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Evolution of Carbonization Technologies in Benin and Worldwide: State of the Art

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Abstract

Charcoal is one of the most widely used energy sources in the world. Primarily used in domestic energy sectors and medicine, it is also extensively utilized in metallurgy. However, the technologies used for its production are poorly understood, and the most commonly used methods, particularly in Africa, result in low yields and inconsistent charcoal quality. The aim of this study is to inventory charcoal production technologies and analyze their impact on yield and quality. To do this, we referred to the literature (scientific articles, dissertations, etc.) to identify various technologies and their operations. Our research reveals that charcoal yield and quality are linked to carbonization time and temperature. The longer the carbonization process, the lower the yield. Furthermore, incomplete carbonization produces charcoal with high volatile matter content (low quality). Regarding temperature, the higher it is, the faster the carbonization process and the better the charcoal quality. Industrial kilns offer the best quality charcoal. The optimal carbonization temperature for high-quality charcoal is between 600˚C and 700˚C. High-quality charcoal should contain at least 50% carbon and approximately 30% volatile matter. The highest yields do not exceed 35% - 40%.

Keywords

Charcoal, Wood, Influence, Quality, Yield, Carbonization Technologies

1. Introduction

For many years, charcoal has been the primary solid fuel, used globally for cooking, metal refining, and medicine. In Africa, the consumption of wood-based fuels (wood, charcoal, plant waste, etc.) accounts for up to 80% to 90% of total household energy consumption in most countries (World Energy Outlook 2002) [1]-[3]. Charcoal is preferred due to its ease of transport and low smoke production. The process that transforms wood into charcoal through slow pyrolysis, *i.e.*, in the absence of oxygen, is called wood carbonization. However, the risks associated with its production and the environmental issues it raises (pressure on forest resources and CO_2 emissions) compromise its attractiveness compared to other energy sources. Despite the many publications on this process in recent decades, mastering the influence of technologies on product yield and quality remains a key scientific concern today. As a result, traditional technology is the most widely used, with low yields (ranging from 10% to 15%) [4] [5].

Meeting charcoal needs through low-yield traditional methods, particularly traditional earth mound kilns, can no longer be considered a sustainable production policy.

In this context, several researchers are studying ways to optimize charcoal yields and quality. Notable works include those by Mfomo *et al.* [6], Issifou *et al.* [5], P. Mundhenk *et al.* [7], among others. Some technologies, such as the traditional earth mound kiln, have been studied and improved, leading to new and more efficient methods, both in terms of mass yield and charcoal quality. This study aims to analyze the influence of carbonization technologies on the quality and yield of charcoal.

2. Research Methodology

2.1. Research Question

What is the influence of different carbonization techniques on charcoal yield and quality? To answer this question, it is necessary to analyze and compare the various available carbonization techniques, such as earth mound kilns, metal and brick kilns, and industrial kilns, and consider key parameters such as carbonization temperature and duration. The goal is to determine the advantages and limitations of each technique, as well as the factors influencing the quality and yield of the produced charcoal.

2.2. Literature Review

This step involves identifying the current knowledge on a subject, situating the state of research, and identifying gaps to fill. In this study on the influence of carbonization techniques on charcoal yield and quality, the literature review was conducted using various information sources such as scientific journals, online databases, specialized books, and websites of research institutions and organizations.

The literature review began with a preliminary analysis of key concepts such as "carbonization", "yield", "quality", "carbonization techniques", and "charcoal". This analysis helped determine the keywords used in the search.

The literature review was conducted using several online databases such as

Google Scholar, Science Direct, Scopus, Web of Science, and other specialized environmental science databases. The selection criteria for the articles were based on relevance and scientific quality. Publications less than ten years old were preferred, but older publications were included to complete missing information.

The literature review was supplemented by consulting specialized books and technical reports. Websites of organizations and research institutions specializing in wood carbonization were also consulted for access to specific data and information on each carbonization technology.

All the information collected during the literature review was carefully analyzed and synthesized to establish a solid knowledge base on the subject of this study. This knowledge was used to identify the main carbonization technologies used for charcoal production, the factors influencing charcoal yield and quality, and the parameters for comparing the different carbonization techniques.

2.3. Study Selection

The selection of studies is a crucial step in any scientific research. In this study, the selection was done following a systematic and rigorous approach to ensure the quality and relevance of the articles included in the literature review.

The first step was searching for relevant scientific articles in the online databases mentioned above. The keywords used in the search included "carbonization", "charcoal", "yield", "quality", and "techniques".

Once the articles were identified, we assessed their relevance based on inclusion and exclusion criteria. The inclusion criteria included topic relevance to our study, publication date (from 2013), research methodology quality, and full-text availability. Exclusion criteria included irrelevant articles, outdated articles, publications in languages other than English, and articles unavailable in full text.

The selected articles were then thoroughly reviewed to extract relevant information for our study, including the carbonization technologies and techniques used, carbonization parameters measured, charcoal yield and quality results, and factors influencing these outcomes.

Finally, we used a narrative synthesis method to group and summarize the results of the studies included in our literature review. This method provided a comprehensive analysis of the various carbonization technologies and their impact on charcoal yield and quality.

2.4. Data to Collect

Data collection for this study focused on the carbonization technologies used for charcoal production and their impacts on the yield and quality of the final product. The data to be collected includes the following information:

- Different carbonization technologies used, such as masonry kilns, metal kilns, industrial kilns, etc.
- Carbonization parameters, including temperature, carbonization duration, airflow rate, etc.
- Properties of the wood used, such as density, moisture content, etc.

- Physico-chemical characteristics of charcoal, such as yield, density, ash content, volatile matter content, porosity, etc.
- Properties of the produced pyroligneous liquid, such as chemical composition, pH, etc.

The necessary data will be collected from the available scientific literature, study reports, and published experimental data. Data sources include academic publications, specialized journals, laboratory reports, government documents, and industrial studies. Data will be analyzed quantitatively using appropriate statistical tools.

2.5. Data Analysis

The data analysis phase involves reviewing the research results and interpreting the collected data. This step allows answering the research questions and drawing objective conclusions based on the obtained results.

The results will be interpreted in terms of their practical implications, and conclusions will be drawn to address the research questions. The study's limitations will also be discussed, and recommendations will be made for future research in this field.

2.6. Study Limitations

The main limitations of this study relate to the bibliographic nature of the research, which does not allow for direct measurement of the results or effects of the various carbonization techniques. The data used for this study come from a variety of sources, which may have different methodologies and approaches. Therefore, it is important to consider potential differences between the results obtained from different sources.

2.7. Study Implications

This study on the influence of carbonization technologies on charcoal yield and quality can have significant implications for charcoal producers and industries using this fuel. Indeed, the results of this study can help them choose the best carbonization technology suited to their needs in terms of quality and yield.

On the other hand, this study can also help improve current carbonization practices by identifying the most important parameters in the process and determining the optimal conditions for producing high-quality charcoal with high yield. Finally, this study can have important environmental implications by encouraging the use of more efficient and environmentally friendly carbonization technologies, thereby reducing the impact of charcoal production on forest ecosystems.

3. Overview of Carbonization

3.1. Different Types of Carbonization

3.1.1. Carbonization by Partial Combustion

The energy required for carbonization is supplied by part of the material load (pits, earth mound kilns, masonry kilns, metal kilns) (Figure 1).

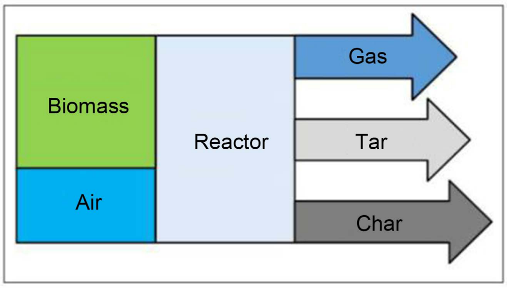

Figure 1. Schematic diagram of the process with internal heating [8].

3.1.2. Carbonization by External Heating

The energy required for carbonization is supplied by an external heat source through a heat exchange surface (vessel, closed chamber, retort) (Figure 2).

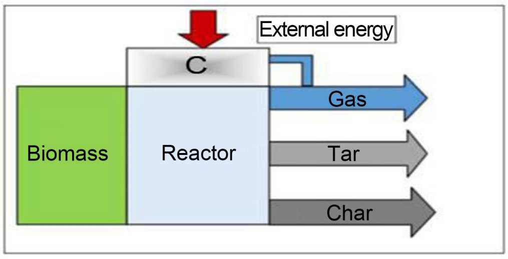

Figure 2. Schematic diagram of the process with external heating [8].

3.1.3. Carbonization by Contact with Hot Gas

The energy required for carbonization is supplied by hot gases from an external heat source, which come into direct contact with the material load (Figure 3).

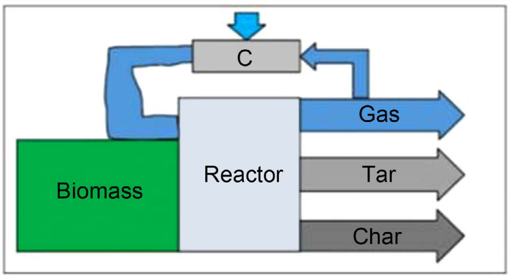

Figure 3. Schematic diagram of the process with heating by contact with hot gases [8].

3.2. Draft Methods

Two draft methods are used: direct draft and reverse draft.

3.2.1. Direct Draft

In this case, the smoke is evacuated directly. A large portion of the heat is thus lost with the smoke, whereas it could be used inside the kiln. This technique is characterized by easy ignition but tends to intensify combustion, posing a risk of sudden intense combustion or a "flash fire".

3.2.2. Reverse Draft

The reverse draft technique addresses the problems associated with direct draft. In this case, the smoke passes through the wood load before being evacuated (Figure 4).

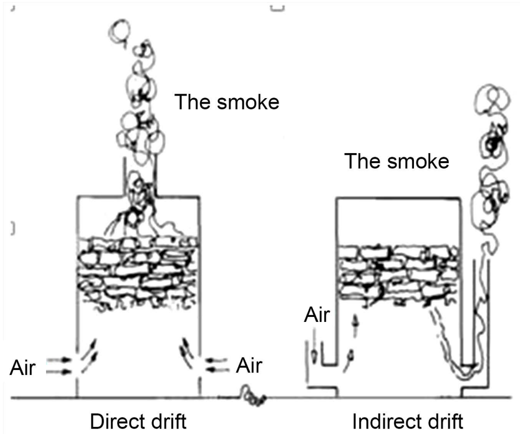

Figure 4. Different draft methods [9].

3.3. Stages of Carbonization

Depending on the temperature progression, four main stages are distinguished during the carbonization process: combustion, dehydration, distillation (carbonization), and cooling.

3.3.1. Combustion

When the fire is initiated by the ignition points, the temperature rises sharply to between 600˚C and 900˚C. A portion of the load that is in direct contact with the embers and in excess of oxygen ignites very quickly. This phenomenon immediately triggers the subsequent phases.

3.3.2. Dehydration

Between 100˚C and 200˚C, the wood primarily loses its moisture. This is the endothermic period corresponding to drying, during which some volatile compounds may be eliminated by water vapor. The duration of this phase depends on the moisture content of the wood and the carbonization method.

3.3.3. Distillation (Carbonization)

Once the water is eliminated, there is a very rapid increase in temperature due to the decomposition of the wood constituents (an exothermic reaction). A mixture of products is formed, primarily consisting of acetic acid, methanol, and tar, which escape into the smoke. If the structure of the chimney (or chimneys) allows, this mixture can condense and flow down the internal walls as pyroligneous liquid. The end of the distillation phase is marked by a reduction and a change in color of the smoke, which turns blue. At this point, carbonization should be stopped.

3.3.4. Cooling

The cooling time depends on the carbonization technique, the thickness, and the radiative capacity of the walls of the apparatus used.

4. State of the Art on Carbonization Technologies

Several wood carbonization technologies are distinguished [3]. However, they can be summarized into five main categories:

- Pit technology
- Metal kiln technology
- Brick (masonry) kiln technology
- Traditional (earth mound) technology
- Retort (industrial) kiln technology

4.1. Traditional Technologies or Earth Mound Technologies

Among the traditional carbonization methods, the earth mound technique is still widely practiced today in developing countries. Used for centuries worldwide, it has been nearly abandoned in Europe, primarily for economic reasons. Indeed, the importance of the labor required to construct and operate an earth mound renders this technique completely outdated. Classically, three types of carbonization mounds are distinguished: the traditional vertical mound, the horizontal mound, and the improved mound, mainly represented by the Casamance mound [10]-[13].

4.1.1. Traditional Vertical Mound

This mound has a circular base and consists of wood arranged vertically around a central post, with small pieces of wood carefully placed in the gaps (**Figure 5**). Once the mound is built, the central post is removed to create a chimney. The covering is made of plant material (straw, grass, branches) topped with a layer of earth, preferably sandy or loamy. The ignition of the load occurs at the center of the mound by dropping embers into the chimney. After the fire rises in this chimney, the carbonization front progresses from top to bottom in a fan shape. Managing this mound requires great expertise and near-constant monitoring. Once carbonization is complete, the mound is covered with an additional layer of earth to seal it during cooling. The carbonization duration is around 50 hours for small mounds (10 steres). The cooling process can last several days.

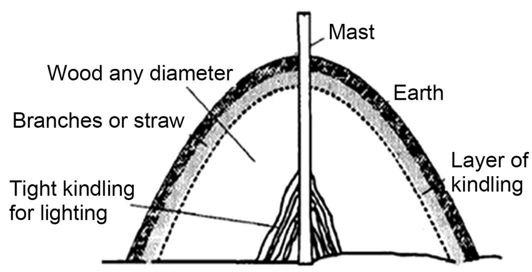

Figure 5. Vertical mound [14].

4.1.2. The Traditional Horizontal Mound

This type of mound is very similar to the previous one in terms of covering and management. Its shape resembles a flattened half-cylinder. The two significant differences compared to the previous method are as follows:

- The wood is arranged horizontally.
- The carbonization front moves from one end to the other of the mound.

In the case of the horizontal mound, the load is placed transversely on a series of logs arranged end to end, thus forming an air circulation grid [13]-[16]. Meanwhile, Hibajene notes that in Zambia, the load is arranged longitudinally rather than transversely. Small pieces of wood are used to fill the gaps left between the logs [17] (**Figure 6**).

The front ignition takes place on the windward side. In the case of a large mound, the removal of the already cooked area (ignition side) can occur before the complete carbonization is finished. The volume of wood in horizontal mounds can reach up to 100 steres, with the complete carbonization cycle lasting more than 3 weeks [14].

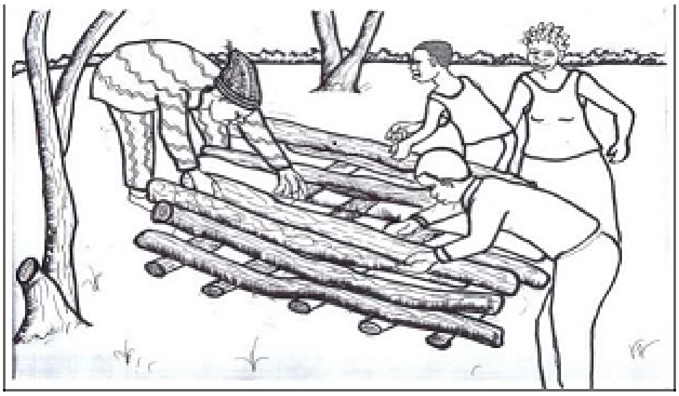

Figure 6. Construction of the base of the horizontal mound [18].

4.2. The Improved or Casamance Mound

The most widely disseminated improved mound is the Casamance mound (**Figure 7**). It features several developments aimed at improving, accelerating, and facilitating carbonization and its management.

The construction of this mound requires good air circulation (a floor made of small wood and the installation of vents using pipes located at the base of the mound), as well as a preferential arrangement of the logs (small wood on the periphery and large wood in the center of the mound). The covering itself does not undergo any modifications compared to traditional mounds.

However, the main improvement is the use of a chimney made from inexpensive materials (old 200 L barrels). This allows for faster carbonization and easier management by forcing the circulation of gases. Furthermore, yields are said to be improved thanks to the inverted draft. A mound of 100 steres requires 3 days of carbonization and 4 days of cooling.

Another type of improved mound is used in Somalia [19]. Its main feature is a simple covering of a large part of the wood load with metal sheets (unrolling old oil barrels). These provide a reliable cover that does not require constant sealing and thus ensures effective sealing of the carbonizing load. Additionally, thanks to these sheets, the charcoal is not contaminated by the covering soil necessary for other types of mounds. The management of this mound is carried out using an inverted draft with ignition at the top, while the air inlets and smoke outlets are located at the base of the mound.

Figure 7. Casamance mound [20].

4.3. The Pit Technology

This technology involves digging a pit in loose sand while preparing air ducts and smoke outlets. In this pit, which can vary in depth from 3 to 60 cm or more and in capacity from 1 m^3 to over 100 m^3 [21], the wood to be carbonized is stacked, taking care to fill the gaps with branches and small wood to improve the filling coefficient. The load is then covered with a large quantity of grasses, straw, and sand, and the pit is ignited through a pre-prepared opening. The carbonization in the pit requires a thick layer of soil. Suitable deposits of loose soil are usually found along the banks of streams. The pit can be large, and the complete carbonization cycle can take up to three months [12]. However, the load can also be covered with old sheets of metal on which a layer of soil is placed.

The carbonization in a pit progresses from one end of the load to the other. During the process, careful monitoring of the load is necessary to seal any openings that appear. When the covering of the pit has collapsed over its entire surface, the carbonization is considered complete. This method is resource-intensive regarding wood and does not allow for controlling gas circulation. It provides low yields and also makes it difficult to obtain a uniform quality of charcoal (**Figures 8-11**).

Figure 8. Dug pit [9].

Figure 9. Loading of wood [9].

Figure 10. Ventilation and gas (smoke) outlet hole [9].

Figure 11. Wood charcoal obtained [9].

4.4. Metal Oven Technology

The cut wood is chopped and stacked for at least three weeks before carbonization. The most suitable dimensions are 45 to 65 cm in length and up to 20 cm in diameter. Wood larger than 30 cm in diameter must be split. It is not recommended to mix branches less than 4 cm in diameter with very large diameter wood in the same charge.

The lower section of the oven is first placed in a well-cleared area, uniformly swept by the wind. The gas ducts are installed as deeply as possible to avoid overheating the wall.

To facilitate gas circulation, a kind of base is formed for the charge, consisting of medium-diameter logs arranged radially at the bottom of the first shell. In the center of the base, dry kindling and dry straw are placed. Moistening this material with a mixture of waste oil and diesel fuel can make ignition easier.

Over the beams and the kindling material, small and medium-diameter wood and "fumerons" (incompletely carbonized wood from a previous batch) are laid crosswise. It is noted that this first layer must completely cover all visible beams. This preliminary phase is valid for both peat and wood.

The installation of the lid concludes the loading process. Care should be taken to place the pyrometric probes each time their respective levels are reached during loading.

To increase the airtightness of the oven, sand or clay soil is placed in the joints between the two sections and between the upper section and the lid. After ensuring that the four steam outlet openings on the lid are fully open, the fire is ignited at the four vents, starting from the sides opposite the wind. Once the fire is well-established, two-liter pots are adapted to the base of the chimney supports for collecting the pyroligneous liquid.

The oven is allowed to burn slowly for thirty minutes to an hour (depending on the moisture content of the wood). During this time, abundant whitish vapor is released from the four openings of the lid (direct draft). The draft will be reduced by placing the chimneys and closing the steam openings. To reinforce the airtightness, clay soil is placed on the covers (tapes) of the steam openings and between the chimneys and their supports. Thus, air can only enter the oven through the admission ducts (vents), and from there it rises through the center of the charge. The combustion gases, drawn by the draft, descend and escape through the chimneys. The air and combustion gases flow in opposite directions: the draft is referred to as "inverted" (**Figures 12-15**).

Figure 12. Start of the inverted draft. The chimneys are installed, and the vents on the windward side are closed to reduce the intake of air [22].

Figure 13. Cooling phase. The chimneys are cleared, and the vents are buried under sand to reinforce the airtightness of the oven [22].

Figure 14. Magnien-type oven [22].

Figure 15. Charcoal produced by a Magnien-type oven [22].

4.4.1. Brick Kilns

When properly constructed and operated, brick kilns are undoubtedly one of the most efficient methods of charcoal production, with several models currently in use around the world, most of which provide good results. Some of these kilns can be adapted for industrial use, such as the Green Mad retort kiln [23]. There are several variations within this category of kilns.

1) Missouri-Type Kilns

This kiln originated in the United States, in the state of Missouri, where it is still in operation. It is generally built from reinforced concrete or concrete blocks with steel chimneys and doors. Some of these kilns are partially buried in the ground (**Figure 16**, **Figure 17**).

Figure 16. Brazilian furnace batteries [23].

Figure 17. Semi-buried brick kiln [23].

4.4.2. Rabo Quente-Type Kilns

This is the most commonly used basic kiln in Brazil for carbonization, accounting for at least 95% of the kilns in operation (Brito José Otávio *et al.*, 2006 [24]). The Rabo Quente-type kiln is built directly on the ground using small red bricks. Depending on the nature of the terrain (in hilly regions), some are either buried or semi-buried (**Figures 18-20**).

Figure 18. Hot tail-type furnaces in operation [24].

Figure 19. Loading of hot tail-type furnaces [24].

Figure 20. Control of kilns gases by transferring the sheet that is on the connection duct with furnace which must be sealed with "barrels" [25].

4.5. The Technology of Continuous Industrial Ovens

The oven consists of six main parts: an external combustion chamber (no. 1 in Figure 2), a connection (pipes) between the combustion chamber and the carbonization chamber (no. 2), a carbonization chamber (between no. 2 and no. 5), a flue gas evacuation channel located beneath the carbonization chamber (no. 3), and finally, two chimneys, the first (no. 4) connected to the flue gas evacuation channel and the second to the carbonization chamber (no. 6). The carbonization chamber and the flue gas channel are separated by a metal plate. These different components are also illustrated in Figure 3. Thermometers measure the gas temperatures at the top and bottom of the carbonization chamber, as well as in the flue gas evacuation chimney from the carbonization chamber.

After loading and sealing the oven, the first step is to ignite a fire in the combustion chamber (no. 1). The hot gases it generates are directed into the channel (no. 3) under the load, towards the flue gas evacuation chimney (no. 4). In this process, the load is heated, and the hot air it contains begins to escape through the other chimney (no. 6), as the entrance of this chimney is located in the carbonization chamber. A flow of air is thus generated in the carbonization chamber: hot air from the combustion chamber (no. 2) enters the carbonization chamber, becomes saturated with water vapor from the wood, and is then evacuated through the chimney connected to the carbonization chamber. This is the drying phase, which lasts from 12 to 36 hours, depending on the initial moisture content of the wood.

During this phase, the temperature does not exceed 100˚C. Once the water has left the wood, its temperature rises to levels that allow carbonization (280˚C and above). The gases emitted during this phase are combustible. When the temperatures in the lower and upper parts of the oven are equal, the flue gas evacuation chimney from the carbonization chamber is closed. The only escape route for the gases is then through the pipes connecting the carbonization chamber and the combustion chamber. Upon entering the combustion chamber, the gases come into contact with the air and ignite violently. This phase lasts 3 to 6 hours and ends with the carbonization. All air access points in the oven are sealed, and the oven is left to cool for 3 to 4 days (**Figure 21**, **Figure 22**).

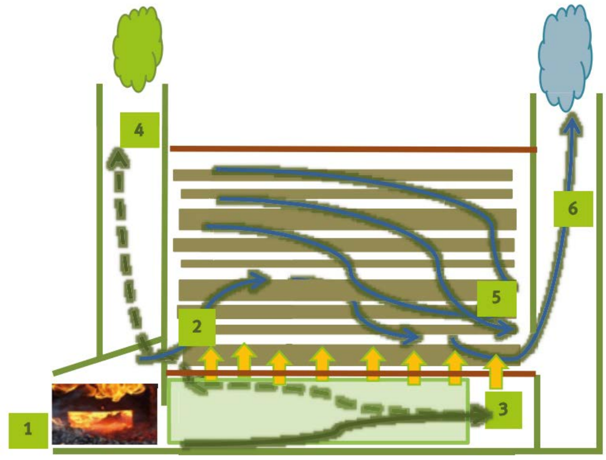

Figure 21. Operation of the industrial oven [26].

Figure 22. Continuous industrial oven [26].

5. Results

Throughout the development, we identified several parameters influencing the yield and quality of charcoal. Some are related to the very essence of the wood and its condition (rotten wood produces low-quality charcoal), while others pertain to the technology used. We will primarily focus on the latter. Tables 1-3 below show the technical characteristics and carbonization details for each of the technologies considered.

Table 1. Various mass yields of technologies.

Technology	Mass Yield %
Traditional kiln	13 - 25
Improved Kiln	21 - 32
Pit	21 - 32
Metal Kiln	21 - 34
Continuous Industrial Oven	25 - 38

Source: based on the literature review adapted from [3].

Table 2. Operating characteristics of technologies.

Technical Characteristics	Technologies				
	Kiln		Pit	Metal Kiln	Continuous Industrial Oven
	Traditional	Improved			
Vents	√	√	√	√	√
Chimney		√		√	√
Construction Material	Sand	Sand	Sand	Metal, Steel	Refractory Brick
Direct Draft	√			√	
Inverted Draft		√	√	√	√
Partial Combustion Carbonization	√	√	√	√	
External Heating Carbonization					√
Hot Gas Contact Carbonization					
Temperature Control				√	√
Air Circulation Control				√	√

Source: Based on the literature review adapted from [3].

Table 3. Technical characteristics of various carbonization technologies.

Operating Characteristics	Technologies				
	Kiln				
	Traditional	Improved	Pit	Metal kiln	Continuous Industrial Oven
Carbonization Temperature	Environ 400˚C	400˚C - 600˚C	400˚C - 600˚C	500˚C - 600˚C	500˚C - 700˚C
Carbonization Time	to “15 Days to 3 Months”	3 to 5 Days	5 to 15 Days	24 to 48 Hours	10 to 24 Hours

Source: Based on the literature review adapted from [3].

6. Discussion

According to the Ministry of Energy through [27], the main challenges of energy management policy in Benin are of three (03) orders: the reduction of energy expenditure; the reduction of energy dependence; and the contribution to the global effort to combat climate change through the reduction of greenhouse gas emissions.

In the biomass energy subsector, wood energy contributes to over 80% of energy needs [27]. The policy for sustainable management of energy resources perfectly aligns with this logic, even though Benin is independent in terms of domestic energy sources like wood energy. One of the objectives of this policy is to use fewer wooden resources to produce more charcoal. This involves implementing environmentally friendly carbonization technologies that yield high mass outputs of good quality charcoal. A state-of-the-art assessment of carbonization technologies indicates five general types of technological variations regarding carbonization in Benin and worldwide. Traditional mounds and pit kilns produce charcoal of variable quality, often contaminated by the cover. With brick and metal kilns, a superior quality charcoal is obtained compared to that from mounds and pits. Continuous industrial kilns are known for producing high-quality charcoal due to the consistency and precision of the carbonization process. With controlled temperatures, they achieve a reasonable rate of volatiles, a low ash content, and therefore a relatively high carbon content. This improves the porosity of the charcoal and allows for a denser and more resilient product. By controlling the duration, it also allows for the production of higher-quality charcoal, minimizing losses and maximizing mass yield while adhering to standards. The Casamance mound, initiated in the city of Casamance in Senegal and tested in various locations across Africa and the world, appears to be the best possible option for addressing the challenges of climate change and sustainable management of wooden resources in developing countries, in the absence of industrial charcoal production technologies. Indeed, these environmentally friendly and high-performance industrial technologies are relatively costly given the level of development of the carbonization sector in developing countries in general and in Benin in particular, or at least due to the undervaluation of the charcoal value chain in these countries. However, while the charcoal produced by Casamance mounds is suitable for domestic use, its quality remains variable and often contaminated by the cover, similar to traditional mounds and pits. Continued research is necessary to optimize charcoal quality alongside process yield. When discussing quality improvement, we think of kiln technologies, as they offer non-contaminating covers in addition to their multiple advantages. Among the two technological variations of carbonization kilns, brick kilns are most suitable for the context of carbonization in developing countries from an economic perspective, even though they are fixed and their use may incur wood transportation costs. Moreover, they can achieve yields of up to 30% (energypedia.info) and are suitable for semi-industrial charcoal production. The main drawback related to the operation of brick kilns is the lack of control over the process. On one hand, the draft is uncontrolled, and on the other hand, the pyroligneous liquids are unrecoverable. This situation leads to significant pollution due to greenhouse gas emissions and affects process yield and the quality of the produced charcoal. Furthermore, it is possible to counter these shortcomings through appropriate technological improvements to these brick kilns. Indeed, the installation of chimneys and vents on a brick kiln could enable the recovery of pyroligneous liquid and control the process through reverse draft. These improvements made to a brick kiln would result in a new type of technology that we will call the "High-Energy Performance Hybrid Mound" (MH-HPE). This technology will be the subject of study in our future work.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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