holes dug in the ground), or in mound kilns (piles of wood stacked on the ground and covered with soil), by farmers and

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[3] Abebe S., Minale A. S., and Teketay D., Spatio-temporal bamboo forest dynamics in the lower beles river basin, north-western Ethiopia, *Remote Sensing Applications: Society and Environment*. (2021) **23**, 100538, **https://doi.org/10.1016/j.rsase.2021.100538**.
[4] Kassahun T., Review of bamboo value chain in Ethiopia, *International Journal of African Society Culture and Traditions*. (2014) **2**, no. 3, 52–67.
[5] Wagemann E. and Ramage M. H., Briefing: bamboo for construction in Pakistan–a scoping review, *Proceedings of the Institution of Civil Engineers-Construction Materials*. (2019) **172**, no. 1, 3–9, **https://doi.org/10.1680/jcoma.17.00045**, 2-s2.0-85060703904.
[6] Zhou Ben-zhi, Fu Mao-yi, XIE Jin-zhong, YANG Xiao-sheng, LI Zheng-cai. 2005. Ecological functions of bamboo forest : Research and Application. Journal of Forestry Research, 16 (2): 143-147.

landless laborers. Yields (weight of charcoal/weight of wood) from pits vary from less than 10% to over 25%.

Brick and concrete kilns

Kilns made of bricks can be more efficient than earth mounds, be operated all year round, have longer lifetimes than metal or mud kilns, and are less susceptible to poor operator practices. However, the high-grade charcoal that they produce may not be acceptable to domestic users, since it is difficult to ignite. Switching to large, efficient kilns, has many economic and social implications, as most charcoal is still produced by farmers and landless peasants who, under normal circumstances, might not be able to benefit from the switch and, indeed, might suffer from it. Brick kilns are ideal for replacing traditional kilns when consistent high-quality charcoal is required in large quantities.

One of the major advantages of the brick kiln over earth kilns of similar size earth kilns is that their carbonization cycle is much quicker. Typically, a 50 cubic meter brick kiln has a carbonization cycle of 8-10 days, whereas that of the comparable earth kiln is, at least twice as long. Moreover, the labor involved in operating the brick kiln is much lower than that required to construct and manage the earth kiln. Furthermore, the operation of the brick kiln is generally much simpler than the earth kiln: workers can be trained in its use relatively easily and shortages of skilled labor are not likely to be a constraint on production. Brick kilns, however, are usually permanent structures: they are, thus, only suitable in locations where there is a sufficiently large supply of wood within a short transport distance that can last five or more years of production.

I.4.1. Characteristics of bamboo charcoal

I.4.1.1. General Characteristics of fuels

Good fuel is defined based on its characteristics. Some of them are:

- High calorific value.
- Proper ignition temperature. The ignition temperature of the fuel should neither be too low nor too high.
- No production of poisonous products during combustion. In other words, it should not cause pollution or combustion.
- Moderate rate of combustion.
- Combustion should be easily controllable i.e. combustion of fuel should be easy to start or stop as and when required.
- Low ash production during combustion.
- Easily available in large amounts.
- Low moisture content.
- It should be cheap.
- Easy to handle and transport.

I.4.1.2. Advantages and disadvantages of solid fuels

Solid fuels have some advantages and disadvantages:

Solid fuels advantages:

- ✓ They are easy to transport.
- ✓ They are easy to store without any hazard of spontaneous explosion.
- ✓ The cost of production of solid fuels is low.
- ✓ They possess moderate ignition temperature.

Disadvantages

- ✓ Their ash content is high.
- ✓ Their thermal efficiency is low, because a large part of heat energy is wasted during combustion.
- ✓ The cost of handling (transportation) is high.
- ✓ Calorific value is low.

I.4.1.3. Physicochemical characteristics of bamboo charcoal

a) Calorific value

In the ***Higher Calorific Value or Higher Heating Value (HHV) or Gross Calorific Value (GCV),*** it is assumed that the water present in combustion gas is entirely condensed and that the heat contained in the water vapor is recovered.

In the *Lower Calorific Value or Lower Heating Value (LHV) or Net Calorific Value (NCV),* it is assumed that the products of combustion contained the water vapor, and that the heat in the water vapor is not recovered. In other words, the NCV is derived from the GCV by deducting the latent heat of vaporization of water present and formed. Thus, **NCV (MJ/kg) = GCV (MJ/kg) − 0.222 (% H).** Net calorific values are typically 5% to 6% less than the gross calorific value for solid and liquid fuels and about 10% less for natural gas.

The calorific value of bamboo charcoal ranges from 6,500 to 7,000 Kcal/Kg.

b) Other characteristics

Some characteristics are essential to determine charcoal quality. Among them we can find: operational temperature, bulk density, volatile matter, fixed carbon, and ash content. Some of them are listed in table 1 below.

Table 1. Characteristics of the charcoal of different bamboo species and of the charcoal of Eucalyptus grandis xurophylla hybrid. (Rusch F et al., 2020)

Species	T	BaD	GY	VC	AC	FC	GCV	Source
Bambusa tuldoides	550	0.32	34.1	21.7	6.1	72.3	6,752	3
Bambusa vulgaris	450	0.37	36.4	27.5	5.1	67.3	7,431	1
Bambusa vulgaris *	550	0.34	34.7	23.6	3.0	73.4	6,777	3
Dendrocalamus asper	550	0.48	36.9	26.5	1.9	71.5	6,640	3

Dendrocalamus giganteus	500	---	---	8.10	3.9	81.5	7,372	2
Bamboo average	520	0.38	35.5	21.5	4.0	73.2	6,994	-
Eucalyptus grandis x urophylla hybrid	550	0.36	30.8	29.1	0.4	70.4	6,670	3

T = Temperature (°C); BaD = Basic density ($g.cm^{-3}$); GY = Gravimetric yield (%); VC = Volatile content (%); AC = Ash content (%); FC = Fixed carbon content (%); GCV = Gross Calorific Value ($kcal.Kg^{-1}$). *Var. Vittata. Source : [1] Balduino Junior et al. (2016); [2] Hernández-Mena et al. (2014); [3] Santos et al. (2016).

A well-managed mature plantation can yield 25-30 tons of culms per hectare. The production of bamboo biomass in two cutting cycles of three years each can reach 180 tons per hectare and consider 30 $tons.ha^{-1}.year^{-1}$ as average[7].

I.4.2. Uses

The demand for wood as biomass for fuel wood and charcoal making represents a threat to the use of resources in African countries and is expected to remain unchanged for many decades to come. This demand is influenced by low household incomes, urbanization, and the growth of informal sector activities. Bamboo charcoal can serve as a viable alternative biomass for firewood and charcoal at the household level. In addition to bamboo charcoal being used for fuel, there are several other uses

Below are some uses of bamboo charcoal in general:

Agriculture: As a carrier of organic manure and micro-organisms in the soil, bamboo charcoal can improve the vigor of the soil, so people use it as a good soil improver.

Chemicals: Bamboo charcoal can be used as the raw materials of bamboo active carbon. Bamboo charcoal shows strong absorption because of the special structure of micro holes of the bamboo stem, and the function would be more outstanding after it is activated. Tests show that the absorption properties of bamboo active carbon are extremely good.

Medicine and health care: Pillows and mats made of bamboo charcoal can soothe the nerves, relax backaches, and control snoring. Bamboo charcoal also has the functions of deodorization, dehumidifier and fungicide, which are essential to family needs.

Environment protection: Bamboo charcoal can be used as a water clarifier, shield off electromagnetic waves and absorber of poisonous gases. Pollution indoors caused by poisonous materials would be absorbed if the panels were made of bamboo charcoal instead of the asbestos flakeboard and plastic boards. 95% of the nicotine and other poisonous materials would be absorbed if cigarette filters were made of bamboo charcoal. It was discovered that bamboo charcoal loaded with microorganisms could purify wastewater efficiently.

[7] Hernández-Mena, L., Pécoraa, A. A. B. & Beraldo, A. L. (2014). Slow pyrolysis of bamboo biomass: analysis of biochar properties. *Chemical Engineering Transactions*, *37*, 115-120.

Other fields: Bamboo charcoal can be made into many kinds of compound materials in the material industry. It also can be made into handicrafts, feed additives and high-capacity rechargeable storage batteries, textile added with bamboo charcoal etc.[8]

I.5. Charcoal Value Chain Actors

The charcoal value chain actors involved are the producers, transporters, traders (wholesalers) and retailers [9]. Charcoal movement from production areas to charcoal markets may increase the chance for charcoal producers to avoid paying the charcoal government fees. Government fees will be paid by wholesalers. But the rural people may benefit through their roles in charcoal production or as small transporters, wholesalers or contract laborer involved in loading, repairing or driving trucks.

I.5.1. Charcoal chain actors in South Kivu and their roles

The charcoal value chain in Bukavu involves some 27,600 producers, 5,600 traders (retailers and wholesalers) and 1,200 transporters[1].

I.5.1.1. Producers

Charcoal producers market their charcoal either locally or at another village market. Charcoal is produced using traditional circular or buried kilns. Most producers (56%) are involved in another income generating activity, the majority of which is agriculture (28%). Of the producers surveyed, 69% purchase the inputs to produce charcoal, either by buying the trees or by renting land. Producers' annual revenues vary from USD 100 to USD 1,400, depending on the origin of the wood (plantation or forest) and the place of sale (production village or another village). Producers sell an average of 37.3 tons of charcoal per year[2].

I.5.1.2. Transporters

The majority of charcoal produced in rural areas (Territories) near Bukavu is transported to Bukavu by truck (around 94%). The other means of transport used to supply Bukavu with charcoal are pirogues for charcoal coming from Idjwi and Kalehe (3%), vans (2%) and on foot (1%) for short distances. [1]

I.5.1.3. Traders

There are different types of traders: wholesalers/producers who employ teams of charcoal makers to produce charcoal and sell it in Bukavu, wholesalers who buy charcoal from producers in the supply basin and resell it wholesale, and retailers who buy charcoal in town from wholesalers and resell it retail. Wholesalers supply 85% of the charcoal to the Bukavu city market. Retailers market the equivalent of 38% of wholesalers' charcoal volumes.

I average, wholesalers have higher annual revenues than producers, as the volumes marketed are much greater. Wholesalers and semi-wholesalers/retailers have annual revenues of 3,150 USD/year and 300 USD/year respectively[2].

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[8] https://energypedia.info/images/3/30/EN-Bamboo_Charcoal_and_sustainable_management-Fu_Jinhe%2CINBAR.pdf

[9] Schure, J., Ingram, V., Sakho-Jimbira, M. S., Levang, P., & Wiersum, K. F. (2013). Formalisation of charcoal value chains and livelihood outcomes in Central- and West Africa. Energy for Sustainable Development, 17(2), 95-105. https://doi.org/10.1016/j.esd.2012.07.002

I.5.1.4. End Users

As far as firewood is concerned, the city of Bukavu is supplied by the province of South Kivu alone, and more specifically from two territories: Walungu (56%) and Kabare (46%). Consumption is estimated at 17,977 tons of fuelwood per year, the majority of which is consumed by households (80%)[1].

I.5.2. Profitability and added value of the charcoal industry

Charcoal-related activities generate a total value added (VA) of around 16.5 million US dollars (USD). The sector is unbalanced, with producers accounting for 67% of VA and traders 33%. It involves some 27,600 producers, 5,600 traders (retailers and wholesalers) and 1,200 transporters (road and lake). State services intervene in the sector via formal and informal taxes, which represent 0.7 million US dollars annually, or a tax rate of 2% of the product's added value. The taxes collected during transport could not be distinguished from the cost of transport[2].

II. METHODOLOGY

Carbonization tests were carried out in 3 types of kilns: Brick kiln (in Kwabakaja), earth mound kiln (in Mushego, Katoke, Mushenyi), and metal kiln (barrel) in Kwabakaja. All 21 beneficiaries trained through the pinnovation bamboo project () participated in the bamboo carbonization tests.

II.1. Bamboo charcoalization

Types/ Species of charred bamboo

Throughout the tests, one species of bamboo was used for charcoal production. The criteria for selecting the bamboos to be carbonized were based on bamboo dimensions and maturity. *Dendrocalamus giganteus* or giant bamboo was used in different locations (Katoke, Idaho, Mushenyi, Mushego). Few differences were noticed in bamboo dimensions (culms thickness, diameter, height) and roughness that could be related to the age of bamboo, the altitude and the soil quality (organic matter, moisture, slope, nutrients).

Fig 1. *Dendrocalamus giganteus* culms

Harvesting

Bamboo harvesting was carried out using machetes and axes, as shown in picture 2. Personal protective equipment had to be worn when cutting the bamboo. Only mature bamboo was harvested. This can be distinguished by the color and foliage of the culms. Unmatured bamboos are whitish in color, with poorly developed foliage, while those over 3 years old are green in color, with more developed branches and leaves.

Fig 2. Bamboo culms harvest

Transportation

The bamboo was transported on foot by the 21 project beneficiaries. A few bamboos were also transported by vehicle during the final test run in the brick kiln. After cutting, the bamboo was stored before being transported to the carbonization site. Distances were greater for carbonization in the brick kiln. For traditional kilns, distances were shorter, as carbonization took place close to where the bamboos were harvested.

Culms cutting

The culms were cut into pieces ready for carbonization using machetes. In the case of the traditional kilns, the culms were cut into 2-metre pieces, while for the brick kiln, measurements ranging from 1.5 m to 1.8 m were used, depending on the height of the kiln. Small pieces are also placed in the kilns, to minimize empty spaces.

Fig 3. Cutting of bamboo culms into small pieces

Weighting

The bamboo is weighed before loading to determine the carbonization yield, based on the mass of bamboo charcoal produced, in relation to the dry (or wet) mass of the loaded bamboos. The culms are generally dried 2 to 4 days before being loaded in the kiln. The following tools were used: tape measure, machetes, scales, rope, bags and metal barrel.

Fig 4. Weighting of bamboo culms

Loading the kiln

The bamboos are arranged vertically in the brick kiln. The vertical arrangement was chosen because it allows the kiln to be filled to a greater extent than the horizontal arrangement, but also because heat transfer is easier in this arrangement. The dry, easily flammable bamboo is arranged horizontally at the bottom of the kiln. A small gap is left at the kiln's entrance door to allow the kiln to be lit.

Fig 5. Earth mound Kiln loading

Initiating the carbonization process

The carbonization is initiated by lighting the dry bamboo placed at the kiln entrance. Once the bamboo is lit, the flame gradually spreads inside the furnace, through the dry thatch placed horizontally at the base of the kiln. As soon as the kiln is primed, the entrance door is filled with bricks and clay to reduce the supply of oxygen that would promote combustion instead of carbonization.

Fig 6. Kiln ignition

Carbonization and aeration control

Once carbonization has begun, the aeration holes are progressively plugged, considering the evolution of carbonization. This can be seen in the color of the smoke. By controlling the rate of carbonization, certain holes are sometimes momentarily reopened if necessary to ensure good heat transfer inside the kiln.

In the case of earth mound kilns, aeration is provided by perforated holes in the floor covering the load to be carbonized. The kiln is monitored to prevent runaway and to better control carbonization.

Fig 7. Carbonization and aeration control: earth mound kiln (left), masonry kiln in bricks and clay (right)

Kiln discharge and charcoal cooling

Once carbonization is complete (including the refining stage), the kiln is cooled by pouring water over the outer walls. When the kiln's door is opened, a quantity of dry clay is introduced into the kiln (with shovels) to extinguish the charcoal produced, to prevent the kiln from igniting due to the influx of oxygen. This is followed by cooling in the open air. Some culms remain uncharred (non-carbonized culms) when the kiln is discharged. Depending on their condition, they are introduced into the next production cycle either to be carbonized, or as a pyrolysis starter fuel.

Charcoal packing and weighing

Once cooled, the charcoal is broken into pieces and packed into bags measuring 74/120 cm (length and width). During packing, the smallest pieces are introduced first, followed by the largest. The bags filled with charcoal (fig 8) are weighed then covered and ready for sale.

Fig 8. Charcoal packed in polypropylene bags

II.2. Bamboo charcoal characterization

II.2.1. Determination of charring yields

The yields (**η_C**) from the kilns were calculated in order to assess the level of efficiency of the carbonization practices among the charcoal producers using the formula:

$$\boldsymbol{\eta_C = \left(\frac{C_w}{W_w}\right) * 100}$$

Where η_C is the carbonization yield; C_W is the weight of the charcoal produced and W_W is the weight of the wood introduced into the kiln. The yield calculation can also be based on dry mass basis, but it should require moisture analysis. Most of time, yield calculation doesn't consider moisture contents of the wood/bamboo/charcoal.

II.2.3. Physico-chemical characteristics

II.2.3.1. Moisture

To determine the moisture content, it must be taken from the weight loss of a test sample (M1) after heating in an oven at 105°C for 24 hours (M2). There are two fractions of moisture: the first is total moisture, including imbibition moisture, and the second is holding moisture, which is the moisture retained by the sample in the atmosphere in which it is located, and which can only be eliminated by steaming above 100°C. Moisture content, volatile dry matter and ash content are determined according to standard procedures: CEN / TS 14774 (CEN, 2005); APHA 1998, APHA 2005 and ISO.

$$\mathbf{Moisture}\ (\%\mathrm{H}) = \frac{\mathbf{M_1 - M_2}}{\mathbf{M_1}} * \mathbf{100}$$

II.2.3.2. Bulk density and specific gravity

- *Bulk density*

This variable is characterized by determining the volume of water that is displaced by a sample when it is submerged. The weight of the sample is then divided by the volume of water displaced to produce a density with a unit of g/cm^3.

- *Specific gravity*

Specific gravity is a unitless measurement of a sample's density relative to water. The equation used to calculate specific gravity is the weight of a dry sample in air divided by the weight of the sample in air minus the weight of the sample in water (i.e., the weight of water displaced by the sample).

II.2.3.3. Ash

For coal, the ash content is determined using the method defined in ISO 1171:2010. A crucible containing the sample is placed in a muffle furnace (MF) at 20°C, then heated under a temperature ramp for 1 hour to a temperature of 815°C. This temperature is maintained for 3 to 6 hours to ensure complete combustion of the fuel.

For each sample, three tests were carried out, and the ash content on crude was obtained using the following equation:

$$\mathbf{Ash}\ (\%) = \frac{\mathbf{m - m_0}}{\mathbf{m_1 - m_0}} * \mathbf{100}$$

m_0: weight of empty crucible,

m_1: weight of empty crucible + sample,

m: weight of empty crucible + incinerated sample.

II.2.3.4. Volatile matter

Determination of the volatile matter index (ISO 562) involves holding a fuel sample at 900°C (950°C in ASTM D 3175) for 7 minutes in the absence of air.

The mass loss recorded is used to determine the standard volatile matter content of crude, dry or pure fuel. This rate is calculated on a crude basis according to the following formula:

$$\mathbf{MV}(\%) = \frac{\mathbf{m_i} - \mathbf{m_f}}{\mathbf{m_i}} * \mathbf{100}$$

m_i: initial fuel weight,

m_f: final weight after devolatilization

II.2.3.5. Fixed Carbon

Fixed carbon (FC) has great energy potential. It is the quantity of carbon remaining after elimination of volatile matter, ash and moisture. It differs from total carbon, which is the sum of fixed carbon and the carbon contained in the volatilized part.

Fixed carbon (FC) is not determined by analysis, but is deduced by the following calculation:

$$\mathbf{FC}(\%) = \mathbf{100} - (\%\mathbf{Moisture} + \%\mathbf{Ash} + \%\mathbf{MSV})$$

II.2.3.6. Elemental composition

The elemental composition was calculated on the basis of the experimentally determined results of proximal analysis, more precisely as a function of fixed carbon and volatile matter content[10]. This approach allows us to determine common organic elements such as carbon (C), hydrogen (H) and oxygen (O), respectively, from the following equations:

$$\mathbf{C}(\%) = 0.637 * \mathbf{FC} + 0.455 * \mathbf{MV}$$

$$\mathbf{H}(\%) = 0.052 * \mathbf{FC} + 0.062 * \mathbf{MV}$$

$$\mathbf{O}(\%) = 0.304 * \mathbf{FC} + 0.476 * \mathbf{MV}$$

II.2.3.7. Calorific value

Calorific value refers to the amount of heat produced by unit volume of a fuel by complete combustion (in the presence of oxygen).

Practical formula: To calculate the anhydrous Calorific value or Net calorific value, empirical formulas can be used to give a reliable value based on knowledge of the elemental composition of the wood. Taking the

[10] Bill Vaneck Bot. Étude et caractérisation du charbon écologique produit à partir des déchets agricoles en vue de son utilisation dans les ménages au Cameroun. Thermique [physics.class-ph]. Université de Douala-Cameroun, 2022. Français. ffNNT : ff. fftel-04165370f

anhydrous PCI of wood at around 5,000 kWh/t as a reference, we obtain various formulas that differ significantly depending on the type of wood[10]:

HCV or GCV = 108 x C % (in kWh/tonne)

LCV or NCV = HCV - 60.5 x H % (in kWh/ton)

Hence, NCV = 108 x C - 60.5 x H

or HCV = 109.5 x C % - 64 (in kWh/ton)

GCV or HCV (Gross calorific value or High Calorific value) was calculated using the approximate formulas of Dulong and Vandraeck, while PCI was calculated using the direct formula and the Cassan formula. The various calorific values obtained from the approximate empirical formulas have a negligible margin of error, between 2% and 7%.

Approximate formulas by Dulong and Vandracek[10] :

$$\mathbf{GCV\ (en\ kJ.kg^{-1}) = 3.6 * (108 * C)}$$

$$\mathbf{GCV\ (en\ KJ.kg^{-1}) = 3.6 * (105.5 * C - 64)}$$

The direct formula for NCV Calculation is:

$$\mathbf{NCV\ (en\ kJ.kg^{-1}) = 4.18 * (94.19 * C - 0.5501 - 52.14 * H)}$$

CASSAN formula calculated from ash content:

$$\mathbf{NCV\ (kcal.kg^{-1}) = 80 * (100 - T_C)}$$

Relationship between LCV and HCV based on hydrogen (H) mass percentage

$$\mathbf{NCV\ (kJ.kg^{-1}) = GCV - 60.5 * H}$$

NCV (MJ/kg.) = GCV (MJ/kg.) – 0.222 (% H)

NCV (cal/g) = (GCV – 0.09 H*587)

Calorific value was calculated with mathematical models from literature review (Regression methods, artificial intelligence, artificial neural network, random forest) setting correlating between charcoal characteristics from proximate analysis. Among them, some were used[11]:

Table 2. Mathematical models of Gross calorific estimation formula from proximate analysis[11]

Author(s)	Unit	Formula
Majumder et al.,(2008)	MJ/kg	GCV= 0.03*A-0.11*M+0.33*VM+0.35*FC
Matin and Chelgani (2016)	MJ/kg	GCV = 38.426-0.49*M-0.41*A-0.083*VM
Seervi (2015)	Kcal/kg	GCV = 7115.197-123.971*M-81.3121*A+20.7421*FC

1. [11] Lethukuthula Vilakazi & Daniel Madyira (14 Apr 2024): Estimation of gross calorific value of coal: A literature review, International Journal of Coal Preparation and Utilization, DOI: 10.1080/19392699.2024.2339340

Huda (2014)	KJ/g	GCV = 25.284*M+30.572*A+62.127*VN+138.117*FC-2890.095

II.2.3.8. Charcoal strength determination

For domestic use, fuel must be strong enough to be transported and used. Fuel that isn't solid enough can prove problematic if a container is placed directly on it, or if the fuel crumbles easily during transport.

The test involves dropping a steel ball onto a solid fuel, or the fuel itself, at different heights. The operator determines the height required to break the fuel. If the height and mass of the steel ball and/or the mass of the fuel are known, the energy required to break the solid can be calculated. In this way, we can compare the strength of the bamboo-based coals and briquettes produced under the project with that of charcoal. The energy (E) required to break the solid can be calculated by the relationship:

$$\boldsymbol{E = h * m * g}$$

With, **E**: energy (J), **h**: height (m); m: steel ball mass, or charcoal's weight (kg); g: gravitational constant (9.8m/sec^2).

II.2.3.9. Determining Charcoal ignition time

Ease of ignition allows us to compare the time required to light a fuel. A sample of fuel is held under a flame similar to that of a conventional lighter. The time taken for the sample to ignite is measured in seconds. The shorter the measured time, the easier the ignition.

II.2.3.10. Combustibility

The combustive power of a fuel is the quantity of dry air (V_a) strictly necessary to ensure neutral combustion of the fuel unit. It is expressed in Nm^3/Kg of fuel.

It can be calculated from the following expression:

$$\boldsymbol{V_a = 0.0895 * C}$$

Or with the technical memo formula (M. Veron)**:** $\boldsymbol{V_a = \frac{PCI}{4180}}$

II.2.3.11. Smoke-producing power

Smoke power represents the volume of smoke, defined under normal conditions, released by the neutral combustion of one kilogram of fuel. It is symbolized by V_{fs} (dry smoke volume) and V_{fh} (wet smoke volume) and is calculated according to the expression:

$$\boldsymbol{V_{fh} = \frac{PCI}{3553}}$$

And

$$\boldsymbol{V_{fs} = \frac{PCI}{4180}}$$

II.2.4. Boiling Water Test (BWT)

The water boiling test can be used to compare the characteristics of different fuels or cooking stoves. Already widely used to compare the performance of improved cooking stoves, the following protocol will be more suitable for comparing different fuels on the same type of fireplace. The test was carried out by a staff PIN during six days at the same time to make sure the climatic conditions will be nearly the same.

A batch of fuel heats a pot containing a fixed initial quantity of water. Two phases will be studied, a temperature rise phase where we'll be interested in the time needed to reach boiling point, as well as the

mass of fuel consumed, followed by a boiling maintenance phase, called “simmering”, where we'll be interested in the mass of charcoal consumed over a 60-minute period. We also measured the mass of water evaporated during the water boiling test to determine the system's energy efficiency, by calculating the ratio between the energy received by the water and the energy released by the fuel.
Materials used are: electronic scale (max 10kgs), a multimeter with temperature probe, a saucepan and a charcoal improved cooking stove.

Fig 9. Water boiling test (left); Charcoal Improved cooking stove (Right)

The stove used has the following characteristics:

- ✓ Inner diameter: 20 cm
- ✓ 0uter diameter: 30 cm
- ✓ Height: 6 cm
- ✓ Aeration holes in the ceramic: 25
- ✓ Aeration Hole diameter: 2cm

The energetic efficiency of the system (charcoal, stove, pot and water) is calculated by the following expressions:

- Evaporated water (kg):

$$E_w = I_w - F_w$$

- Charcoal consumed (kg):

$$C_{Char} = I_{Char} - F_{char}$$

- Temperature rise gradient (K/min):

$$\frac{dT}{dt} = \frac{T_b - T_0}{t_b - t_0}$$

- Specific boiling time:

$$T_{bs} = \frac{T_b - T_0}{\frac{dT}{dt}}$$

- Overall system energetic efficiency:

$$\eta_T = \left(\frac{\left(I_w * S_{h,w} * (T_b - T_0) + L_{Vap} * E_w\right)}{C_{Char} * PCI}\right) * 100$$

Where:

E_w is the evaporated water (kg), **I_w**: initial weight of the water(kg), **F_w** final weight of the water after test (kg), **C_{char}** Weight of charcoal consumed(kg), **I_{char}** initial weight of charcoal(kg), **F_{char}** final weight of charcoal, **dT/dt**: temperature gradient (°C/min or °K/min); **T_e**: boiling temperature (°K); **T_0**: initial water temperature, **t_e**: boiling time (min); t_0: initial time(min), **T_{es}**: specific boiling time (min); **η_T**: Overall system energetic efficiency (%)[10].

Interpretation limits of the Water Boiling Test

Interpretation of the results must consider the difficulty of controlling certain parameters precisely, such as the quality of ignition, the homogeneity of the fuel used, the positioning of the pot in relation to the fuel, and the similarity of the hearths. It is therefore important to note any observations made during the Water Boiling Test (WBT) process, and to take at least three measurements per fuel.

II.3. Bamboo briquette production

Bamboo briquettes were produced by Briquette du Kivu, a local company specialized in eco briquettes manufacturing. Sixty (60) kilograms of bamboo charcoal were used as raw material. To be able to compare bamboo briquettes to other types of briquettes, organic waste-based briquettes were provided by the same company. The production process of bamboo charcoal consists of five main steps:

- ✓ Grinding of the bamboo charcoal
- ✓ Binder preparation: binders used are starch and clay. These two components, mixed with water are heated up to reach homogeneity.
- ✓ Mixing bamboo charcoal powder with binder and water
- ✓ Molding of the mixture to obtain a specific shape
- ✓ Drying of the molded mixture to reduce the moisture's quantity. Drying can take place during 2 to 4 days.

Dry briquettes obtained are weighed before packing in polypropylene bags.

II.4. Survey methods and market systems analysis

The survey methodology and market systems analysis were based on the results of previous work in the charcoal industry, reports (GIZ, USAID, UNDP, CIRAD, etc.), interviews with industry experts and surveys with stakeholders. The various stakeholders surveyed are located in the Karhongo groupement (Nyangezi, Kwabakaja, Mushenyi, etc.) and in Bukavu. The survey questionnaire can be found in Appendix 2.

Survey was carried out by two PIN's staffs. Survey questionnaires were reviewed par Country program MEAL department. Online survey questionnaire(Ms Forms format) was submitted to bamboo charcoal end users.

II.4.1. Survey of producers

The producer survey was carried out in Mushenyi (5 persons surveyed) , Kwabakaja , Katoke, Mushego (7 persons surveyed), in Nyangezi (2 people surveyed) and Bukavu (1 person surveyed). Charcoal producers were targeted randomly for greater representativeness. The information sought was: direct and indirect production costs (purchase of wood, transport, labor, taxes), production capacity, charcoal selling price, carbonization technique, yield, type of customer, means of financing.

II.4.2. Survey of transporters

Charcoal is transported from the production site to the market on foot and by truck. The information sought was: the distance between the production site and the market, the number of bags transported per trip, the frequency of transport (weekly, monthly), the price of transport and the number of customers. Trucks make transport between Bukavu and Mushenyi/Kaziba).

II.4.3. Survey of charcoal traders (wholesalers and retailers)

Charcoal traders are divided into two categories: wholesalers and retailers. Survey questions were addressed to traders in Mushenyi, Kwabakaja, Nyangezi and Bukavu (La voix du Congo, Kamagema, Nyawera and Nguba). Information sought was: purchase and selling price, quantity bought per month/year, category of customers, transport and storage costs, other indirect fees (taxes), charcoal preferences (wood carbonized, quality).

II.4.4. Survey of end users (households and businesses)

Charcoal end users are mainly businesses (restaurants, hotels, poultry houses) and households. Charcoal is used for cooking purposes, and sometimes for house heating. Survey questions were asking about combustion time, charcoal price, duration of a bag of charcoal, household composition, charcoal characteristics (burning time, smoke, ashes, ignition time, etc.). Surveys were conducted in Mushenyi (13 households), Kwabakaja (9 households), Nyangezi (5 households) and Bukavu (19 households).

II.5. Profitability calculations and data processing

The margin is the difference between the sale price and the purchase price (or the cost of access to the resource in the case of producers):

$$Margin = \text{Selling Price} - \text{Purchase price}$$

Value added (VA) is calculated by subtracting intermediate consumption (IC) (production costs, transport costs, storage costs, purchase price of empty bags, etc.) from the margin:

$$\text{VA} = Margin - \text{IC}$$

Finally, Gross Operating Profit (GOP) is calculated by subtracting tax and labor costs from VA:

$$\text{GOP} = VA - Taxes - \text{L}$$

These indicators are established per unit weight of marketed product. Annual Revenue (AR) is thus obtained as follows:

$$\text{AR} = \text{GOP} x \text{ Annual Sales quantity}$$

Data collected is processed in excel sheets.

II.6. Limitations of the methodology

The limitations of the methodology applied include the difficulty of reaching a large number of players in the charcoal value chain, the absence of markets and transporters in some of the areas surveyed (e.g. Kwabakaja, where charcoal is sold on the street), and the non-existence of bamboo charcoal producers.

Around 15 bags of bamboo charcoal were produced by the beneficiaries during the study to carry out the market analysis, and a further 11 bags after the study.

The study focused on the Pinnovation project area (Nyangezi-Kwabakaja-Mushenyi) and did not consider other areas of origin of charcoal supplied in the city of Bukavu.

Calorific value was calculated from proximate analysis, due to the lack of a calorimetric bomb. This method is 90-97% accurate.

III. MAIN FINDINGS - TECHNICAL CHARACTERISTICS OF BAMBOO CHARCOAL

III.1. Availability and Accessibility to bamboo

In the project area, bamboo is found in private plots and fields and has mostly been planted. The most common species are B*ambusa vulgaris* and giant bamboos (including *Dendrocalamus giganteus*). Some species are tracers (unipodial) and others are non-tracers (sympodial), as in the case of giant bamboo. The bamboo clump comprises between 50 and 120 culms.

To access the resource, the owner sets the price per piece of bamboo or the price for the whole clump. Only mature bamboo is harvested.

III.2. Bamboo carbonization yields

The charcoal resulting from carbonization in different types of kilns was weighed. The weight of a bag of bamboo charcoal as illustrated below varies between 44 and 55 kg. The weight of a bag of bamboo charcoal, packaged according to local market standards, varies between 72 and 80 kg. The bag of charcoal from the brick kiln was slightly lighter (44 kg), while those from the traditional kiln were heavier (50-55 kg). Carbonization yields obtained by different methods are shown in Table 3 below:

Table 3. Carbonization yields of various kilns used in the study

	Unit	Brick kiln Test 1	Brick kiln Test 2	Improved Earth mound test	Earth mound test	Metal drum kiln
Dimensions	(D*H ou L*l*H)	2*1.85	2*1.75	3.2*1.7*1	4.3*2*1.1	0.55*0.95
Volume	m^3	5.809	5.495	5.44	9.46	0.23
Weight of bamboo culms	Kg	965	845	1025	1596	84
Number of culms		25	22	26	41	2.16
Culm average weight	Kg	38.60	38.41	39.40	38.93	38.83
Culm moisture	%	22	22	22	22	22
Bamboo bulk density in the kiln	Kg/m^3	166.12	153.78	188.42	168.71	372.36
Bamboo charcoal produced	Kg	79	95	136	295	11
Bamboo not carbonized	Kg	0	34	64	116	13
Carbonization yield (wet mass basis)	%	**8.19**	**11.24**	**13.27**	**18.48**	**13.10**
Carbonization yield (dry mass basis)	%	**10.50**	**14.41**	**17.01**	**23.70**	**16.79**

Earth mound kiln has a shown better result with higher carbonization yields (18.5% based on wet mass and 23.7% based on dry mass of bamboo), compared to the other categories of kiln tested. This can be explained by the difficulties to control the temperature in the brick kiln (yields of 11.2% wet mass basis and 14.4% dry mass basis), leading to very high temperatures. Bamboo obtained from the brick kiln were lighter compared to those obtained in earth mound kiln.

III.2.1. Earth mound kiln (in comparison with Eucalyptus)

Carbonization yields obtained with earth mound kiln vary from 13% to 18.5% for improved kiln. Yields depend on factors, including the bamboo species used, kiln aeration, wind exposure, culm dimensions (thickness, length) and kiln dimensions (length, width and height). These various factors affect the yield and quality of the charcoal produced and the quantity of uncharred culms. Carbonization yields can be improved up to 30%.

III.2.2. Brick kiln

Yields obtained in brick and clay kiln vary from 9% to 12%. This is due to the difficulty of controlling the temperature increase inside the kiln. There is a big volume of oxygen inside the kiln before the carbonization starts due to the inability to fill in the empty spaces between vertically ranged bamboo. An improved kiln can achieve higher yields with better filling rate and temperature control.

III.2.3. Metallic barrel kiln

Metal barrel kiln carbonization efficiency was 13%. Cutting bamboo culms in small pieces could help improve efficiency while reducing empty spaces inside the kiln. Observations made show that some parts of culms were not well carbonized, which reduces the quantity of charcoal produced.

III.3. Bamboo briquettes vs waste-based briquettes

Bamboo briquettes were made by binding crushed bamboo charcoal. Clay and starch from maize flour were used as the binder in equal quantity. Waste carbonization recovery was 20% to 25%. Proportion of water during manufacturing was 50% but only 6-8% remained after drying. Carbonized waste and binder proportions were 81% and 12% respectively. Regarding the bamboo briquettes, moisture and binder represent 21% (76 kg of bamboo briquettes obtained from 60 kg of bamboo charcoal sample) of the bamboo briquette’s final weight.

III.4. Characteristics of bamboo charcoal

Bamboo charcoal characteristics were analyzed. Physicochemical characteristics were determined by laboratory analyzes done by the agronomic and soil laboratory at the Catholic University of Bukavu. Calorific value was determined using the calculations detailed in the section II.3. Water boiling test was carried out to determine the energy efficiency of produced bamboo charcoal and briquettes.

III.4.1. Physicochemical Characteristics

Findings from physicochemical laboratory tests are summarized in the table 4 below:

Table 4. Physicochemical characteristics of bamboo charcoal

Characteristic	Unit	Brick kiln bamboo	Earth mound bamboo	Earth mound bamboo	Bamboo briquette	Waste based	Hardwood charcoal Sample 1	Hardwood charcoal Sample 2

		charcoal from Test 2	charcoal/ Mushenyi	charcoal/ Kwabakaja & Katoke		Eco-briquettes		
Moisture	%	7.53	2.53	3.64	6.72	6.51	5.29	8.10
Bulk density	kg/m^3	217	285	297	654	683	309	288
Volatile matter	%	17.73	33.46	24.89	22.58	14.62	35.18	33.44
Ash	%	15.13	4.21	4.01	18.86	24.75	1.60	3.96
Fixed Carbon	%	59.60	59.80	67.47	51.84	54.12	57.94	54.51
C	%	46.03	53.32	54.30	43.30	41.13	52.91	49.94
H	%	4.20	5.18	5.05	4.10	3.72	5.19	4.91
N	%	26.56	34.11	32.36	26.51	23.41	34.36	32.49
Gross Calorific value	MJ/kg	**26.57**	**31.00**	**31.80**	**24.74**	**23.57**	**30.60**	**28.64**
Net calorific value	**MJ/kg**	**25.64**	**29.85**	**30.68**	**23.83**	**22.74**	**29.45**	**27.55**
	Kcal/kg	**6,153.21**	**7,164.95**	**7,363.51**	**5,719.37**	**5,457.94**	**7,066.90**	**6,612.01**
Ignition time	min	4	4.5	4.2	13	7	5	5.6
Abrasion Strength	J	4.41	6.38	5.64	6.87	4.28	5.89	6.13
Combustibility	Nm^3/Kg	4.12	4.77	4.86	3.88	3.68	4.74	4.47
Smoke producing power	m^3/Kg	6.13	7.14	7.34	5.70	5.44	7.04	6.59

The results show that bamboo charcoal from the masonry kiln (brick and clay) produces a large quantity of ash but contains less dry volatile matter than other types of bamboo charcoal. This is due to the high carbonization and refining temperature, but affects the calorific value, which is lower compared to charcoal produced in earth mound kiln.

Briquettes produced much dust and had the lowest calorific value compared to charcoal. Nevertheless, bamboo briquettes had better characteristics compared to waste-based briquettes in terms of strength and calorific value.

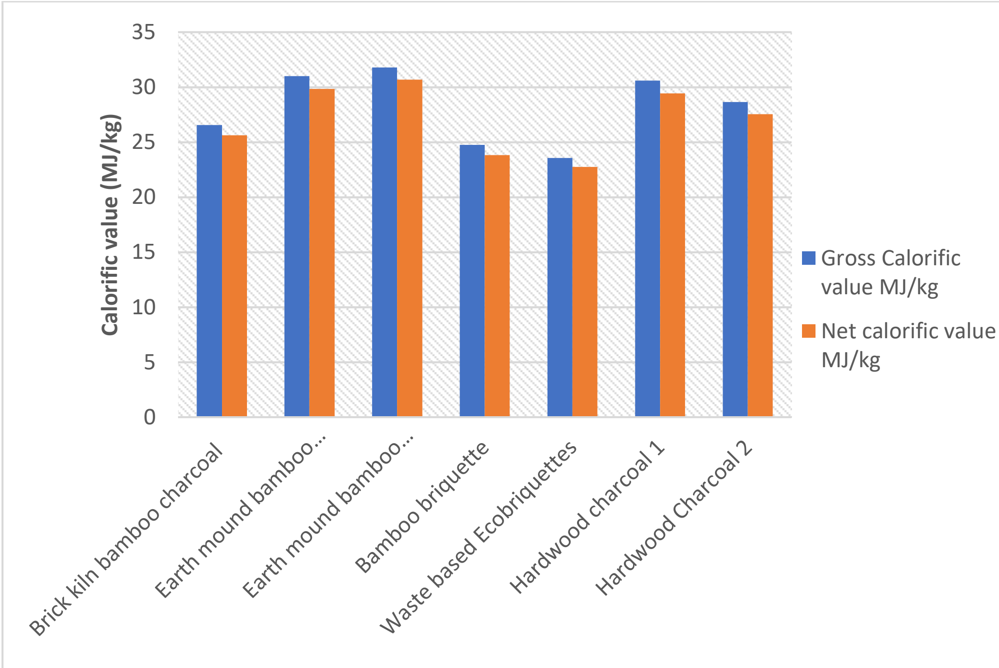

Fig 10. Caloric values of bamboo charcoal

Results shown in table 3 and in picture 10 show that bamboo charcoal from earth mound kiln has slightly better characteristics than charcoal (from eucalyptus) in terms of calorific value, although it produces slightly more ash during combustion. The characteristics of both bamboo charcoal and hardwood charcoal are similar.

III.4.2. Water boiling test

Water boiling test has been carried out with 6 types of biomass fuel:

- ✓ Bamboo charcoal from a brick and clay kiln
- ✓ Bamboo charcoal from an earth mound kiln in Mushenyi
- ✓ Bamboo charcoal from earth mound kiln in Mushego & KwabakajaBamboo briquettes
- ✓ Waste based briquettes
- ✓ Hardwood charcoal (from eucalyptus)

Tests were carried out under the following conditions:

- Temperature: 22±3°C
- Pressure between 1016±2 Bar.

Findings obtained are summarized in the table 5 below.

Table 5. Water Boiling Test findings

Paramètres	Unit	Brick kiln bamboo charcoal from Test 2	Earth mound Mushenyi	Earth mound bamboo charcoal Kwabakaja /Mushego	Hardwood charcoal	Bamboo briquette	Waste eco-briquettes

Reference temperature	°K	303	303	303	303	303	303
Initial temperature	°K	295	296	298	292	296	295
Initial water volume	L	3	3	3	3	3	3
Initial weight of water	Kg	2.898	2.898	2.898	2.898	2.898	2.898
Water volumic mass	g/cm3	0.966	0.966	0.966	0.966	0.966	0.966
Final weight of boiled water	Kg	2.162	2.258	2.009	2.21	2.246	2.765
Weight of evaporated water	Kg	0.736	0.64	0.889	0.688	0.652	0.133
Charcoal weight	Kg	0.5	0.5	0.5	0.5	0.5	0.5
Charcoal weight remained	Kg	0.143	0.167	0.13	0.165	0.134	0.198
Weight of consumed charcoal	Kg	0.357	0.333	0.37	0.335	0.366	0.302
Ebullition temperature	°K	368	367	366	366	367	365
Ebullition time	Min	35	27	28	30	33	55
Specific ebullition time	Min	33.562	26.620	28.824	28.378	32.535	55.0
Temperature rise gradient	K/min	**2.086**	**2.630**	**2.429**	**2.467**	**2.152**	**1.273**
Latent mass heat of vaporization of water	KJ/Kg	2257	2257	2257	2257	2257	2257
Thermal mass capacity of water P Const (30°C)	KJ/Kg.°K	4.185	4.185	4.185	4.185	4.185	4.185
PCI(h)	KJ/Kg	**25638.4**	**29854**	**30681.3**	**29445.4**	**23830.7**	**22741.4**
Ash	Kg	0.032	0.017	0.019	0.01	0.079	0.068
Ash to charcoal consumed ratio	(%)	8.964	5.105	5.135	2.985	21.585	22.517
Fuel consumption	(kg/h)	**0.306**	**0.285**	**0.317**	**0.287**	**0.314**	**0.259**
η System energetic efficiency	(%)	27.822	23.192	24.940	24.840	26.744	16.732

Highlighted results show that after 70 minutes of combustion, the temperature gradient, charcoal consumption, weight of evaporated water and energetic efficiencies of hardwood charcoal (from eucalyptus) and bamboo charcoal are nearly the same (±10%). On the other hand, the burning speed of waste-based briquettes is low compared to other types of coal, including briquettes from bamboo charcoal. The energetic efficiency of bamboo charcoal from the brick kiln is higher, showing that it burns fast and produces more heat than other types of charcoal tested in this study. This is due to its low content in volatile matters. This type of charcoal is the best for industrial use or being used as activated carbon.

The comparison between bamboo charcoal, hardwood charcoal and briquettes, based on water boiling test is shown in graph 11 below.

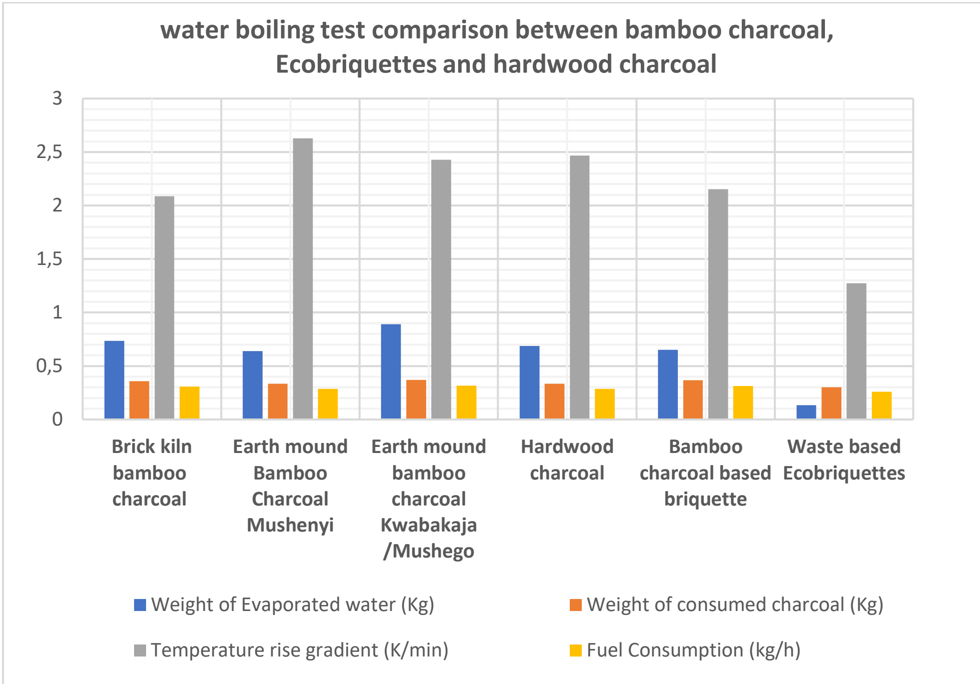

Fig 11. Water boiling test findings: comparison between bamboo charcoal, eco-briquettes and hardwood charcoal

Bamboo charcoal from earth mound kiln produced in Mushenyi has the highest temperature rise gradient, meaning it generates more heat than the other types of charcoal (takes less time to make water reach its boiling point), whereas waste-based eco-briquettes have the lowest temperature rise gradient (longest time to boil water). Charcoal consumption was nearly the same for both types of charcoal and briquettes. The main problem with briquettes is the fact that they cannot be relit once extinguished and produce a large quantity of clay dust, probably that contained in the binder during briquette manufacture.

Energy efficiency (heat transferred from the fuel to the water) is shown in graph 12 below:

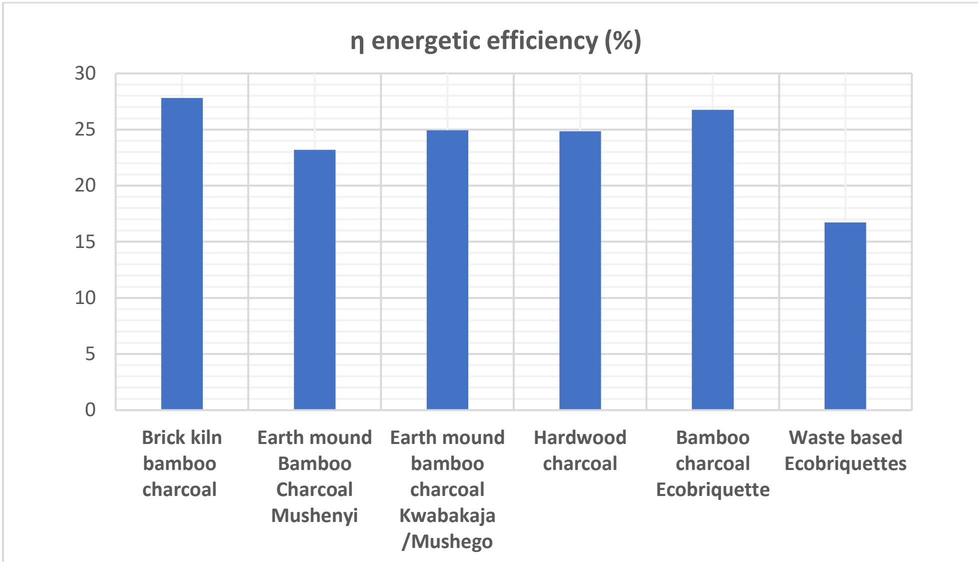

Fig 12. Water boiling test: Energy efficiency of various types of bamboo charcoal, eco-briquettes and hardwood charcoal

The energy efficiency is based on charcoal consumption, vaporized water, calorific value and boiling time. The graph 12 shows that during the water boiling test, bamboo charcoal produced in the brick kiln had the highest energy efficiency (27.8%), followed by bamboo charcoal eco-briquettes (26.7%). Hardwood charcoal and bamboo charcoal had similar efficiencies (23.2-24.9%). Waste-based eco-briquettes had the lowest energy efficiency (16.7%).

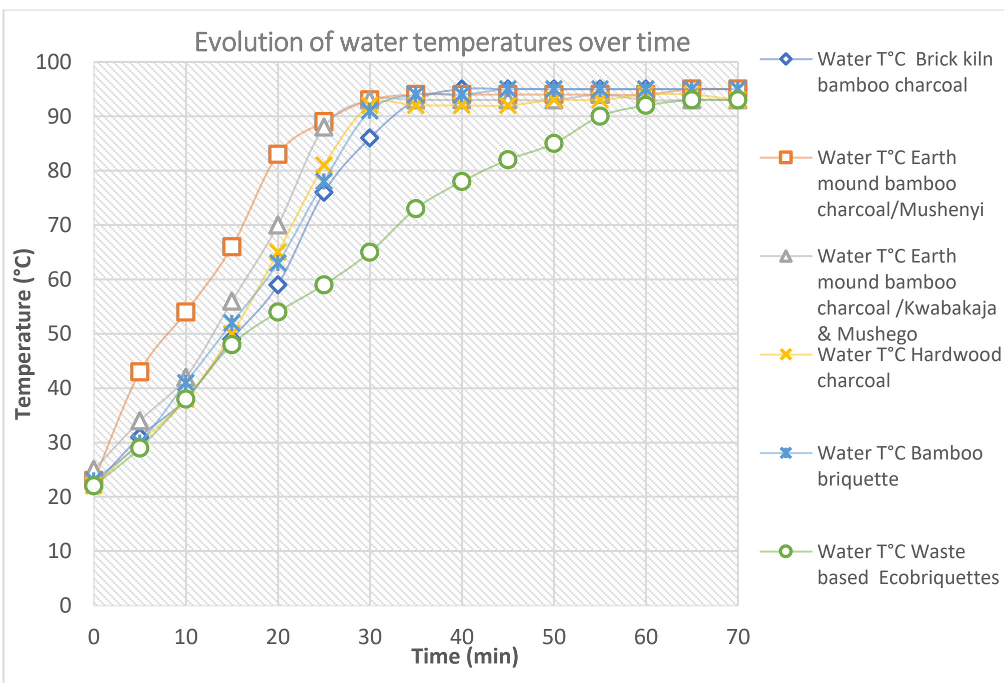

Fig 13. Water boiling test: comparison of the temperature profiles of different types of bamboo charcoal, hardwood charcoal, bamboo briquettes and waste briquettes

The heat transfer between bamboo charcoal and water is quicker for the bamboo charcoal produced in Mushenyi, reaching 80°C after 18 minutes. All the remaining types of charcoal and briquettes have similar heating rates (reaching 80°C between 23 and 25 minutes), except for the waste based eco-briquettes that have the lowest heat transfer rate (water reached 80°C after 42 minutes). The boiling temperature is reached after 27 to 35 minutes for all types of charcoal except for the waste based eco-briquettes where the water boiling is reached after 55 minutes.

IV. MAIN FINDINGS FROM MARKET SYSTEMS ANALYSIS

IV.1. Organization of the charcoal and bamboo charcoal value chain

With population growth, demand for charcoal has risen from 11,460 tonnes per 1 million inhabitants per year in 2020 to 13,638 tonnes of charcoal per year for 1.19 million inhabitants in 2024.[1]

IV.1.1. Charcoal producers

Hardwood Charcoal

All the producers who took part in this survey used earth mound kiln. They explained that they produce and sell charcoal because this activity generates income faster than trading or farming, but it is also an occupation they are used to performing. All of the surveyed producers were men, as the production requires considerable physical labor.

Table 6. Charcoal production and market matrix

Locations	Producers	M	W	Kiln type	Yield (%)	Quantity produced per year	Number of customers per producer	Type of customers	Financing methods	Production frequency
Mushenyi	5	5	0	Earth mound	15(1) and 10 (4)	80-120 bags	3-6 people	Retailers	Own funds (5), debts (2) and VSLA (1)	Depends on trees availability
Kwabakaja and Katoke	7	7	0	Earth mound	12	60-120 sacs	Occasional	Households	Own funds	Depends on trees availability
Nyangezi	2	2	0	Earth mound	10	80-100 bags	2-4 people	Retailers	Own funds	Every month
Bukavu	1	2	0	Earth mound	10	60-90 sacs	2-5 people	Households	Own funds	Every month

VSLA : Village Savings and Loan Association. M : Men, W : Women

In Mushenyi and Nyangezi, customers are regulars, while in Kwabakaja, charcoal is bought by occasional customers returning to Bukavu. Two of the 14 producers from the above mentioned locations sometimes borrow money from relatives or ask small-value loans from VSLA to start production (purchase of trees and carbonization), while the others admit to producing at their own cost. Approximately 60 to 350 bags of charcoal can be produced by one charcoal maker per year.

The charcoal producer we met in Bukavu (at “la voix du Congo” Market), although domiciled in Bukavu, produces charcoal in Kaziba. His customers are located in Bukavu. Most of them are retailers who buy between 4 and 10 bags per week, but also households who buy 1 or 2 bags per month.

Eucalyptus and Acacia are the preferred species for carbonization. Cypress is not used, given its poor charcoal quality. Producers rent and operate a 50m*50m or a 25m*25m wooded plot of land 2 to 4 times a year. Yields are low (around 10%), except for one charcoal maker who has received training in improved charcoal-making methods and who achieves charcoal yields of between 15% and 20%.

Bamboo Charcoal

Bamboo charcoal producers weren't found (except those engaged by Pinnovation trial) and so the bamboo charcoal was produced for the market analysis.

Concerning bamboo charcoal, all the 21 beneficiaries (12 women, 9 men) of the Pinnovation bamboo project participated in the charring tests. Some community members also participated and were very interested in bamboo charcoal making. Approximately 15 bags of charcoal were produced during tests:

- ✓ 4 bags of bamboo charcoal from brick kiln (in 2 production rounds)
- ✓ 8 bags produced at Katoke in an earth mound kiln (EMK) with chimney
- ✓ 3 bags at Mushego (EMK)
- ✓ 4 bags at Mushenyi (EMK)
- ✓ 1 bag at Kwabakaja (EMK)
- ✓ ¼ of a bag (11 kg)of charcoal from INBAR metallic barrel kiln

Around 9 bags were sold by the beneficiaries to customers interested in doing a trial of cooking with bamboo charcoal and the remaining bags were distributed to beneficiaries, community members and charcoal users in Bukavu for survey purposes. After the tests, beneficiaries produced 14 more bags of bamboo charcoal that were sold to households in Bukavu.

IV.1.2. Transporters

During the survey, we noted that charcoal is transported by truck from villages to Bukavu. Bukavu is the largest charcoal market in South Kivu with a growing population of 1.19 million inhabitants from which 90% of households use exclusively charcoal for cooking. Results of the survey conducted in Mushenyi, Kwabakaja, Nyangezi and Bukavu are summarized in table 7 below:

Table 7. Charcoal transportation matrix

Locations	Transporters	Means of transport	Useful truck volume (m^3)	Sacs transported per round	Number of customers	Type of customers	Market	Frequency
Mushenyi	4	Truck	28; 52; 36; 60	20-30 sacs and max 100 sacs	8-21	Retailers	Kamagema, La voix du Congo	Twice a week
Kwabakaja	0	-	-	-	-	-	-	-
Nyangezi	1	Truck	36	20-50 sacs	4-7	Wholesalers	La voix du Congo	Twice per month
Bukavu	1	Truck	52	60-100 sacs	2	Wholesalers	Nyawera	Twice per month

Transport of charcoal between Mushenyi and Bukavu, which is a distance of 45 km, is by truck, with cargo tank dimensions of 28m^3; 52 m^3; 36m^3, and 60 m^3. Approximately 20 to 30 bags are transported by 1 truck per shift, and a maximum of 100 to 130 bags is sometimes transported (these orders are rare). Bags' weights vary from 40 kg to 50 kg. The truck makes 2 rounds a week, on Thursday and Sunday, which are market days. The bags transported are 74/120 centimeters in size. Approximately 21 people (18 women and 3 men) buy charcoal (around 4-10 bags per person on a weekly basis) in Mushenyi for resale in Bukavu. The bags are unloaded at either Kamagema market, CAHI parish or LA VOIX DU CONGO/Kimbangu market. Transport is paid directly, either when the charcoal is loaded in Mushenyi or Nyangezi, or when it is unloaded in Bukavu. The transport cost per bag is 3500-5000 CDF (1.25-1.79 USD).

IV.1.3. Charcoal traders (wholesalers and retailers)

Charcoal traders were divided into two categories, depending on the quantity of charcoal sold per round. Wholesalers are those who buy 5 bags or more. Retailers buy 1 to 4 bags and sell it in sachets.

Wholesalers

The quantity bought per round varies between 5 and 10 bags, and the transport takes place twice a week (Thursday and Sunday) to Bukavu for sale. 9 of 13 traders surveyed buy from 5 to 8 suppliers, depending on whether they have available charcoal bags. The stock sent to Bukavu usually lasts a week before being sold out. Then the money is sent to the producer to renew the stock. Charcoal is paid for in cash and sometimes wholesalers accrue a debt after giving an advance of half or a third of the price of goods to the charcoal producer. The cost of transporting a bag of charcoal from Mushenyi to Bukavu (Kamagema and La voix du Congo market) is 5,000 CDF(1.79 USD). To this 1,000 CDF(0.36 USD) must be added for handling (loading and unloading). Wholesalers buy charcoal from charcoal producers and sometimes from the market. Preference is given to charcoal produced from a mature eucalyptus, which is heavier (denser) and burns slowly. Wholesalers from Mushenyi buy between 20 and 35 bags a month, while those in Nyangezi and Bukavu buy 30 to 90 bags a month. The drawback of this business is that in the absence of customers and as the profit margin is small, traders lose out paying taxes and storage fees without selling,. The selling price of a bag of 60-70 kg ranges from 50,000 CDF to 70,000 CDF.

Retailers (roadside vendors and market vendors)

Charcoal retailers interviewed attested that their customers are mainly households (95%) and restaurants (5%). The stock purchased lasts a week or two before it is sold out in Bukavu. Then the money is sent to the wholesaler to renew the stock.

Retailers sell charcoal in any amount from 1 full bag (weighting 65-70 kg) to 1 sachet of less than 1 kg to households. The selling price of a full bag ranges from 60,000 to 85,000 CDF. A sachet of charcoal is sold at 1,000 CDF.

IV.1.4. Charcoal end users

Results from studies and reports on charcoal value chain in South Kivu show that approximately 97% of households living in urban and peri-urban areas use charcoal (around 15% combine charcoal, gas, electricity). More than 90% of households use exclusively charcoal as cooking fuel. With 97% of households being charcoal users, charcoal net demand in Bukavu is 13,228 tons per year[1].

At Kwabakaja and Mushenyi, firewood is used because of the low households' spending power. People interviewed said they did not have enough money to buy charcoal. On the other hand, only 2 of 13 households surveyed in Mushenyi cook exclusively with charcoal as it offers several advantages, notably no smoke, no odors and no soot on cooking utensils. Households that use charcoal also combine it with firewood. Charcoal is used 5 days out of 7 or sometimes 3 to 10 days a month. For the rest of the days, firewood is used because households cannot afford to buy more charcoal. The average household composition is 6.5 people. All 13/13 and 9/9 households surveyed in Mushenyi and Kwabakaja respectively preferred briquettes to charcoal or bamboo charcoal, as they burn longer. All the 5 households surveyed in Nyangezi said they were used only to hardwood charcoal.

Restaurants owners in Mushenyi buy 8-10 kg of charcoal, for approximately 3,000 to 6,000 CDF twice a month. Small sized charcoal used by restaurant owners' costs 50-65% less than large size charcoal and is bought from children who produce charcoal from eucalyptus seedlings, which are prematurely cut before they reach maturity.

An improved cooking stove filled with large size charcoal lasts between 3 and 4 hours. Low-grade charcoal (small size) lasts between 30 minutes and an hour on the cooking stove.

More than half of households surveyed in Kwabakaja (5/9) and Mushenyi(7/13) prepare food once a day (only in the evening), 9/22 twice a day and 1/22 three time per day. Restaurants are opened every day, but more specifically on Thursdays and Sundays (market days), given their proximity to the market. Improved stoves are used by 16/22 of surveyed people, while 6/22 use unimproved cookstove. All of them have traditional three-stone stove because firewood is widely used in rural areas.

Households buy charcoal from street vendors (who are often children), but also at the market. The seller sometimes pays the cost of charcoal transportation from the market to customers' residence, and sometimes it is the customers who either transport or pay for the transportation of the purchased charcoal themselves. The charcoal preferred by customers is that made from eucalyptus, acacia, and *Grevillea robusta*. Households pay for charcoal one to three times a month (spending on average 1,000-3,000 CDF), restaurants purchase charcoal 2 times a month (spending on average 3,000-6,000 CDF). Community members in Mushenyi and Kwabakaja villages greatly appreciated the quality of bamboo charcoal but are still using firewood as cooking fuel because its collection is for free, and firewood is collected on their way back from the farm. Some users including those from Nyangezi (8/27) engaged in bamboo charcoal testing said they would like to continue using bamboo charcoal thanks to its good quality. All of them appreciated the most the bamboo charcoal produced in earth mound kiln due to its high weight (density), low ash production, good calorific value and long combustion duration compared to the charcoal produced in brick and clay kiln.

All customers who bought bamboo charcoal were from Bukavu. The online survey done in Bukavu had 19 respondents. 83% of them appreciated the bamboo charcoal quality, saying its combustion lasted long time, no dust remained on hands after use, ignition time was short, and it had high density compared to hardwood charcoal (from eucalyptus). 79% mentioned the high presence of ashes, while 16% mentioned the difficulties to ignite. Comparing bamboo charcoal to hardwood charcoal, 47% of respondents said bamboo charcoal lasted longer, while 16% assumed that hardwood lasted longer and 37% believed that both had a similar burning time.

Among the factors that can influence the adoption of bamboo charcoal by users, we find: price (68%), burning time (84%), forest preservation (63%) and ease of ignition (42%). According to the survey, a bag of charcoal weighing between 60 and 70 kg sells for an average of 70,000 CDF (25 USD). After using bamboo charcoal, the average price they offered to buy it was 60,000 CDF(21.4 USD).

Waste briquettes are not adopted by charcoal users, as they are not water-resistant (they disintegrate), are not reusable, produce less heat than charcoal, although burning over a long period they disintegrate on contact with a pan, and are very dusty after combustion. Charcoal users also rely on the speed of ignition and combustion, which briquettes containing clay as a binder do not offer.

IV.2. Profitability analysis of the bamboo charcoal

Charcoal-related activities in South Kivu, especially in Bukavu, generated total value added (VA) of around 16.5 million USD in 2020 and 19.6 million USD in 2024[2].

IV.2.1. Wood charcoal and bamboo charcoal rentability analysis

Production cost

A well stocked 50*50 m^2 area of trees (a wooded area without a lot of empty spaces. Where space between tress is minimal) costs 1,000 USD. If this wooded area is not sufficiently lined, with empty spaces, it costs 500 USD. The cost of felling trees and cutting wood varies between 200 and 350 USD. Taxes paid are 50 USD (grouping or chieftaincy) and 5,000 to 15,000 CDF (1.79 to 5.36 USD) is paid as environmental tax. Operating costs range from 7,000 to 10,000 CDF(2.5 to 3.6 USD) per person per day. Around 4 to 6 people are hired for this work. The work is done between 3 and 5 days. An empty bag for charcoal packaging costs 1,000 CDF (0.36 USD). After carbonization, 150 to 170 bags of charcoal are produced in a 50m*50m wooded area.

Selling Price

The producer's retail price of a full bag (60-70 kg) of charcoal at Kwabakaja village varies depending on the season, from 40,000 CDF to 50,000 CDF(14.3 USD to 17.9 USD). Wholesale prices vary between 35,000 CDF(12.5 USD) and 45,000 CDF(16.1 USD) per full bag.

At Mushenyi, the prices vary from 25,000 CDF(9 USD) to 35,000 CDF(12.5 USD) per bag (40-50 Kg). The bags produced in Mushenyi are not as full as the ones produced at Kwabakaja and Nyangezi.

Rentability analysis of hardwood charcoal is presented in the table 8 below:

Table 8. Profitability analysis of hardwood (Eucalyptus) charcoal produced in Mushenyi and Kwabakaja

Costs	Charcoal producers	Wholesalers	Retailers	Total		%
	(CDF/kg)	(CDF/kg)	(CDF/kg)	(CDF/kg)	(USD/Kg)	
Access to wood resources	235.294			235.294	0.084	23.523
Chieftancy taxes	11.765	2.353		14.118	0.005	1.412
Environment service	1.261			1.262	0.0005	0.1262
Local manpower	25.212	0.840		26.052	0.0093	2.605
Transport of wood to production area	10.714	4.286		15	0.0054	1.5
Charcoal purchase price	-	500	785.714	-	-	-

Miscellaneous purchases and packaging	14.286		23	37.286	0.0133	3.729
Truck transport		47.059		47.059	0.0168	4.706
Storage & security	25.2	23.529		48.729	0.0174	4.873
Discharging/ Carrying in Bukavu	-	7.143	28.57143	35.714	0.0128	3.571
Bagging losses	-	-	40.08677	40.087	0.0143	4.009
Miscellaneous taxes (market taxes, patents)		15.184	7.142857	22.327	0.0080	2.233
Unofficial taxes	5.7	11.844		17.5438	0.0063	1.754
Gross profit	**170.568**	**173.476**	**115.4847**	**459.529**	**0.1641**	**45.953**
Charcoal selling price	**500**	**785.714**	**1000**	**1000**	**0.3571**	**100**

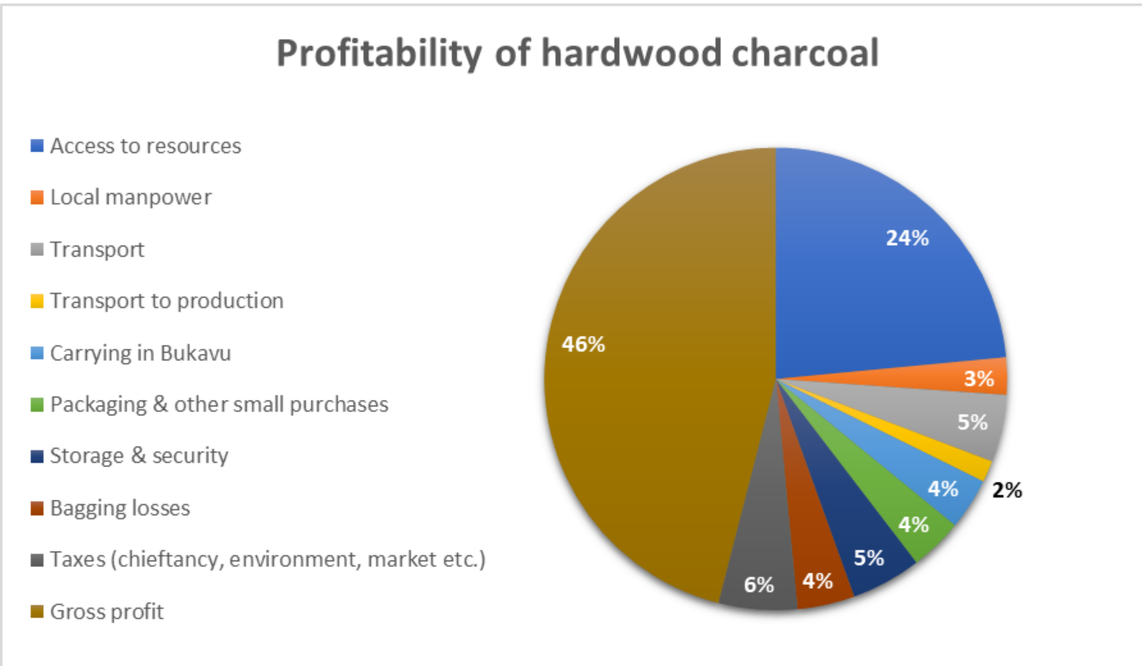

Fig 14. Profitability of hardwood charcoal

The overall gross operating profit is **459.5 CDF (0.1641 USD)/kg** of charcoal. Charcoal makers and wholesalers have similar profit of 37% and 38% respectively, while retailers' profit is only 25%. Access to resources (hardwood) represents the largest cost (71% of charcoal making costs and 47% of overall costs) for charcoal producers, while purchase price is the main expense (82.7%) for wholesalers, followed by transport cost (7.7%) apart of. Purchase price represent 88.8% of retailer's expenses while Bagging losses represent 4.5% of their overall costs.

IV.2.2. Bamboo charcoal marketing

During this study, bamboo charcoal production costs were lower than wood charcoal production costs. The cost of access to resources (bamboo) varies between 128 and 257 CDF/kg of bamboo charcoal produced. This cost is lower than hardwood charcoal's because as giant bamboo is not used in construction since few years in Karhongo grouping (because they are currently using bricks for house building), it values decreased and its price is lower. The average cost of access is 167 CDF/kg for bamboo charcoal and 235

CDF/kg for wood charcoal. This cost can be reduced if bamboo plantations are widespread in the area and may increase with the scarcity of bamboo. This applies to costs of our small testing production.

Table 9. Bamboo charcoal marketing and rentability

Costs	Charcoal producers (CDF/kg)	Wholesalers (CDF/kg)	Retailers (CDF/kg)	Total (CDF/kg)	Total (USD/Kg)	%
Access to resources	167.143			167.1429	0.0597	16.7143
Chieftancy taxes	11.765	2.353		14.12	0.005	1.412
Environment service	1.261			1.2612	0.0005	0.126
Local manpower	25.212	0.840		26.052	0.0093	2.605
Transport to production area	10.714	4.286		15	0.0054	1.5
Charcoal purchase price		500	714.286			
Miscellaneous purchases and packaging	14.286		23	37.286	0.0133	3.729
Truck transport		47.059		47.059	0.0168	4.706
Storage & security	25.2	23.529		48.729	0.0174	4.873
Carrying in Bukavu		7.143	28.571	35.714	0.0128	3.571
Bagging losses			40.087	40.087	0.0143	4.009
Miscellaneous taxes (market taxes, patents)		15.184	7.143	22.327	0.008	2.233
Unofficial taxes	5.7	11.844		17.544	0.0063	1.754
Margin	238.719	102.047	186.913	527.68	0.1885	52.768
Charcoal selling price (35,000 CDF per 70 kg bag)	**500**	**714.286**	**1000**	**1000**	**0.3571**	**100**

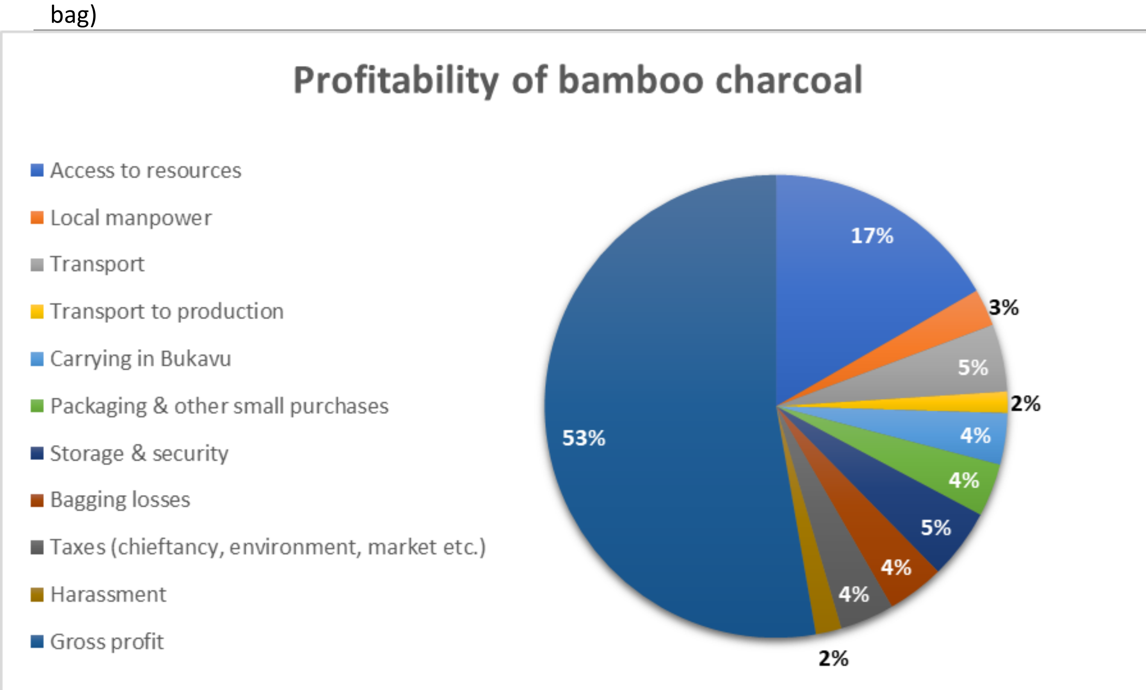

Fig 15. Profitability of bamboo charcoal

The overall profit is **527.7 CDF (0.1885 USD)/**Kg of bamboo charcoal. In this situation, charcoal producers have the highest proportion of profit (45%), while wholesalers retailers get only 19% and 35% respectively. The overall profit depends on the bamboo charcoal price at the market. In the case of market price reduction, profits will be reduced. The overall gross operational profit of bamboo charcoal represents 115% of the overall hardwood profit.

The study found that the cost of producing bamboo charcoal from the masonry kiln is higher than that of the clod kiln, given the additional cost of transporting the bamboo culms (on foot) from the bamboo plantation to the carbonization kiln. Depending on the distance, this cost varies between 20 and 40 USD, with an average of 30USD (84000 CDF) for the transport of 20 to 40 bamboo culms. With the weight of a bamboo culm varying between 30 and 40 kg (average 35 kg), the total mass of bamboo transported would be between 930 kg and 1000 Kg (average 947.2 kg). With the carbonization yield of 11.24% obtained, the transport cost would be around 789 CDF/Kg of charcoal produced. The total production cost is thus **1261.3 CDF/kg** of bamboo charcoal. The profit margin is negative (**-261.3 CDF/kg)**, making this approach difficult and unattractive for players in the charcoal value chain.

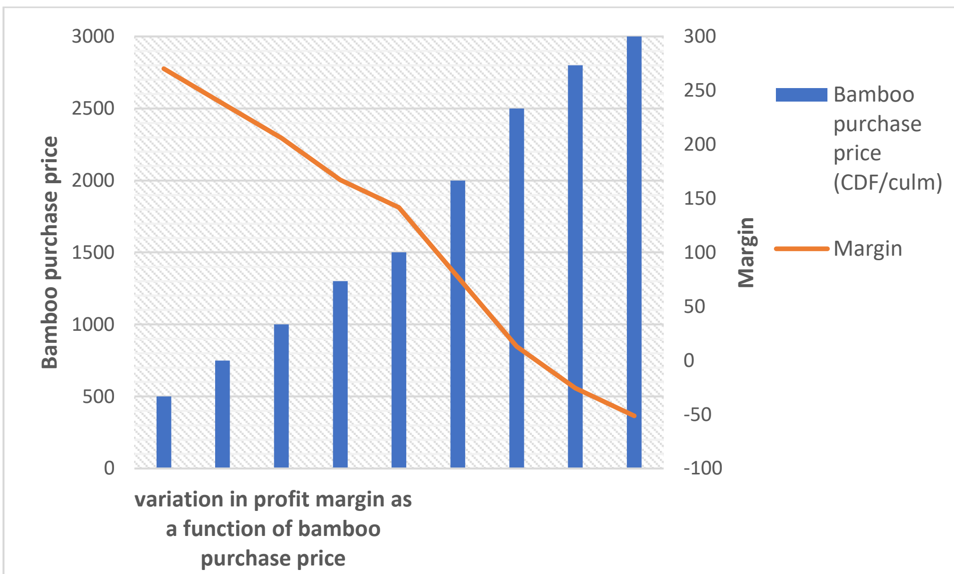

Fig 16. Evolution of bamboo charcoal profit margin as a function of bamboo purchase price

The above findings show that the profit decreases with the increase of bamboo price. The acceptable price is found for a purchase price of 1,650 CDF/bamboo culm and a charcoal maker's profit of 125 CDF/ kg of bamboo charcoal. This acceptable price lies at the intersection between the price curve and the profit margin curve.

The results below show the variation of profit in function of bamboo selling price.

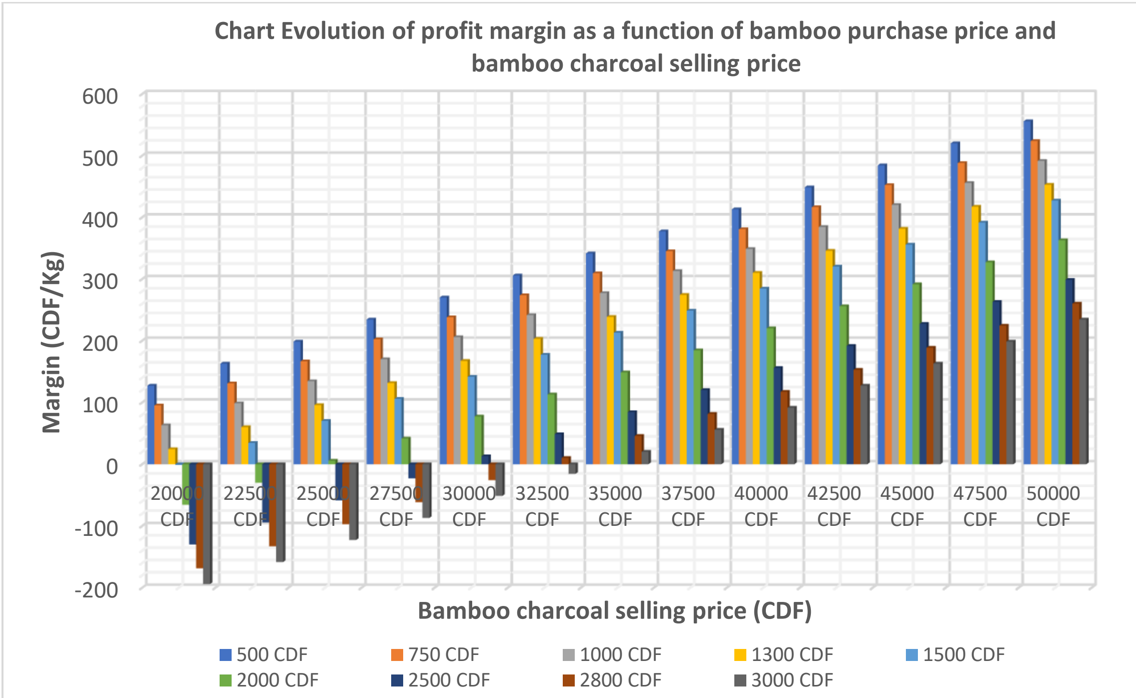

Fig 17. Chart Evolution of profit margin as a function of bamboo purchase price and bamboo charcoal selling price

The chart on the graph 17 shows the evolution of the margin as a function of bamboo purchase price and selling price. For purchase prices of 1,000 CDF or below, bamboo charcoal can be profitable for producers even when a full bag of charcoal (60-70 kgs) is sold for 20,000 CDF (7.14 USD) but the profit is acceptable (around 125 CDF/kg and above) for 25,000 CDF (8.9 USD). For bamboo purchase prices of 2,000 CDF, bamboo charcoal can be profitable when a bag selling price is 35,000CDF (12.5 USD). When bamboo is purchasing price is 3,000 CDF, a bag of bamboo charcoal is only profitable from 45,000 CDF (16.1 USD). This is only applicable for bamboo produced in earth mound kiln located on short distances from the bamboo plantation.

IV.2.3. Bamboo briquettes market

Briquettes available at the market in Bukavu are sold at 1,000 CDF (0.357 USD) per kilogram. For bamboo briquettes (same as for waste-based briquettes), manpower (105.26 CDF/kg), binder (59.21 CDF for 2kg of maize flour) and fuel (26.32 CDF for charcoal used to heat the binder) costs are added to the overall production cost of the bamboo charcoal. The overall profit is reduced by 190.79 CDF representing the total additional cost. On the other hand, bagging losses (40 CDF/kg) costs will be reduced. Thus, the additional costs added on bamboo charcoal production costs for bamboo-based briquette making is 150.7 CDF/kg. This makes bamboo briquettes 15% less profitable compared to bamboo charcoal. This can be compensated by a higher selling price of bamboo briquettes due to their higher density.

V. CHALLENGES AND OPPORTUNITIES

V.1. Challenges

The production and marketing of bamboo charcoal is an excellent opportunity to replace hardwood charcoal, but it faces several challenges. The greatest of these is the scarcity of planted bamboo, which is rarely used as a building material for semi-sustainable homes. With the latter becoming less and less common, bamboo, especially green and giant species, are no longer planted and are sometimes considered useless, especially when they are found close by, or on agricultural land. To replace charcoal with bamboo charcoal, bamboo nurseries need to be set up to create bamboo groves and even bamboo forests. Sympodial species and especially giant bamboo would be recommended in this case.

Where to plant bamboo is also a problem, as people living in rural areas and close to deforested areas have no interest in bamboo, unlike other species such as eucalyptus.

In some places, locals assume that bamboo could be a hiding place for bandits and criminals, or a breeding ground for snakes.

Bamboo carbonization yields are low and need to be improved. On the other hand, the ground oven method has shown the best results. The masonry kiln presents a problem in terms of controlling the carbonization temperature and stopping the carbonization process. Bamboo charcoal obtained from this kiln is light, but produces high energy, given its low volatile dry matter composition, reduced by the refining stage (800-1000°C). As a result, the yield is low, as is the loading rate. Another drawback is the distance between the furnace and the bamboo plantation. This distance adds the cost of transporting the bamboo to the production costs, making the process less or not at all profitable.

Concerning the marketing of bamboo charcoal, the major challenge is the lack of information among users, who are used to charcoal. 95% of those interviewed assured us that bamboo cannot produce charcoal, and if it can, the charcoal will be of poor quality. Charcoal users have doubts about bamboo. This doubt stems from local and cultural experience, where dry bamboo used as firewood burned quickly. People who had used bamboo charcoal purchased from beneficiaries mentioned that it produced slightly more ashes than charcoal. Bamboo-based briquettes can face difficulties in community ownership just as waste-based briquettes due to the fact that briquettes are not water resistant (disintegrate when in contact with water) , mustn't be in direct contact with a cooking pan and can't be reused.

V.2. Opportunities

Bamboo is a plant with multiple benefits and can help protect the environment and contribute as a mitigation measure to climate change. Bamboo forests can reduce the negative effects of global warming so that bamboo can store and absorb carbon and CO_2 and as one phytoremediation option, it can also detoxify environmental contaminations. It absorbs 30% more carbon dioxide than trees and releases 30% more oxygen into the atmosphere, making it an essential element in the absorption of CO_2. With its powerful root system, bamboo is an effective means of combating erosion and landslides. It has many uses, mainly in construction (flooring, roofing, designing, and scaffolding), furniture, food, biofuel, fabrics, cloth, paper, pulp, charcoal, ornamental garden planting.

Bamboo charcoal's resistance, long combustion time and high calorific value make it is a perfect substitute for charcoal. As its production cost is low compared to that of hardwood charcoal, bamboo charcoal offers a better opportunity for players in the charcoal value chain. Good marketing and strong promotion of bamboo charcoal can contribute to reducing the rate of deforestation and the pressure exerted on forests by charcoal production activities. Bamboo briquettes can also offer a good opportunity of using less dense and consistent bamboo species in charcoal making. As the production process is simpler and well known by charcoal makers, improving earth mound kilns efficiency for bamboo charcoal production makes it more attractive for producers.

Considering that some bamboo species like *Dendrocalamus giganteus* can have an annual yield of 20 to 30 tons of biomass per hectare, with a harvesting cycle of 3-4 years for bamboo charcoal purposes while *Eucalyptus grandis* has an annual yield ranging between 4-15 dry tonnes per hectare with a rotation of 3-7 years; over a 10-year period, one hectare of bamboo planted for charcoal production can protect 1.3 to 1,875 hectares of forest from degradation and deforestation caused by charcoal production, while producing around 1,700 MJ of heat from 50 tonnes of charcoal (with a carbonization efficiency of 25%). With improved carbonization, 10% to 20 % more of forest area can be protected.

Bamboo charcoal has similar characteristics to charcoal and can therefore be used to replace charcoal and help reduce deforestation. Activated carbon can also be produced and used to purify water and decontaminate liquid substances and effluents.

It seems that the biggest bottleneck is the lack of awareness of bamboo potential and a lack of attention regarding the development of marketing in this sector.

Table 10.SWOT Analysis of bamboo-based fuels

	Bamboo charcoal	Bamboo briquettes	Hardwood Charcoal	Waste-based briquettes
Strengths	• High calorific value (6% more) • Burns longer than wood charcoal (15 to 45 minutes de plus) • Resists to abrasion • Reusable • Retains its properties after exposure to high humidity • Doesn't contain smallest particle sizes (dust) • Low production costs	• High bulk density • Resists to abrasion • Burns longer (45 min to 90 mins longer than hardwood charcoal)	• Good calorific value but 6% less than bamboo charcoal's • Widely known and accepted by users • Reusable • Retains its properties after exposure to high humidity	• High bulk density • Burns45-90 minutes longer than hardwood charcoal • Resists to abrasion if not exposed to water
Weaknesses	• High quantity of ashes generated (47%- 180% more than wood charcoal) • Not known by users • Fewer available resources	• Low calorific value (21% less than bamboo charcoal) • High presence of ashes after cooking (578% more than hardwood charcoal) composed mostly clay used as binder • Not reusable • Not resistant when exposed to humidity • High production costs	• Low resistance to abrasion compared to briquettes and bamboo charcoal • High presence of small size particles of charcoal	• Low calorific value (25% less than bamboo charcoal) • High presence of clay after cooking (790% more than hardwood charcoal) • Not reusable • Not resistant when exposed to humidity • High production costs
Opportunities	• Carbon sink (absorbs 30% more CO_2 than other trees) • Short harvesting cycle (3years)	• Good option for using bamboo with low biomass and carbon content	• Renewable resource • Improvement of carbonization	• Good option for organic waste valorization

	• Sustainable resource: Bamboo culms yield 20-40 tons/ha.year • Growth rate: reach maximum height after 6 months. • Can be a good option for protecting Congo Basin forest from deforestation and degradation • Reforestation with bamboo can quickly generate carbon credits for communities	• Valorization option for small pieces of charcoal remaining after carbonization	efficiencies in masonry kilns	• Adapted to areas with wood inaccessibility and scarcity (such as IDP camps)
Threats	• Needs strong promotion and marketing • Bamboo scarcity can influence production costs and cause challenge to behavior change regarding bamboo charcoal use	• Difficulties to be adopted due to its drawbacks • Needs strong promotion and marketing	• Mismanagement of charcoal production leads to deforestation and forest degradation	• Difficulties of community ownership • Needs strong promotion and marketing

CONCLUSION

The aim of this study was to assess the technical and economic feasibility of replacement of wood charcoal by bamboo charcoal as a means of protecting the forest resources from deforestation while giving an alternative to charcoal value chain actors.

Another objective was to carry out profitability and market systems analysis to assess the bamboo charcoal's market in Karhongo grouping, especially in Nyangezi, Kwabakaja, Mushenyi and in Bukavu City which is the largest charcoal market in South Kivu.

To this end, the methodology consisted of:

- ✓ Conducting a technical study of the various bamboo charcoal production processes. Species used for bamboo charcoal and hardwood charcoal production are respectively giant bamboo (especially *Dendrocalamus giganteus*) and *Eucalyptus grandis*.
- ✓ Carring out a comparative analysis between bamboo charcoal produced by different processes with wood charcoal, bamboo briquettes and briquettes produced from waste.
- ✓ Conducting a study of bamboo charcoal market systems, comparing them with those of charcoal.
- ✓ Conducting a study of the economic profitability of bamboo charcoal.
- ✓ Identifying challenges, opportunities and lessons learned.

The results of this study showed that bamboo carbonization in the earth mound kiln gave the highest yield (18.48%), producing the highest quality bamboo charcoal (calorific value: 29.85 - 30.68 MJ/Kg) which is 6% higher than the calorific value of wood charcoal (27.5 - 29.4 MJ/Kg). Bamboo briquettes and those made from waste have a respective calorific value of 21% and 25% lower than that of bamboo charcoal (23.8 and 22.7 MJ/Kg), with 578% and 790% more ashes than charcoal. Bamboo charcoal produced in the masonry kiln has a higher ash content (47% to 180% more than charcoal), and a calorific value 15.3% lower than that of bamboo charcoal produced in the earth mound kiln. Furthermore, the energy yield of bamboo charcoal is the highest, despite its lower density, which makes it less attractive to users. Briquettes have a higher density than wood and bamboo charcoal.

The overall profit margin of bamboo charcoal carbonized in masonry kiln is negative (-261.3 CDF/Kg). Bamboo charcoal produced in the earth mound kiln, bamboo briquettes, and hardwood charcoal (from eucalyptus) have positive overall profit margins respectively of 527.5 CDF/kg, 336.71 CDF/kg and 459.5 CDF/kg. The profit margin is distributed between charcoal producers, wholesalers and retailers. Bamboo charcoal is profitable for producers at an optimum selling price of 32,500 CDF for a 65-70 kg bag, with a profit of 125-140 CDF/kg.

Some bamboo species like *Dendrocalamus giganteus (used in the study)* can have an annual yield of 20 to 30 tons of biomass per hectare, with a harvesting cycle of 3-4 years for bamboo charcoal purposes. Eucalyptus grandis have an annual yield ranging between 4-15 dry tonnes per hectare with a rotation of 3-7 years. Over a 10-year period, one hectare of bamboo planted for charcoal production can protect 1.3 to 1,875 hectares of forest from degradation and deforestation caused by charcoal production, while producing around 1,700 MJ from 50 tonnes of charcoal.

The main results are summarized in the table 11 below.

Table 11. Summary Table of the Main findings

Parameters	Unit	Brick kiln bamboo charcoal	Earth mound bamboo charcoal	Bamboo briquettes	Hardwood charcoal	Waste based briquettes
Carbonization efficiency	%	11.24	18.48	-	-	-
Density	kg/m3	217	297	**654**	309	**683**
Calorific value	MJ/kg	25.64	**29.85 - 30.68**	23.8	**27.5 - 29.4**	22.7
WBT System energetic efficiency	%	27.8	23.2-24.94	26.7	24.8	16.7
Production costs	CDF/kg	1261.3	261.3	452.09	329.4	-
Overall profit (all the actors) of the value chain	CDF/kg	-261.3	**527.5**	336.71	459.5	-

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APPENDIX

Appendix 1: Some Typical Charcoal Analyses (FAO,

Wood species Production Method		Moisture content %	Ash %	Volatile matter - %	Fixed carbon %	Bulk density raw -kg/m^3	Bulk density pulverised kg/m^3	Gross calorific value kJ/kg Oven dry basis	Remarks
Dakama	Earth pit	7.5	1.4	16.9	74.2	314	708	32410	Pulverised fuel for rotary kilns 1/
Wallaba	"	6.9	1.3	14.7	77.1	261	563	35580	1/
Kautaballi	"	6.6	3.0	24.8	65.6	290	596	29990	1/
Mixed Tropical Hardwood	"	5.4	8.9	17.1	68.6				Low grade charcoal fines 1/
"	"	5.4	1.2	23.6	69.8				Domestic charcoal 1/
Wallaba	Earth mound	5.9	1.3	8.5	84.2				Well burned sample 1/
"	"	5.8	0.7	46.0	47.6				Soft burned sample 1/
Oak	Portable steel kiln	3.5	2.1	13.3	81.1			32500	2/
Coconut shells	"	4.0	1.5	13.5	83.0			30140	4/
Eucalyptus Saligna	Retort	5.1	2.6	25.8	66.8				3/

1/= Guyana. 2/= U.K. 3/= Brazil. 4/= Fiji.

Chemical and Physical Composition of Charcoal Dry Basis - by weight	Range Max. Min.		Yearly Average	Charcoal considered good to excel lent
Carbon	80%	60%	70%	75 - 80%
Ash	10%	3%	5%	3 - 4%
Volatile matter	26%	15%	25%	20 - 25%
Bulk density - as received (kg/m^3)	330	200	260	250 - 300
Bulk density - dry	270	180	235	230 - 270
Average Size (mm) as received	60	10	35	20 - 50
Fines content - as received (<6.35 mm)	22%	10%	15%	10% max.
Moisture content -as received	25%	5%	10%	10% max.

Appendix 2: Survey questionnaires

The analysis of the bamboo charcoal market system requires linking between the production area and the market area.

Table 12. Required informations and Market Systems Survey methodology

Required information	Description	Location	Source et method
Identification of players in the charcoal and bamboo charcoal value chain	Tree growers, Forest workers, Charcoal makers, Roadside charcoal vendors, Wholesalers, Transporters, Retailers, Consumers	Kwabakaja, Nyangezi, Bukavu	Reports (GIZ, USAID), Survey of various players in the sector
Demand for hardwood charcoal/ bamboo charcoal	Quantity of charcoal demanded by households in the city of Bukavu	Nyangezi et Bukavu	Reports, interviews with industry experts, surveys with stakeholders
Charcoal/ Bamboo supply	Quantity of charcoal supplied	Bukavu, Nyangezi	Reports, interviews with industry experts, surveys with stakeholders
Costs of the various stages in the bamboo charcoal / charcoal value chain	Bamboo prices, transport costs, carbonization costs, transport prices/ additional operating costs (briquettes), taxes and contributions, storage costs, wholesaler prices, retailer prices, consumer purchase prices	Bukavu, Nyangezi	Reports, interviews with industry experts, surveys with stakeholders
Consumers classification	Industries (bakeries, metallurgy, water purification) ? Restaurants, hotels, catering services, Households: High income, Middle income, Low income	Bukavu, Nyangezi	Reports, interviews with industry experts, surveys with stakeholders
Pricing & Marketing Strategy	Positioning, quantity, quality, credit or cash, price, availability, after-sales service, etc.	Bukavu, Nyangezi	Reports, interviews with industry experts, surveys with stakeholders
Consumers' preference	Quality, density, burning time, roughness,appearance, price, environmentally friendly,	Bukavu, Nyangezi	Reports, interviews with industry experts, surveys with stakeholders

Questionnaires (KIIs)

Questionnaires addressed to different categories of the bamboo/woods charcoal value chain stakeholders

Forest workers/ trees or bamboo plantation owners

1. Uses of woods/bamboo (purposes: antierosion, reforestation, afforestation, selling to charcoal makers,)
2. Price of woods/bamboo (per/ha or per m^2).
3. Cost of wood cutting and transportation from the farm to the kiln, if applicable
4. Direct and indirect costs of trees plantation (price of seedlings, fertilizers, pesticides
5. Quantity of woods/bamboo produced or cut per year
6. Number of customers
7. Frequency of buying
8. Type of customers (construction materials sellers: boards, rafters; charcoal producers, construction support sellers: scaffolding;)
9. How do you fund the production of trees/bamboo and/or forest or land acquisition?

10. What types of trees do you plant? Why?
11. Advantages and drawbacks

(bamboo/woods) Charcoal producers

1. Preference of charcoal over gas, wood, electricity as business
2. Price of woods/bamboo (per/ha or per m^2).
3. Cost of wood cutting and transportation from the farm to the kiln, if applicable
4. Direct and indirect costs of carbonization
5. Cost of packaging (PP woven sacs)
6. Selling Price of charcoal (price range and factors including taxes)
7. Recovery or yield of carbonization (weight of charcoal produced per weight of woods carbonized)
8. Recovery or yield
9. Type of Kiln used (traditional, earth, Casamance, brick …)
10. Quantity produced per month or per round
11. Number of customers
12. Frequency of buying
13. Type of customers (retailers, restaurants, businesses, households: considering incomes)
14. How do you fund the production (cash, debt, fund by a wholesaler, credit from VSLAs)?
15. How do you obtain woods/bamboo? do buy them, harvest for free? Why this supply route?
16. What type of charcoal do you prefer (granulometry, density, weight, aspect, …?)
17. How often do you buy a stock of wood? (on what parameters does it depend on?)
18. Quantity of woods or planted area bought per month/year (trees, Ha, Tons).
19. Advantages and drawbacks

Transporters

1. Trucks specifications in terms of useful volume
2. Volume transported/Number of sacs per round and per month
3. Cost of the transport (price range and factors including taxes)
4. Distance from the production site/store to the market
5. Number of customers (who do the same business)
6. Frequency of buying/transport
7. Type of customers (wholesalers, retailers, producers)
8. How do you pay the charcoal and transport (cash, debt, fund the production; cost of transport)
9. Where do you go and why?
10. Average weight per sac.
11. How often per month do you use your car to transport charcoal (it depends on what? seasons)
12. Quantity bought per month/year.
13. Advantages and drawbacks

Wholesalers

1. Preference of charcoal over gas, wood, electricity as business

2. Cost of charcoal (price range and factors including taxes)
3. How long it lasts in the store
4. Number of customers
5. Frequency of buying
6. Type of customers (retailers, restaurants, businesses, households: considering incomes)
7. How do you pay the charcoal and transport (cash, debt, fund the production; cost of transport)
8. Where do you pay and why?
9. What type of charcoal do you prefer (granulometry, density, weight, aspect, …?)
10. How often do you buy a stock (it depends on what?)
11. Quantity bought per month/year.
12. Advantages and drawbacks

Retailers

1. Preference of charcoal over gas, wood, electricity as business
2. Cost of charcoal (price range and factors including taxes)
3. How long it lasts in the store
4. Number of customers
5. Frequency of buying (stock renewal)
13. Type of customers (restaurants, businesses, households: considering incomes)
14. How do you pay the charcoal and transport (cash, debt, cost of transport)
15. Where do you pay and why?
16. What type of charcoal do you prefer (granulometry, density, weight, aspect, …?)
17. How often do you pay
18. Advantages and drawbacks

Consumers/ End Users

1. Preference of charcoal over gas, wood, electricity
2. Price of charcoal (price range and factors influencing the price)
3. How long does it last (burning time)?
4. Presence of smoke?
5. Number of household members (household composition)
6. Frequency of cooking (1 to 4 times per day)
7. Type of stove (traditional, improved, …)
8. How do you pay the charcoal and its transportation (cash, debt, cost of transportation)?
9. Where do you pay and why (some advantages, quality, debt, distance)?
10. What type of charcoal do you prefer (granulometry, density, weight, aspect, …?)
11. How often do you pay charcoal per month, semester or year?
12. Advantages and drawbacks

Appendix 3: Valorific value conversion Table

Table 13. Calorific value Unit conversion

Unit	J/g	Kcal/Kg	KWh/ton
J/g	1	0.24	0.278

Kcal/Kg	4.18	1	1.161
KWh/ton	3.6	0.86	1

Appendix 4: Sensitivity analysis of bamboo charcoal margin

Table 14. Variation in profit margin as a function of bamboo purchase price

Costs	**variation in profit margin as a function of bamboo purchase price**								
Bamboo purchase price (CDF/culm)	500 CDF	750 CDF	1000 CDF	1300 CDF	1500 CDF	2000 CDF	2500 CDF	2800 CDF	3000 CDF
Number of bamboos purchased	5600	3733.33	2800	2153.846	1866.67	1400	1120	1000	933.33
Number of bags of charcoal	622.22	414.81	311.11	239.32	207.41	155.56	124.44	111.11	103.70
Resource access cost (CDF/Kg)	64.286	96.429	128.571	167.143	192.857	257.143	321.429	360.	385.714
Cost price	**158.424**	**190.567**	**222.709**	**261.281**	**286.995**	**351.281**	**415.567**	**454.138**	**479.852**
Selling Price (30000CDF)	428.57	428.57	428.57	428.57	428.57	428.57	428.57	428.57	428.57
Margin	270.148	238.005	205.862	167.291	141.576	77.291	13.005	-25.567	-51.281

Table 15.Variation in profit margin as a function of bamboo purchase and selling price

Costs		**variation in profit margin as a function of bamboo purchase and selling price**								
Bamboo purchase price (CDF/culm)		500 CDF	750 CDF	1000 CDF	1300 CDF	1500 CDF	2000 CDF	2500 CDF	2800 CDF	3000 CDF
Overall Costs		158.4	190.6	222.7	261.3	287.0	351.3	415.6	454.1	479.9
Bamboo charcoal selling price	20000 CDF	127.3	95.1	63.0	24.4	-1.3	-65.6	-129.9	-168.4	-194.1
	22500 CDF	163.0	130.9	98.7	60.1	34.4	-29.9	-94.1	-132.7	-158.4
	25000 CDF	198.7	166.6	134.4	95.9	70.1	5.9	-58.4	-97.0	-122.7
	27500 CDF	234.4	202.3	170.1	131.6	105.9	41.6	-22.7	-61.3	-87.0
	30000 CDF	270.1	238.0	205.9	167.3	141.6	77.3	13.0	-25.6	-51.3
	32500 CDF	305.9	273.7	241.6	203.0	177.3	113.0	48.7	10.1	-15.6
	35000 CDF	341.6	309.4	277.3	238.7	213.0	148.7	84.4	45.9	20.1
	37500 CDF	377.3	345.1	313.0	274.4	248.7	184.4	120.1	81.6	55.9
	40000 CDF	413.0	380.9	348.7	310.1	284.4	220.1	155.9	117.3	91.6
	42500 CDF	448.7	416.6	384.4	345.9	320.1	255.9	191.6	153.0	127.3
	45000 CDF	484.4	452.3	420.1	381.6	355.9	291.6	227.3	188.7	163.0
	47500 CDF	520.1	488.0	455.9	417.3	391.6	327.3	263.0	224.4	198.7
	50000 CDF	555.9	523.7	491.6	453.0	427.3	363.0	298.7	260.1	234.4

Appendix 5: Laboratory analysis certificate

UNIVERSITE CATHOLIQUE DE BUKAVU

UCB

LABORATOIRE DES SCIENCES DU SOL

Certificat d'analyse chimique

Je soussigné, Ir Bienvenu RUKIRANUKA, Responsable du Laboratoire des Sciences du Sol de l'UCB, déclare avoir examiné sept échantillons des charbons de bambou et des bois apportés par PEOPLE IN NEED pour analyse et avoir trouvé les résultats suivants :

DESIGNATION	HUMIDITE (%)	MATIERES SECHES VOLATILES (%)	TAUX DES CENDRES (%)
BAMBOU FOUR EN BRIQUE	7,533	17,733	15,132
BAMBOU KATOKE	3,636	24,890	4,006
BAMBOU MUSHENYI	2,553	33,463	4,208
BRIQUETTE DE BAMBOU	6,715	22,581	18,863
BRIQUETTE EN BASE DES DECHETS	6,505	14,622	24,749
CHARBON DE BOIS	5,288	35,178	1,597
CHARBON DE BOIS 2	8,095	33,442	3,958

Fait à Bukavu, le 11/09/2024

Le Responsable du Laboratoire des Sciences du Sol

Ir Bienvenu RUKIRANUKA

Survey_Bamboo charcoal Users_Buka

Bamboo Charcoal study_Data.xlsx