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RESEARCH ARTICLE

From Residues to Revenues: Unlocking the Value Chain of Green Charcoal in Uganda

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Abstract

In Uganda, green charcoal – briquettes made of carbonized biochar from agricultural residues – has the potential to replace wood charcoal. This can contribute to halting deforestation and reducing national carbon emissions. Yet, the acceptance of green charcoal by consumers is very slow. In this article, using Michael Porter's value chain model, we present a comprehensive and holistic model describing the conditions for successful production and marketing of briquettes by private businesses. Based primarily on observations of production and interviews conducted with Ugandan enterprises producing green charcoal, green finance organizations, green charcoal consumers, and wood charcoal producers, we describe barriers impeding access to capital, the production of a competitive product, and the marketing of green charcoal briquettes. Since one barrier has an impact on the entire production and marketing chain, we argue that all aspects of the green charcoal enterprise must work simultaneously to successfully compete with wood charcoal. Financial institutions and governmental policies must also support the green charcoal value chain.

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Green charcoal, Briquettes, Cooking fuel, Sustainable energy, Value chain, Uganda.

Introduction

Sub-Saharan Africa is characterized by some of the highest levels of poverty and population growth in the world (World Bank 2024). Moreover, 80% of people living in sub-Saharan Africa rely on wood as a daily source of cooking fuel (Iiyama et al. 2014), which is cheaper and more accessible than other forms of fuel such as electricity, petrol, or LPG (Liquified Petroleum Gas). Due to energy poverty, most Ugandans cannot afford cleaner sources of cooking fuels (Ssennono et al. 2021). Firewood is preferred in rural areas, because it is the most easily accessible and the cheapest form of cooking energy for large families, while wood charcoal is preferred in urban areas because of its higher energy density (providing savings on transport) and lower smoke emissions. 21% of Ugandan households rely on wood charcoal as their main source of cooking fuel (UBOS 2021), and, in 2023, the demand for wood charcoal in Uganda was estimated to be 2.3 million tons per year (FAO 2023). This high reliance on wood as cooking fuel, combined with high population growth and increasing rates of logging, lead to rapid deforestation and loss of biodiversity (Nabukalu and Gieré 2019; Nalule 2021), which, at the same time, threaten the livelihood of most of the population depending on wood as cooking fuel.

To mitigate these problems, the Ugandan government and international donors have tried for decades to introduce several solutions as alternatives to wood charcoal – and to fossil fuel. Since the 1980s, solar cookers have been promoted in sub-Saharan Africa. Sun is abundant and free, and solar cookers sound like a wonderful solution – at least on paper. But although they have enjoyed uptake in a few pilot projects in refugee camps, solar cookers remain widely unknown and unused in sub-Saharan Africa. The blame has been mainly placed on the high cost of solar cookers, the slow cooking process, the small volume of food processed, and a mismatch between traditional time slots used for cooking and sunlight time (Krämer 2010; Mosses, Makundi, and Hamza 2023; Troconis 2017). In the 2000s, biogas (produced from agricultural waste and animal dejections) has been promoted as another alternative to firewood and wood charcoal by international organizations such as the African Biogas Partnership Program – ABPP (Clemens et al. 2018). Yet, biogas digesters remain so far relatively rare and confined mainly to a few school institutions, and they are out of financial reach for most Ugandan households. Those that have been adopted have been financed at a high cost by donors, and a large proportion of these digesters have fallen in

disrepair just a few years later (Hewitt et al. 2022; Mabecua et al. 2024; Mwirigi et al. 2014). Bioethanol is a third source of green energy that has been recently promoted as alternative to wood charcoal. Because it is industrially produced in large plants and because it requires the acquisition of gas plate and pressure cooker, bioethanol competes more with electricity and gas as cooking fuel, and it suffers from the same barriers, mainly a high entry cost, which discourage many people in sub-Saharan Africa from accessing this technology (Johnson and Matsika 2006; Osiolo, Warwah, and Leach 2023).

Most recently (less than 20 years ago), green charcoal has been introduced and has increasingly been presented as the best alternative to wood charcoal. Green charcoal refers to briquettes made with biochar from agricultural residues (biomass) carbonized through the pyrolysis technique, which is the same method of thermal decomposition of materials at elevated temperatures and limited oxygen intake that is used for wood charcoal. Green charcoal briquettes are the closest substitute for wood charcoal since it has comparable black color, consistency, and calorific values (Akolgo et al. 2021; FAO 2018; Njenga et al. 2013; Tumutegyereize et al. 2016). In Europe, green charcoal briquettes have widely replaced wood charcoal as cooking fuels for barbecues, for example, and the question is whether the same replacement can take place in sub-Saharan Africa. Briquettes burn longer than wood charcoal and emit less smoke, which makes them healthier. For all these reasons, green charcoal is widely presented in the recent literature as the main realistic alternative to wood charcoal (for instance, Ferguson 2012; Mahoro et al. 2017; Mugabi and Kisakye 2021; Ngusale, Luo, and Kiplagat 2014; Njenga et al. 2013; 2014; Tumusiime 2021).

Because of its potential to replace up to 50% of the current wood charcoal consumption (Ferguson 2012; MEMD 2016), government agencies, international donors, non-governmental organizations (NGOs), and faith-based organizations (FBOs) have trained tens of thousands of members of local communities in briquettes making and have provided hundreds (if not thousands) of self-help groups throughout sub-Saharan Africa with sets of machines to produce briquettes. Yet, despite these efforts, and despite the considerable amount of time and money invested by national agencies and international donors, the uptake of green charcoal as a source of cooking fuel remains very slow. This lack of successful uptake has been emphasized by several authors, who have noted, for example, that "In spite of the advantages of briquettes, their uptake as a substitute for firewood and charcoal […] remains limited" (Gebrezgabher, Amewu, and Njenga 2018: 26), and that "briquettes do not seem to be as popular as would be expected" (Mugabi and Kisakye 2021: 1). It has also been asked: "Why have briquettes failed to take off despite the potential to displace charcoal?" (Wagabaza 2023).

On this basis, the key purpose of our research has been to understand the reasons behind the slow uptake of green charcoal, taking Uganda as our focal point. We argue that the failure of green charcoal is largely due to a lack of understanding of the green charcoal value chain. While several authors have identified some of the factors explaining this failure, it is striking that they focus on a limited number of issues, such as price (Mainimo et al. 2022; Mukwaya 2016), the point of view of consumer preferences (Gebrezgabher, Amewu, and Njenga 2018), briquettes qualities and complications during the production process (Mugabi and Kisakye 2021), or issues of marketing and policies (Elasu et al. 2023; Wagabaza 2023). Our contribution to this debate is the argument that any piecemeal understanding of the problem is not sufficient to secure the successful uptake of green charcoal. We argue instead that *all* aspects of the green charcoal value chain must be understood holistically, and *all* of them must be under control, if briquettes are to compete successfully with wood charcoal. In other words, any disruption or gap in the green charcoal value chain can lead to failure in uptake.

Theoretical Framework: Porter's Value Chain Model

This article studies the conditions for the successful uptake of green charcoal, with success being understood in terms of green charcoal becoming a mainstream product, widely available and widely used, instead of being a product for a niche market. Our theoretical framework is inspired by Michael Porter's (1985) work on competitive advantage and value chain, illustrated in Figure 1.

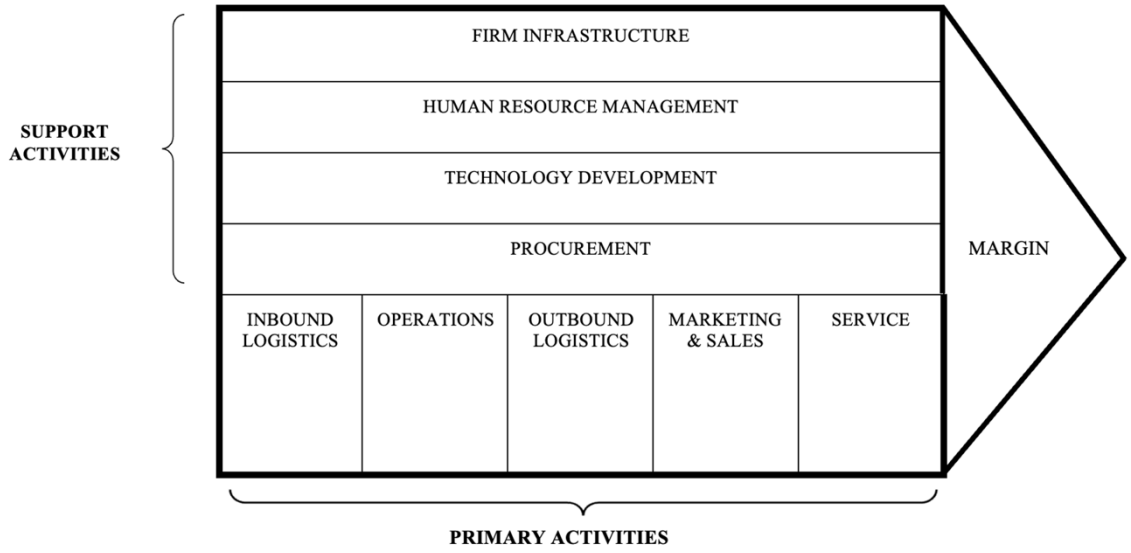

Figure 1: Michael Porter's value chain model.

According to Porter, the competitiveness of a product depends on five primary activities:

- Inbound logistics: acquiring and storing raw materials.
- Operations: all activities transforming raw materials into finished products.
- Outbounds logistics: distributing the finished products to customers.
- Marketing and sales: advertising, promoting products, persuading customers to purchase products.
- Service: after-sales services enhancing or maintaining the value of the product after it is sold.

It also depends on four kinds of support activities:

- Firm infrastructure: the support services (legal, accounting, etc.) enabling daily and core operations.
- Human resources management: the management of the labor force in terms of recruitment, training, salary, etc.
- Technology development: the knowledge needed to innovate and improve the products or technology.
- Procurement: the acquisition of resources needed, including raw materials, equipment, and services.

Porter's model is primarily focusing on firms/producers and conceptualizes the value chain from their point of view. We adopt the same focus in this article, and the customers' perspective is only discussed through the lenses of the green charcoal producers, focusing on what producers know about the needs and satisfaction of the customers purchasing their briquettes. Our study, however, also brings some adaptation to Porter's model.

First, Porter's framework is mainly developed to account for formal western enterprises. In our study, we only identified three enterprises registered as formal businesses and paying taxes, and only five semi-formal enterprises (that have a license to trade, but no more). The rest were informal self-help groups and self-employed individuals. Since Porter's model applies primarily to formal businesses, not all points stressed by Porter's model are relevant when understanding the value chain of green charcoal.

Second, Porter's model describes the competitive advantage of firms, while we discuss the competitive advantage of green charcoal over wood charcoal – and only by extension the competitive advantage of green charcoal producers over wood charcoal producers. Today, the production of briquettes is so small and so localized, and transport is such a barrier that briquettes producers do not compete with one another.

Instead, the competition is between green charcoal and other sources of cooking fuel – mainly wood charcoal and firewood. One does find alternative sources of cooking fuel, mainly electricity, ethanol, or biogas, but these options are more costly and circumscribed to the middle-class (Elasu et al. 2025; Katutsi et al. 2024; Mukisa et al. 2023; Price 2017).

Third, Porter's model has been criticized for neglecting the political context or other external factors that can have an important impact on competitive advantage (Bejleri, Kraja, and Memaj 2024; Narayanan and Fahey 2005; Van den Bosch and De Man 1994). We will, therefore, supplement his framework with a specific focus on two external actors that play an important role in the successful uptake of green charcoal (or lack thereof); namely, policy makers and the financial sector.

Research Methods: Exploring Green Charcoal in Uganda

Our study is part of the UPCHAIN research project (Unlocking the Potential of Green Charcoal in Northern Uganda), conducted in a collaboration between Gulu University and the University of Copenhagen. The project is focusing on the marketability of green charcoal seen from the perspective of producers. It is based on an approach combining semi-structured interviews, ethnographic fieldwork, and participant observation from March 2023 until July 2024.

Since green charcoal production remains rare in Uganda, we adopted a snowball sampling strategy to identify briquettes producers, taking as point of departure the CREEC network (Center of Research in Energy and Energy Conservation) from Makerere University and the list of the Clean Cooking Alliance. We then used the network of these contacts to reach as many formal and semi-formal Ugandan enterprises as we could find within the Northern, Eastern, and Central regions (eight in total). We also identified all the self-help groups we could find producing green charcoal in the Acholi Sub-region in the North (10 groups in total). Finally, we interviewed seven self-employed individuals producing briquettes at home – one who was self-taught and six who had been trained as part of self-help groups that had collapsed, and who were continuing to produce green charcoal on an individual basis. In this article, our focus on formal and semi-formal producers is explained by the fact that they are the ones producing significant amounts of briquettes on a regular basis, while self-help groups are often at a standstill (with some rare exceptions), and individual producers operate irregularly at a very small and local scale.

Semi-structured interviews were conducted with all selected producers to elicit data on the production process, the business model, and the value chain. The interviews were voice recorded, and interviews in English were transcribed with the help of the Buzz program, while

others were transcribed manually. We observed and took photographs of techniques and processes of actual briquettes production in six formal and semi-formal enterprises, in six self-help groups, and with one self-employed individual (see Table 1). Moreover, we bought samples everywhere (10-50 kg) to test the product quality at home. Additionally, we interviewed four green finance organizations, two improved stove producers, two wood charcoal producers, and two staff members from the Uganda National Forestry Authority (NFA) and from the Ministry of Water and Environment (MWE). Finally, we conducted a marketing experiment at St. Peter and Cerelenu markets to try to connect two local briquettes producers with two local wood charcoal vendors and ascertain if green charcoal displayed alongside wood charcoal would be marketable (see more under "Outbound Logistics Supplying Customers" below).

Validity was secured by providing informants with the descriptions of their enterprise and asking them to validate the results by giving them the opportunity to correct any mistake or misunderstanding in the process. More generally, our findings are also validated by being in line with the description of green charcoal production in the existing literature. We enrich this literature with a description of the different entrepreneurial models and with a holistic model of the value chain, pointing to the importance of controlling and aligning all factors if one wants to speed up the uptake of briquettes. One limitation of our sampling (due to limited time and resources) is that we did not try to find formal or semi-formal enterprises in the Western region, and that we limited the study of informal producers to the Acholi sub-region. We nevertheless think that our results are generalizable because the relevant differences observed in the field pertain to the type of business rather than the location of business.

Our analytical approach to observations and interviews was inductive and based on identifying cross-cutting themes that impact the green charcoal value chain. We carried out content analysis in order to generate themes from the transcribed data. The "Voyant tools" program was used to help us visualize salient areas of analysis. As first author, Awacorach conducted research over 15 months (from March 2023 to July 2024). She developed the research protocol, the questionnaire, the interview guides, the sampling strategy, and the marketing experiment. In addition, she conducted ethnographic fieldwork with participant observation in briquettes production in all semi-formal production sites. She also conducted all semi-structured interviews, the focus group discussion, and collected all questionnaire data. As second author, Gausset accompanied Awacorach during two fieldworks of two weeks each (in March and August 2023), provided support for the design of the research, and participated in the data analysis. As third author, Olido guided in the analysis of the data.

Name of Enterprise (location, region)	**Category**	**Production observed**
Bio-Energy (Mukono, Central)	Formal enterprise	Yes
Green Charcoal Uganda (Tororo, East)	Formal enterprise	Yes
Josa Green (Wakiso, Central)	Formal enterprise	Yes
Appropriate Energy Saving Technologies (Soroti, East)	Semi-formal enterprise	Yes
Masupa (Wakiso, Central)	Semi-formal enterprise	Yes
AAA (Kampala, Central)	Semi-formal enterprise	No
SH Energy (Kampala, Central)	Semi-formal enterprise	No
Kibinge (Masaka, Central)	Semi-formal enterprise	Yes
Akwo ki lweta (Gulu, North)	Self-help group	Yes
Ribe ber (Gulu, North)	Self-help group	No (stopped producing)
Bungatira briquette group (Gulu, North)	Self-help group	Yes
Kulu keno community briquette (Gulu, North)	Self-help group	Yes
One Energy saving (Lamwo, North)	Self-help group	No (stopped producing)
Briquette 3 making subproject (Lamwo, North)	Self-help group	No (stopped producing)
Anyim pe nen (Amuru, North)	Self-help group	Yes
Can deg ming (Amuru, North)	Self-help group	Yes
Kal B briquette group (Amuru, North)	Self-help group	Yes
Kitgum cluster briquettes (Kitgum, North)	Self-help group	No (stopped producing)
Seven individual producers	Self-employed individuals	Yes (1/7) and no (6/7)
Total production units: 25		

Table 1: Overview of briquettes producers sampled in the research.

Ethical clearance was sought from Gulu University Research Ethics Committee (GUREC-2024-827) and the Uganda National Council for Science and Technology (UNCST-SS2993ES). The study background and objectives were explained to the respondents and only those willing to participate were considered. Written consent was obtained before each interview, and oral consent was obtained before audio recording or taking photographs.

Support Activities: Three Different Models

We now use Porter's value chain model to organize the results of our research, starting with the different forms of firm infrastructures and support activities, and continuing with a description of the primary activities involved in making and selling briquettes.

During our research, we encountered three different clusters of entrepreneurial models that are characterized by different access to capital and different levels of formality. The first model consists of *self-employed individuals* who produce balls of green charcoal manually and dry it in their courtyard before selling it to their neighbors. The natural, financial, physical, and human capital in this entrepreneurial model is minimal, although the production process can be time-consuming. Self-employed individuals buy a bag of charcoal fines (a cheap waste product of wood charcoal, also called charcoal dust) for two or three US dollars, bind the fines with local clay soil, and dry the briquettes at home. Doing this requires minimal skills and training. All the self-employed individuals we met are women who run an informal business and sell their briquettes in their neighborhood.

The second model encompasses *self-help groups* consisting of people recruited from local communities who are trained by NGOs, faith-based organizations, or local governments to have a source of income and contribute to the welfare of their community. The training usually focuses on teaching participants how to make briquettes, but it can also sometimes include basic commercial skills. Many groups choose to produce green charcoal exclusively with charcoal fines crushed into powder, although some groups blend it with carbonized agricultural residues. NGO/donor organizations donate in-kind low-quality, manually powered machines, which can be problematic when the elderly cannot contribute the hard labor required. These self-help groups generally have very low levels of support activities, and they experience low production and low sales. They rarely plan ahead to allocate money to repair machines or replenish raw materials. They also experience conflicts and other group problems. Consequently, many self-help groups stop their production within a few months of starting up, and others have a low and irregular production.

The third model comprises *semi-formal or formal private businesses* which usually start with two or three close friends or family members who invest their savings and time in the green charcoal business to make a profit and to have a good return on investment. The initial financial capital for this type of production comes from equity or small loans. Later, the most successful of these businesses access start-up grants or soft/patient loans or donations, primarily from international donors, which allow them to buy bigger machines and to step up production. All the machines used are powered by diesel, petrol, or electricity. Most business owners have university degrees and have good connections with international NGOs or international donors and other business communities in the same field. The smaller businesses have less than five employees and the larger ones up to 20 employees. Most of the smaller semi-formal businesses use charcoal fines as the main source of biochar, but some complement charcoal dust with 50-60% biochar from agricultural residues. We know of only one formal producer who uses 100% biochar from agricultural waste. Production in private businesses is regular (between a few tons per week for the smaller sites to a few tons per day for the bigger sites) and is profitable.

When comparing the three firm infrastructures described above, our research shows that self-employed individuals have a profitable business, but their production is made at a very low scale. Self-help groups (at least those we have met in Uganda) face many internal conflicts, have an erratic production, and do not sell their briquettes on the market. In fact, they seem mainly to produce to satisfy donors' demand. Only private semi-formal and formal businesses are successful in producing briquettes on a regular basis and on a large scale to compete with other sources of cooking fuel. Our research suggests, therefore, that the future of green charcoal lies in the development of small and medium-sized private businesses owned by entrepreneurs working and innovating to improve efficiency. We now turn to the description of primary activities.

Inbound Logistics

Briquettes are made with biochar created by carbonizing farm residues through pyrolysis in kilns (also called carbonizers). Any agricultural waste can be used, and some of the most common sources are groundnut shells, coffee husks, rice husks, maize cobs, and palm kernels. Accessing enough agricultural residue and carbonizing it is a real challenge and can be a strong bottleneck that limits production (see also Njenga et al. 2014). Raw materials are spread in the landscape, which complicates its collection and transportation. Moreover, in Uganda, most carbonizers are empty oil barrels that have a chimney and are pierced with small holes to control the oxygen level. A carbonizing drum takes approximately six

hours to carbonize 50 kg of agricultural residues (Ferguson 2012). When several tons of biochar are required every day, the limited capacity of carbonizing drums poses a big challenge.

Private businesses have different strategies to solve this problem. Some distribute dozens of carbonizing drums in neighboring farming communities and buy biochar from villagers (200 UGX/kg) or barter biochar for finished briquettes. Others place milling machines (that separate grains from husk or make flour) in neighboring communities and provide milling services at an advantageous price in exchange for the right to keep the agricultural residues for carbonizing. This also allows for the transportation of larger quantities of waste, and is also a strategy to compete with other industries interested in crop residues.

A very common and widespread strategy is to replace biochar made from agricultural waste with wood charcoal fines (the pieces of wood charcoal that are too small to be commercialized as cooking fuel). Most producers in Uganda blend biochar from agricultural residue with at least 40% of wood charcoal residues. This allows them to make important savings in labor, a factor that accounts for up to 30% of the cost of green charcoal (Bot et al. 2022). However, this strategy is untenable if green charcoal is to be promoted as a more sustainable alternative to wood charcoal. Producing briquettes that are 100% made from agricultural residues will require that all producers create a network of rural collaborators that can provide them either with agriculture residues or with biochar made from such residues. This will ensure that the poorest communities also get their share of profit in the value chain.

When compared to wood charcoal, the inbound logistics of green charcoal is heavier and more complicated. The raw material for green charcoal is decentralized in households or spread out in the landscape, while raw material for wood charcoal is concentrated in one forested place. No more than 50kg of agricultural waste can be carbonized at a time in metallic drums to make green biochar, while an earth kiln can carbonize 10 to 20 times that amount of wood. Carbonizing biochar is only the first step in producing briquettes, while carbonized wood is the end product in wood charcoal. For these reasons, inbound logistics confers a competitive edge to wood charcoal.

Operations

Making green charcoal requires five different stages (Donald et al. 2022; Ferguson 2012). First, as described above, biochar is produced by carbonizing farm residues through pyrolysis in carbonizers. Second, the carbonized biochar is crushed with a crushing machine to make biochar powder (self-employed individuals jump over this step by using uncrushed charcoal residues when molding their briquettes by hand). Third, the biochar is mixed with a binder such as clay, cooked cassava

flour, or molasses. Cooking cassava flour requires extra labor and suffers from market price fluctuations according to season. Fourth, the biochar mass is pressed/molded in briquettes that can have different shapes, the most common being stick, honeycomb, and mussel shell shapes. Fifth, the molded briquettes are dried, either directly in the sun or on shelves in a quasi-greenhouse built for this purpose. During the second, third, and fourth steps, self-help groups use machines (crushers, binders, extruders) that are operated manually and require heavy labor, while private businesses use electric or diesel engines.

Keeping prices competitive requires a high level of innovation in green charcoal production. Since green charcoal is still a developing technology, all the private businesses we met are constantly trying to upgrade and improve their machines, which are key to efficient and low cost of production. But such improvements also increase maintenance costs as the machines (crushers, binders, molders, extruders) are upgraded. Interestingly, an increasing number of machines are now made in Uganda, which simplifies acquisition and maintenance and cuts down related costs. Private businesses make experiments to improve the quality of their carbonizing drums, which can greatly increase the efficiency of pyrolysis. They also experiment to improve the ingredients in the briquettes (the source of biochar, carbon content, and binder), the dryers, the level of ash content, and so on. While the technology used to produce wood charcoal is rather static and has not changed much in the past decades, the technology used in green charcoal production is constantly improving in order to maximize both the efficiency of production and the profit.

As can be seen, producing briquettes requires several operative stages. Attaining a significant level of production requires electric or diesel engines that are expensive and require maintenance. By contrast, producing wood charcoal requires only a chainsaw and much less labor, which makes operation costs to produce wood charcoal much cheaper than for green charcoal.

Outbound Logistics Supplying Customers

Most green charcoal is either bought on site from the producer, which saves on transport and facilitates promotion by word of mouth, or it is ordered directly (through a WhatsApp platform) from the producer, who delivers the order with the customer paying the delivery cost. Some of the larger producers have shops in different towns to promote their sales. Some producers also sell their products in weekly local markets in their communities. The biggest and best organized producers can make agreements with supermarkets interested in selling their product, but this requires that green charcoal is packed in paper bags with clear labels. The price in supermarkets is higher than if green charcoal were bought

directly from the producer because of the cost of packaging and labelling and the profit margin added by the supermarket, but supermarket customers have a higher purchasing power than average and seem to be willing to pay a higher price.

From this point of view, the outbound logistics of green charcoal is much less developed than that of wood charcoal, which is sold practically everywhere, both in towns and in villages, and both in 50kg bags and in retail. Some private middlemen have been experimenting with bulk purchasing of green charcoal from the producer and reselling it in smaller quantities with an added profit margin, but these market chains were interrupted by the Covid pandemic. As part of our research, we experimented with trials of green charcoal to initiate such a market chain in Gulu by connecting two local briquettes producers with two local wood charcoal vendors. We asked the vendors to sell green charcoal alongside wood charcoal, and we provided the first bags of green charcoal for free. We then asked the vendors to order new bags of green charcoal directly from the producers after they had subtracted their profit margin. The result of this experiment was that the vendors could sell green charcoal in small retail with profit. They sold 1kg at a time below the price of wood charcoal, and the customers were interested in buying this product, although they complained about the high ash content. The vendors sent new orders to the producers, but the business connection halted due to issues of transport (which is not as organized as for wood charcoal) and storage (green charcoal needs a very dry space for storage since it can dissolve if left in a dump place, unlike wood charcoal).

It should be noted that the price of green charcoal produced in rural areas and small trading centers is often more expensive than the price of wood charcoal. At the time of our research in Pabbo trading center, for example, a bag of 50 kg of wood charcoal produced locally could be bought for 20,000 UGX, while a bag of 50 kg green charcoal sold for 30,000 UGX (50% more expensive than wood charcoal). To sell at a competitive price, producers must produce briquettes in town (where wood charcoal is much more expensive than purchased on production sites in the countryside) and must sell directly to customers, to avoid middlemen who capture the greatest share of benefit in the wood charcoal value chain (see also Shively et al. 2010).

In conclusion, even though there are an interest and a market for green charcoal, outbound logistics remains underdeveloped and at a disadvantage compared to wood charcoal. Today, most customers purchase green charcoal on production sites, and there is a need to develop outbound logistics if green charcoal is to compete more widely with wood charcoal.

Marketing

Green charcoal is still largely unknown to the general population, who are so inclined to wood charcoal. When considering buying green charcoal, consumers automatically compare its qualities and price to wood charcoal and firewood. Producers and vendors are well aware of this and develop their marketing arguments in comparison to wood charcoal. As a producer explained:

> We believe in three things when we say that our briquettes are better than wood charcoal. First, we say they are cheaper so as to encourage people to adopt them, because it is a new product. Second, we want people to get used to it, because they are smoke free since they are dry. You do not see any smoke unless at the stage when you are lighting them. And third, briquettes burn longer. If you put the briquettes once in the cook stove, the dry beans will get ready, while, with the wood charcoal, you have to put it like three times before the beans can get ready. So, those are the three things we use in our marketing language when we are passing our messages.

This quote shows that green charcoal is competing intensely with wood charcoal. To be successful in gaining new consumers and replacing wood charcoal, the quality and price of green charcoal must match or outcompete those of wood charcoal (even though some customers also appreciate the fact that it is made out of agricultural residues and is protecting the environment).

The first key factor is quality, which is a question of calorific content, cleanliness/health, and burning time (which is influenced by shape). The calorific content of green charcoal usually matches that of wood charcoal, depending on the type of wood used in wood charcoal and the kind of biochar used in green charcoal. To secure a high calorific content, most producers mix carbonized biochar with charcoal fines crushed into powder, a waste product from wood charcoal production. Some private businesses also buy oil palm kernels, because they are carbon- and energy-rich. Charcoal fines are still a cheap and widely available resource, because wood charcoal production is still widespread, but, with time, as tree resources get exhausted, wood charcoal production will decline, and we can expect a greater reliance on biochar from agricultural residues to produce green charcoal.

Another important argument for the higher quality of green charcoal is that it emits less smoke than wood charcoal, although this depends on the kind of binder used. It is also cleaner than wood charcoal, leaving fewer black traces on fingers and clothes. Burning firewood and wood charcoal in kitchens is a serious health issue, as it creates air pollution that is causing millions of premature deaths due to pulmonary diseases and lung cancer (Florkowski and Neupane 2023; Odame and

Amoah 2023). In comparison, different studies show that burning green charcoal emits significantly less smoke than wood charcoal (Mugabi and Kisakye 2021; Shao et al. 2016).

Yet another aspect of quality is burning time and efficiency in burning. A study by Gloria Mahoro et al. (2017) compares the performance of wood charcoal and green charcoal using a modified water boiling test (MWBT) and a controlled cooking test (CCT) for beans. The result of the boiling test shows that green charcoal boils water in 11-13 minutes and uses between 180 and 231 grams of briquettes (depending on their ingredients), while wood charcoal boils the same amount of water in 16.5 minutes and uses 392 grams of wood charcoal. The result of the cooking test shows that green charcoal cooks beans in between two hours 48 minutes and three hours and six minutes and uses between 421 and 460 grams (depending on the type of briquette), while wood charcoal does the same in two hours and 22 minutes using 1560 grams of wood charcoal.

These results show two things. First, green charcoal performs better than wood charcoal per weight. For the same weight, green charcoal burns longer, which means that one uses between 41% and 73% less green charcoal to do the same job as wood charcoal. Second, green charcoal boils water faster, but cooks beans more slowly than wood charcoal. In terms of time saved, green charcoal performs better for short cooking times than for longer cooking times. Additionally, green charcoal emits less smoke and requires less attention for longer cooking or heating, since one does not need to refuel the stove as frequently as for wood charcoal.

The second key factor determining the choice of fuel is price. To be competitive, the producers of green charcoal in urban areas adapt their price to either match the price of wood charcoal or sell green charcoal slightly cheaper. Since the price per weight of green charcoal in urban areas is lower than the price per weight of wood charcoal, and since 1kg of green charcoal burns longer than 1kg of wood charcoal, green charcoal is more economical than wood charcoal. Moreover, a significant proportion of the wood charcoal bought in bags (up to 20% of the total) is usually made of small pieces of wood charcoal fines that cannot be directly used in cooking, which further increases the real cost of wood charcoal. But this is not always something that consumers realize because, when comparing green and wood charcoal, consumers see that, for the same price, they get a much bigger volume of wood charcoal than they do of green charcoal (green charcoal has a higher density than wood charcoal, which may constitute a psychological barrier).

Giving free samples is commonly practiced by most producers for all types of green charcoal. Small customers at the household level who seem to be interested in green charcoal but are hesitant can be given 1kg

of stick- or small honeycomb-shaped green charcoal to try in their kitchen at home. Larger customers such as poultry farmers might be given 5-10kgs of large honeycomb-shaped green charcoal to test on their farm. This strategy is apparently a very successful method to make the green charcoal better known and to attract new customers.

In conclusion, green charcoal remains largely unknown, and there is a need for investing heavily in marketing. When comparing their product with wood charcoal, producers talk about a higher efficiency of briquettes, a longer burning time, less smoke, and a cheaper price. At this stage, general consumers show curiosity and interest but need to adapt to the characteristics of the new product in terms of time required in lighting, getting acquainted with the burning qualities, and in storage requirements.

Customer Service

Green charcoal is not exactly the same product as black charcoal. It is more difficult to light, it cannot be extinguished and reused at a later stage (as is the case with wood charcoal), it dissolves when exposed to humidity and needs to be stored in a dry place, and it has a high calorific intensity that require heavier pans and well-aerated stoves for cooking. Its burning qualities differ from wood charcoal, which has a direct impact on how food is cooked and, therefore, also on food taste. It follows, then, that the adoption of green charcoal requires some adaptation in how to cook and appreciate food (Sarick-Whiteside 2025).

The larger producers all engage in customer care. They explain to their customers how to store green charcoal and light it, how to position it in the cook stove, and so on. They might have to repeat this information from time to time, as new maids in a household, for instance, may not have any experience with green charcoal lighting and use. As one producer told us:

> It is important that you put up a whole service of customer care. Let me give you an example. Middle income earners who buy two bags per month, have maids, and they change maids on a monthly basis or every three months. Few of them have maintained maids for a longer time. That means it doesn't matter whether this middle-income earner has appreciated our briquette products and whether they know the benefits that come from them. If we don't train their maids all the time, they will not use the briquettes properly.

Producers sometimes call their customers by phone to ask for feedback and to hear if they are satisfied with the product. Customers are also given the producer's phone number or at least the number of the person in charge of customer care, so that they can call if they have any question

or problem regarding the product. However, while customer care is an important part of the successful uptake of briquettes, it is also costly in time and resources, which impedes its competitiveness as compared to wood charcoal.

External Factors: Enriching Porter's Value Chain Model

Porter's value chain model has been criticized for lacking sensitivity to the external factors impacting competitiveness (Bejleri, Kraja, and Memaj 2024, Narayanan and Fahey 2005; Van den Bosch and De Man 1994). In the case of green charcoal in Uganda, our research shows that two aspects play a prominent role as external factors: access to finance and policy making relating to taxation.

Access to Finance

Medium-size producers use machines powered by diesel, petrol, or electricity, which require a substantial capital investment. The storage of raw material, briquettes machines, and drying shelves demand space, which requires capital to buy titled land and construct buildings. Packaging, commercialization, and customer care are also costly and require capital. Without access to financial capital, it is difficult to start a green charcoal business and renewable energy uptake or scale it up.

Accessing capital is problematic for green charcoal producers for several reasons. First, loans are difficult to access for the producers, which makes the cost of capital a glaring, seemingly impossible challenge. All formal and semi-formal firms stated that they had difficulties in accessing loans from financial institutions, because these do not perceive briquette-making machines or the briquette business in general as important assets in valuing the portfolio of enterprises.

The interest on loans can also be very high. One of the producers we interviewed took out a loan in 2024 with his land title at an annual interest rate of 18%, which is significantly higher than the interest rate provided to farmers (8-12% annually). Our research shows that *all* the green charcoal producers (whether formal, semi-formal, or informal) have benefitted from prizes, accelerator programs, seed money, startup grants, and free capacity building training from donors or local governments. One producer gives an example of this:

> With us, we had about 13,000,000 UGX in savings, and we bought a small piece of land. We got a loan from Renewable Energy Business Incubator (REBI). We were trying to scale up our markets in schools, so we started that one. Then, in the same year, we got funding from a United Nations Capital Development Fund (UNCDF) because they had seen what we could do. This year, we

got a green financing loan from Uganda Green Enterprise Finance Accelerator (UGEFA).

These types of alternative financing require knowledge, skills, and networks. The producers who succeed in getting alternative types of financing not only have university degrees, but usually also good connections to development NGOs or international donors, whom they know from earlier employment.

Finance constitutes a major barrier to the scaling up of green charcoal production. None of the formal and semi-formal businesses we visited during our study would be operating today if they had not been able to find non-traditional (alternative) sources of financing: grants, prizes, donations, soft loans, patient loans, and equity from their own savings.

Government Policy

Governmental policies have a strong influence on the operations of formal and semi-formal enterprises through the governmental regulation of private businesses. The Ugandan government also influences the choice of energy in households (Ocen et al. 2024). Government policies are, therefore, crucial for the production and successful uptake of green charcoal.

The 2023 Energy Policy for Uganda states that "The Government shall promote sustainable biomass energy production and utilisation across all sectors" (MEMD 2023: 37). Yet, the word "briquette" is only mentioned twice in passing, without getting the attention that it deserves as an alternative source of cooking fuel.

More importantly, a two-week ban on selling wood charcoal in 2006 led to sharp price increases that lasted for years (Nabukalu and Gieré 2020). More recently, a Presidential decree signed in August 2023 banned the transport of more than eight bags of wood charcoal on the same vehicle. This led to a doubling of the price of wood charcoal in Kampala from 1000 UGX to 2000 UGX per kilo. The price of green charcoal did not increase simultaneously, and all the green charcoal producers we interviewed reported a sharp increase in interest for their product in the aftermath of the 2023 decree. Yet, because the government did not ensure any realistic alternative to wood charcoal, and because green charcoal producers do not yet have the capacity to increase production, the decree ended up increasing the cost of wood charcoal without reducing its demand, to the detriment of the poorest households.

Another governmental aspect that has a strong impact on green charcoal is taxation. Currently, wood charcoal burners are expected to acquire a license from the local National Forestry administration, which costs between 500,000 and 1,200,000 UGX, depending on the nature of

the forest. Moreover, middlemen transporting wood charcoal from the production site to consumers must pay a transport tax to the local government at the district level. For transport on a motorbike, this tax costs 2000 UGX per bag. For transport in a larger truck, the tax is between 200,000 and 1,500,000 UGX per truck, depending on the size of the vehicle. This tax calculation normally varies from one district to another. As the production of green charcoal remains marginal and is primarily located in towns, green charcoal avoids this kind of taxation.

But the larger and more formal enterprises producing green charcoal do not escape paying taxes, including an 18% value added tax (VAT) and tax on profit. Wood charcoal, on the other hand, is an informal business and avoids such taxation (except on transport, as described above), which gives it a competitive advantage in the marketplace. In the words of a producer from a formal enterprise:

> Producing briquettes in Uganda is tough because your first competitor is wood charcoal. Wood charcoal is not regulated, but if you have our kind of green charcoal enterprise, you pay VAT and shareholders pay taxes. You have to pay social benefit, a decent wage, and offer vocational training to your employees, while the competing wood charcoal business sector is informal and does not have these obligations.

The Ugandan government can easily tip the balance in favor of green charcoal by providing (at least temporarily) a tax exemption for green charcoal businesses or by beginning to tax the production and selling of wood charcoal. Subsidies of green charcoal production are another possible avenue to support briquette production.

To summarize, there is no doubt that the Ugandan government policy in general and its taxation policy in particular have a tremendous influence on green charcoal production and can potentially be used to give a competitive advantage to green charcoal (Mwampamba, Owen, and Pigaht 2013; Standal et al. 2024).

Discussion

Green charcoal competes with wood charcoal, and green charcoal producers compete with wood charcoal producers, so far with very modest success. In order to be successful, green charcoal producers must develop the right firm infrastructure and must organize their primary activities efficiently. Moreover, external factors, such as governmental regulations and access to capital, must be designed to facilitate briquette business. A successful uptake of green charcoal requires that all factors are controlled and aligned to reinforce each other. Taking Porter's value chain model as point of departure, we summarize in Figure 2 the factors that need to be controlled.

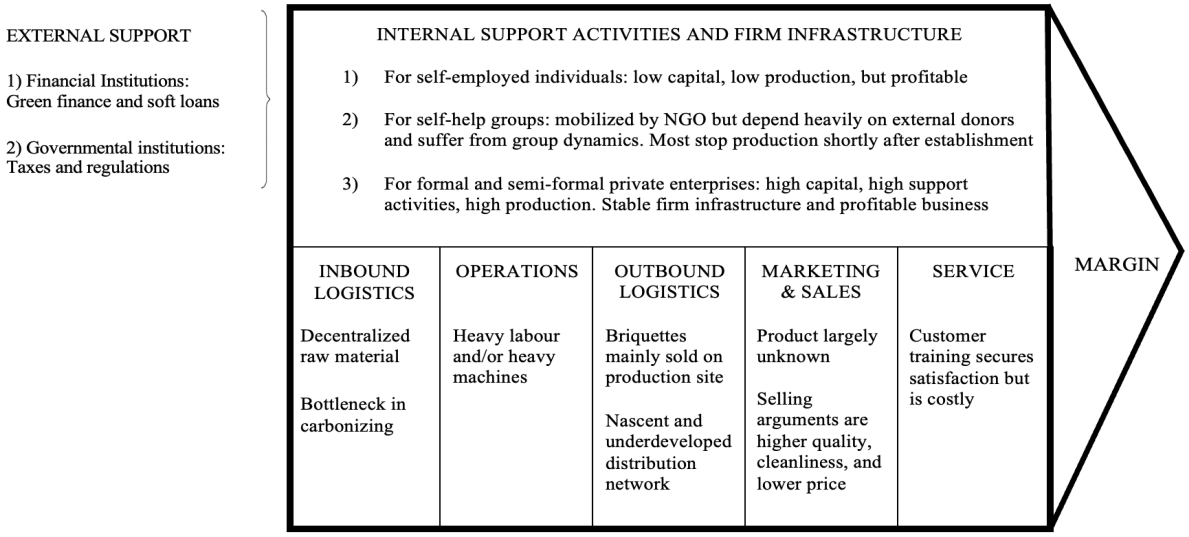

Figure 2: Value chain for green charcoal production and marketing.

When it comes to support activities, only formal and semi-formal private enterprises are viable firm infrastructure. The production of self-employed individuals is made at a very low scale and depends exclusively on wood charcoal fines as raw material, which is not sustainable in the long term. Self-help groups are ridden with group conflicts and are waiting for external donors to solve their problems. Private enterprises, on their side, are highly dynamic, innovative, and adaptive, and they succeed in developing a profitable business, despite the fact that external factors do not always facilitate their business.

When looking at the primary activities in production, inbound logistics suffers from the fact that agricultural waste is spread out in the landscape, and from a bottleneck in the production of biochar which can only be done (so far) in small quantities at a time. Operations are heavier than for wood charcoal because they are more labor intensive and require more machinery. Outbound logistics is very rudimentary, as briquettes are not widely sold everywhere (unlike wood charcoal) and as most customers buy briquettes on production sites. Marketing strategies are required to make the product known to the general public and to make customers familiar with the different properties of briquettes. The novelty of the product also requires significant after-sale service to ensure customers' correct use and satisfaction and to gather feedback that can be used to improve the product.

External support is crucial in facilitating or impeding the development of green charcoal businesses. Financial institutions can open or close access to credit, which is one of the biggest challenges for green charcoal production as it requires heavy investments. Government policy influences the competitiveness of green charcoal through taxation of briquettes and wood charcoal, and influences consumer acceptance through its energy market regulations. It can also potentially influence

financial institutions and ask them to develop financial products that can support the green transition.

The core argument of this article is that all the factors in Porter's value chain model need to be taken into account simultaneously and holistically to enable a sustainable uptake of green charcoal. Our in-depth description of the value chain shows, however, that Porter's model needs to be complemented with a focus on external support. It does not help to train and equip self-help groups to produce briquettes in rural areas if production costs make this product 50% more expensive than wood charcoal. It is meaningless to decree a ban on the transport of wood charcoal if no alternative fuel for cooking or heating is commonly available. Having a good technology and a good product is pointless if the financial capital to develop production remains out of reach. It is useless to produce briquettes in large quantities if no customer knows the qualities of briquettes or if the product is not available in open markets. All factors described in the model need to be present and under control for a successful uptake of green charcoal.

Conclusion

Green charcoal has a real potential to replace a large part of the current wood charcoal consumption in towns and cities, which can contribute to reducing deforestation and national carbon emissions. It also has a potential to provide an alternative source of cooking fuel in areas where all forests have already disappeared. This potential, however, is currently very far from being met. Our article proposes a comprehensive and holistic model describing the conditions for successful production and uptake of green charcoal.

First, governmental agencies and international donors must realize that self-help groups are not a successful firm model able to support the production of green charcoal. Briquette making and selling requires many skills that are difficult to master and to share equitably in a self-help group, which leads to production and marketing failure. Experience from our fieldwork teaches us that only formal and semi-formal enterprises can develop a significant and successful production and marketing of briquettes.

Second, production and inbound logistics require access to large quantities of raw material. It is here that large numbers of peasants can benefit from the green charcoal industry (possibly in self-help groups or as individuals) by supplying biochar to localized production plants. Carbonizing agricultural waste is a relatively simple activity which does not require much labor, but which requires to be decentralized where biomass is located. The operation and the briquette production require heavy labor and, therefore, machines powered by electricity or diesel, which are costly and require maintenance. As briquette production is

labor and capital intensive, the price of green charcoal on production site is higher than the price of wood charcoal on production site. To be competitive on price, green charcoal must, therefore, be produced close to consumers and sold directly to them, to save on intermediaries and transport cost. Since briquettes are still largely unknown, promoting them also requires explaining their qualities to customers and educating them on how to store and use them.

Third, external support is essential for the scaling up of green charcoal production. Currently, financial institutions do not have adequate tools to support this kind of business, which is a barrier to its development. Moreover, the Ugandan government has currently no specific strategy to support green charcoal production and marketing. Raising taxes on wood charcoal production and transport, and providing tax exemption for green charcoal, are crucial instruments to make green charcoal more competitive.

Many attempts to replace wood charcoal with greener alternatives remain constrained, despite the urgency to mitigate deforestation and despite the efforts and resources invested in this endeavor. Our contribution to this debate, focusing on green charcoal, is to show that success requires a holistic approach encompassing all aspects impacting the value chain. It is when all factors of the value chain are controlled and aligned that green charcoal can have a chance to replace wood charcoal and gain a significant share of the market for cooking fuels in towns.

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