*Article*

# Organic Waste to Clean Energy: Briquette Du Kivu as a Model for Valorising Urban Waste into Charcoal in the DR Congo

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**Abstract**

*Briquette du Kivu* (*BdK*) is a social enterprise operating in Bukavu, eastern Democratic Republic of the Congo, a region facing persistent food insecurity and environmental degradation linked to prolonged conflict. To reduce dependence on wood-derived cooking fuels and associated deforestation, estimated at approximately 300 hectares of forest lost annually, BdK produces clean-burning charcoal briquettes from locally available organic waste. Because food waste cannot be directly carbonized due to its high moisture content, BdK's process first employs black soldier fly larvae (BSFL, *Hermetia illucens*; Diptera: Stratiomyidae) to bio-convert organic substrates into a stabilized residue (frass) while substantially reducing substrate volume. The resulting frass is then carbonized in specialized kilns, mixed with a clay binder, extruded into long cylinders and then sun-dried to produce the final fuel product. In addition to providing a renewable cooking fuel, the system generates protein-rich insect larvae that are sold locally as livestock feed, while a portion of the frass is used as fertilizer in BdK's fruit tree nursery. The nursery supplies grafted trees to regional households, contributing to food production and supplemental income generation. By integrating waste management, insect bioconversion and fuel production, BdK's model demonstrates how small-scale circular bioeconomy systems can simultaneously address waste accumulation, energy access and livelihood development in conflict-affected regions.

**Keywords:** biochar; black soldier fly larvae; organic waste valorisation; rainforest conservation; Sub-Saharan Africa

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## Introduction

The eastern region of the Democratic Republic of the Congo (DRC) has experienced persistent poverty, rapid population growth and recurrent political instability for much of the past three decades (Stearns 2011; Kara 2023). Ongoing conflict, weak governance, geographical isolation, currency volatility and high costs for goods and services continue to present major barriers to economic development. These challenges have been intensified by the resurgence of the M23 rebel–paramilitary movement (Miriti 2025a) and by reductions in international development funding, including the restructuring of the USAID in 2025. As a result, there is an increasing need for locally self-sufficient approaches to energy production and waste management in the region.

In eastern DRC, energy access remains a critical challenge. Approximately 94% of household energy needs are met through the combustion of fuelwood and wood-derived charcoal, and even in urban areas an estimated 90% of households rely on biomass fuels for cooking (UNCDF 2019). Much of this wood is harvested from nearby forests, including old-growth tropical rainforest. This practice raises significant environmental concerns given the global importance of the Congo Basin, often referred to as the 'Green Heart of Africa'. The region contains the world's second-largest tropical rainforest, supports roughly 20% of global biodiversity, hosts over 3,000 endemic tropical plant species and represents one of the world's largest terrestrial carbon sinks (White et al. 2025).

Within the DRC, forests cover approximately 67% of the national territory (about 155.5 million hectares). However, eastern provinces bordering Uganda, Rwanda and Burundi have among the highest population densities in the country, creating intense pressure on surrounding forest resources (European Commission et al. 2010). Household energy demand is a key driver of this pressure. A typical family consumes roughly 120 kg of charcoal per month, equivalent to the biomass derived from approximately five large trees. For a city such as Bukavu, with an estimated population of 1.3 million residents, this demand contributes to significant forest loss, estimated at roughly 500 hectares of rainforest annually. The region's dependence on wood-based cooking fuels, therefore, generates several interconnected challenges: increasing deforestation, health risks associated with indoor air pollution from low-quality charcoal and substantial time burdens for households, particularly women and children who often collect fuelwood.

Simultaneously urban waste management is also a major challenge in eastern DRC. Limited infrastructure and institutional capacity constrain the effective collection and processing of municipal waste. In many cases, waste is either transported to unmanaged landfills without sorting or recycling, or it accumulates within urban environments where it decomposes and is transported by rainfall into waterways, further contaminating the Kahuwa and Mpungwe rivers that flow into Lake Kivu (Zirirane et al. 2015; RUNRES core team 2024), which is one of the Great African Lakes and is central to the culture and mythos of Congolese lakeside communities (Farelius 2025). Despite many initiatives by local authorities, civil society and other organizations working in the field of recovery and management of waste, these problems continue to worsen.

A recent report estimates that Bukavu now generates 900 tonnes of solid household waste per day, with an organic content of 65% (RUNRES core team 2024) (possibly due to the influx of plastics). The main sources of waste continue to be food markets, households, restaurants, food depots and shops. Although some collection and valorisation of the waste is done by scavengers at the dumpsite, most of the waste that does make it to the landfills is left to accumulate on site. Consequently, the official landfills are overburdened, and residents of the city region turn to a variety of informal dumping sites: roads, markets, trails, neighbours' plots, rivers, lakes, wells, abandoned buildings, and the roofs of other people's homes. Of particular concern is the regular usage of coastal areas as dumping grounds (RUNRES core team 2021).

While this situation poses significant environmental and public health risks, it also represents a potential opportunity. A large fraction of the region's municipal waste consists of biodegradable organic material, which could potentially be recovered or transformed into useful products (RUNRES core team 2024). That said, organic waste streams typically exhibit high moisture content and low bulk density, making them unsuitable for direct carbonization. Attempts to carbonize such material often produce incomplete or fragmented charcoal that burns inefficiently and generates excessive smoke. To improve charcoal quality, an intermediate processing step is required to stabilize the substrate and reduce moisture content before carbonization.

Charcoal production itself is based on carbonization, a pyrolytic process in which organic material is heated at high temperatures (typically 700–800 °C) under low-oxygen conditions (Devi et al. 2021). During pyrolysis, a series of thermochemical reactions—including dehydration, condensation, hydrogen transfer and aromatization—break down organic compounds and convert them into volatile gases and solid carbonaceous material, i.e., charcoal (Devi et al. 2021). In eastern DRC, charcoal production traditionally relies on wood harvested from rural forests, which is carbonized in earth kilns before being transported to urban markets. When this process is poorly controlled, incomplete carbonization produces charcoal containing residual tar and volatile compounds. Such fuel burns inefficiently, producing less heat and flame while releasing higher levels of smoke and carbon monoxide. Given the combined challenges of deforestation, inefficient charcoal production and unmanaged organic waste, alternative approaches to fuel production are urgently needed.

Here we present an integrated approach to organic waste valorisation and sustainable fuel production that combines the rearing of black soldier fly (BSF, *Hermetia illucens;* Diptera: Stratiomyidae) larvae with the production of ecological charcoal briquettes. This system has been developed by the company *Briquette du Kivu* in Bukavu, eastern DRC. BSFL are widely used in waste bioconversion systems due to their ability to rapidly consume diverse organic substrates, including agricultural residues and market waste. During feeding, larval movement continuously reworks the substrate, improving aeration and promoting moisture reduction (Sheppard et al. 1994). The digestion process produces a residual material known as frass, in which nutrients are concentrated into a form suitable for subsequent carbonization.

The frass can then be carbonized through pyrolysis and processed into clean-burning charcoal briquettes. In addition to producing an alternative cooking fuel, the system generates protein-rich larvae that can be used as livestock feed, while a portion of the frass can be used directly as fertilizer in local agricultural systems. By integrating waste management, insect bioconversion and fuel production, BdK's approach demonstrates how circular resource systems can simultaneously address waste accumulation, energy access and forest conservation in resource-constrained environments.

## Methods

*Site Description*

Approximately 66% of the population in the DRC lives below the international extreme poverty line, earning less than USD 2.15 per day (Miriti 2025b). Access to modern energy remains severely limited: less than 5% of the population has access to clean cooking fuels, and only 22% have access to electricity, resulting in a clean-cooking energy deficit affecting ~101 million people and a broader energy deficit affecting ~79.3 million people (Adair-Rohani et al. 2025; Kohli et al. 2025). The country's economy is predominantly agrarian, with 80% of the population engaged in agriculture, complemented by the mining sector as a primary driver of economic activity (Miriti 2025b). Even in the capital, Kinshasa, demand for fuelwood and charcoal exceeds production capacity by roughly 13-fold (UNCDF 2019).

The eastern city of Bukavu (2°30′22″S, 28°51′39″E) spans 60 km² within the highlands of South Kivu Province, bordering Rwanda (Figure 1). Administratively, it is divided into three municipalities: Ibanda, Kadutu and Bagira. Population projections estimate 1.43 million inhabitants (up from 878,000 in 2016), with ~46% under the age of 14 (Miriti 2025b) (https://populationstat.com/). The population is expected to exceed 2 million in the next decade, driven both by high natural growth (average 5 children per woman) and migration from rural areas due to livelihood pressures. Rapid population growth places significant strain on municipal infrastructure, resulting in challenges in solid waste management, sanitation, food security, employment and education.

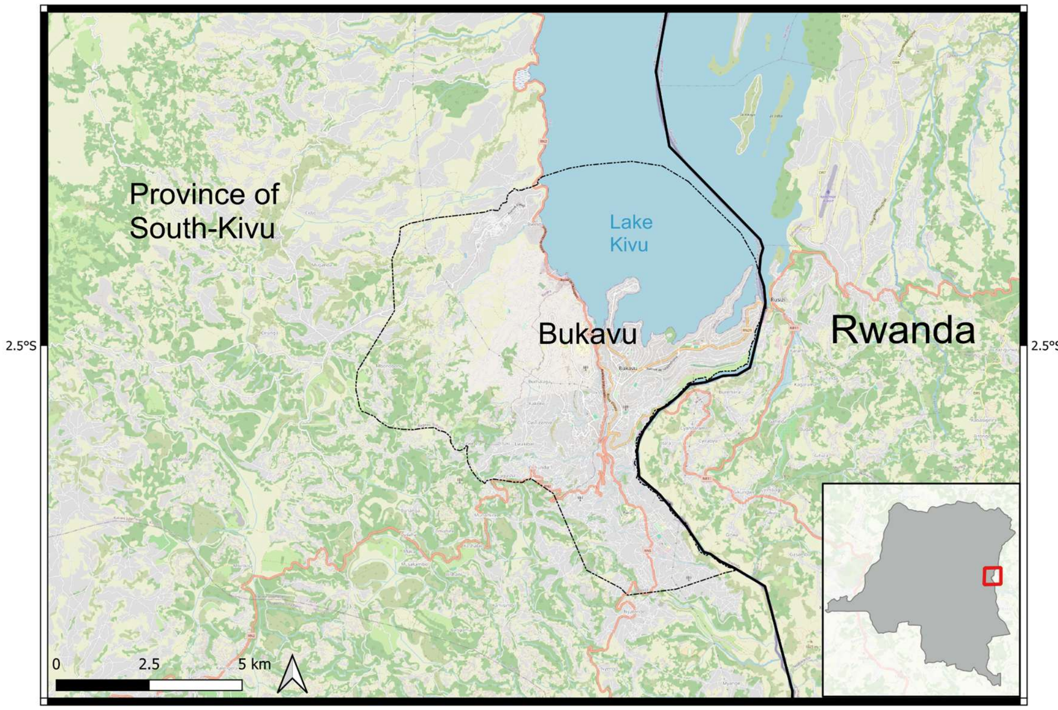


**Figure 1.** Map of Bukavu and its surrounding region in the Eastern Democratic Republic of the Congo.

*Briquette du Kivu*

*Briquette du Kivu* is a youth-led enterprise operating in Bukavu that addresses critical regional challenges, including deforestation, inadequate sanitation and food insecurity, through innovative waste management and resource valorisation. The company focuses on utilizing green and food waste streams from the municipality, diverting them from overburdened landfills while generating sustainable alternatives for energy and food production (Figure 2). *BdK*'s operations are organized around three core components:

1. Waste valorisation using BSF larvae. Food waste is fed to BSF larvae, producing high-protein animal feed (Kenis et al. 2014) and frass (Lopes et al. 2022), a nutrient-rich residual material suitable for composting or carbonization into charcoal briquettes.

2. Biomass carbonization into briquettes. Organic waste from municipal markets is processed through pyrolysis and densified into clean-burning charcoal briquettes, providing a renewable substitute for traditional wood charcoal in the form of biochar.

3. Urban green space and fruit tree nursery management. *BdK* maintains green spaces within Bukavu and uses collected organic waste for composting and fruit tree production. In a context where the local market for compost is limited, this activity diversifies *BdK*'s operations while supporting local food production and environmental improvement.

Through this integrated model, *BdK* demonstrates how waste-to-resource systems can simultaneously address environmental, energy and socio-economic challenges in a rapidly growing urban context.

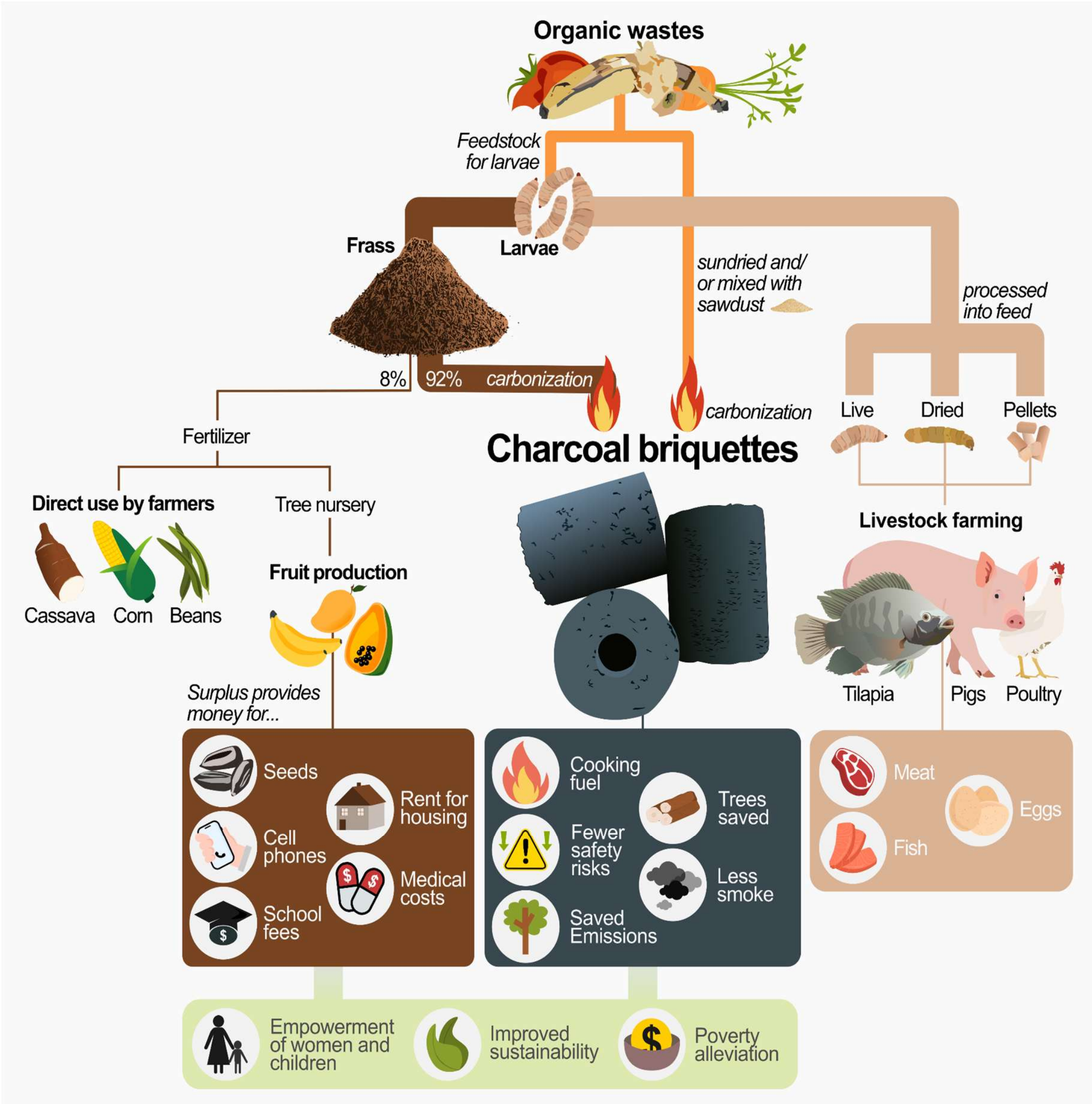


**Figure 2.** Added community value of insect-based bioconversion and *Briquette du Kivu*'s process to convert organic waste streams into charcoal briquettes.

*Organic Waste Valorisation*

***Collection and separation.*** The production of charcoal briquettes by *BdK* in Bukavu begins with the manual collection of organic biomass residues from public dumping areas, primarily located within or near municipal markets. These residues include fruit peels, vegetable trimmings, spoiled or discarded food, chicken litter, cow and pig manure, as well as plant-based materials such as grass, tree leaves, sawdust and cardboard. Because organic waste is frequently mixed with plastics and other non-biodegradable materials, manual sorting is required at the point of collection to remove contaminants and minimize the risk of microplastics entering downstream processes or the food chain. The separated organic waste streams are then transported by truck to the *BdK* processing facility for further valorisation.

***Drying.*** Many food wastes collected by *BdK* contain very high moisture levels (>80%), particularly fruit peels and animal manure. To improve process efficiency, part of the collected waste must first undergo moisture reduction prior to carbonization. Most post-consumer food waste (e.g., bread, meat, fish, vegetables) is fed directly to BSF larvae for bioconversion. However, certain agricultural residues are produced in volumes that exceed the facility's BSF larvae processing capacity. Banana and pineapple peels are extremely abundant in the region. Approximately 50% of these pre-consumer residues are therefore sun-dried before carbonization rather than processed through the insect bioconversion stage. While this reduces moisture sufficiently for pyrolysis, it represents a less efficient form of resource valorisation compared with BSF larvae processing.

***Digestion with BSF larvae.*** Once delivered to the facility, suitable organic substrates are fed to BSF larvae, which rapidly consume and transform the material during the larval phase of their holometabolic life cycle (Lemke and Puniamoorthy 2025) (Figure 3). Before feeding, substrates are homogenized and often mixed with bulking agents such as sawdust or spoiled maize bran to further reduce overall moisture content. Sawdust has recently been shown to be an effective structural additive in BSF larvae systems (Kubayi et al. 2026).

Black soldier fly larvae were originally studied for their capacity to reduce moisture in poultry manure (Sheppard 1983; Sheppard et al. 1994), and subsequent research has demonstrated their effectiveness in processing substrates with moisture contents up to 90% (Lalander et al. 2020). During development, larvae convert part of the organic substrate into insect biomass, while the remaining material is transformed into a residual product commonly referred to as frass. Strictly speaking, frass refers only to the powdery larval excreta. In practice, however, the material typically called "frass" also contains shed exoskeletons, partially digested substrate and small quantities of dead larvae. Under optimized feeding conditions, frass generally exhibits substantially lower moisture content than the original substrate, sometimes reaching levels as low as ~10% (Klammsteiner et al. 2020). Because of its high nutrient content and microbial activity, frass has been widely studied for applications in agriculture, soil management and pest control (Lopes et al. 2022; Team Acrres et al. 2023).

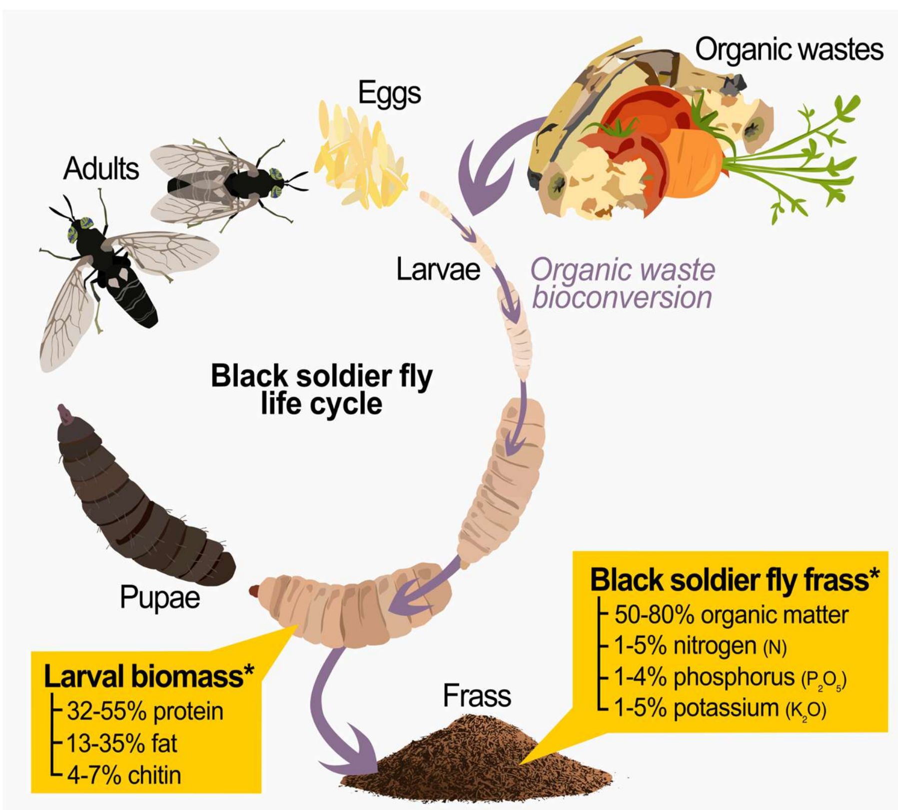


**Figure 3.** The life cycle of black soldier fly, Hermetia illucens, including main input and output products (on a dry matter basis). Data on larval biomass and frass composition are based on Basri et al. 2022; Lu et al. 2022; Kim et al. 2023.

*BSF Rearing for Waste Valorisation*

The BSF larvae must be obtained from eggs that are produced by fertile adult BSF (Lemke et al. 2023). To sustain operations, *BdK* maintains a colony of BSF (inside a house, with the roof modified to allow natural light through transparent sheets) originally sourced from the wild. The equatorial climate of the Eastern DR Congo is amenable to producing BSF year round, since the BSF is itself a tropical fly introduced from the New World into Africa (Kaya et al. 2021; Muchina et al. 2026). *BdK* sourced flies for its colony by finding eggs laid in the rumen/paunch of cows (i.e., the undigested material that is evacuated from the guts of animals when they die) collected at a nearby slaughterhouse (the largest in the area, which processes >100 head of cattle per day). Indeed, many other studies have reported being able to trap wild females or their eggs in a similar manner (e.g., (Sripontan et al. 2017; Ewusie et al. 2019)). Wild BSF are commonly seen throughout Bukavu in gardens and community science records of BSF have been logged for the eastern DR Congo (as well as Uganda, Rwanda and Burundi) (www.iNaturalist.org).

***BSF Colony Management.*** To sustain continuous waste processing, *BdK* maintains an on-site colony of black soldier flies housed in a modified structure designed to allow natural sunlight through transparent roofing panels (Figure 4). *BdK* operates four wooden rearing cages in a continuous production cycle (Dickerson et al. 2024; Coudron et al. 2025; Lemke et al. 2025). Each cage measures approximately 1.5 m³ and receives 3–5 kg of pupae (~30,000–50,000 flies) every two weeks. Dead flies collected from the cages are periodically used as attractants, combined with pineapple peels and maize bran, following established BSF production practices (Dortmans et al. 2017). Egg-laying sites consist of stacked wooden planks with narrow gaps, which mimic the dry crevices preferred by female BSF for oviposition (Sheppard et al. 2002). The planks are intentionally not washed between cycles, as residual odours from previous egg deposits enhance attraction (Heussler et al. 2023; Klüber et al. 2024; Klammsteiner et al. 2025).


**Figure 4. Panel of images related to waste processing with black soldier fly larvae:** (a) Urban wastes are collected by *Briquette du Kivu*'s workers throughout Bukavu and transported via truck to its facility; (b) wastes are homogenized and then fed to black soldier fly larvae maintained in yellow pans constructed from used oil containers; (c) the system is circular and fed by the fertile egg output of BdK's breeding colony; (d) workers sift

contents of the pans to isolate larvae from frass; (e) those larvae are sold as animal feed and the remaining frass is used for biochar and fertilizer.

Egg production varies seasonally. During sunny periods in the dry season, the four cages collectively produce approximately 70 g of eggs per day, whereas during the wetter season production decreases to 30–40 g per day. Around 20% of eggs are retained for colony maintenance, while the remainder are used for waste processing or occasionally sold to customers. For hatching, eggs scraped off the wood planks of the traps are placed on trays containing fresh brewery waste and kept indoors for approximately one week. The resulting larvae are then separated from the substrate and distributed in 30–50 g aliquots into feeding containers to begin a new production cycle.

***Carbonization.*** After larval digestion, the resulting frass is fed into a modified kiln for carbonization (Figure 5). The kilns are equipped with air-inlet apertures and chimney vents that allow controlled airflow during the pyrolysis process. Carbonization typically requires at least 45 minutes. *BdK* operates six carbonizers simultaneously, each capable of processing 30 kg of frass per batch. When operating continuously, the six kilns generate an average output of approximately 96 kg of charcoal per hour.


**Figure 5. Panel of images related to biochar.** (a) Workers operating a carbonizer modified from an oil drum; (b) Workers are operating the compaction-extruder; (c) briquettes are formed and laid out to dry; (d) workers stockpile dried briquettes; (e) briquettes are sold in bags, (f) smokeless flames generated by briquettes, (g)

briquettes used to prepare food. (h) a portion of the frass generated by BdK's operations is used to fertilize fruit trees in the nursery; and (i) the nursery provides an opportunity for the community to learn about green agriculture and BdK's process.

***Briquette formation.*** Following carbonization, the charcoal is cooled with water. The resulting slurry is sun-dried before briquette formation. The carbonized material is then processed to obtain a controlled particle size distribution: approximately 80% fine powder, which enhances burn duration, and 20% coarse particles, which improve ignition stability. In addition, two porridges are also prepared, mixed, and added to the carbonized material: (A) spoiled maize (which can no longer be consumed as food) is cooked with water until it boils and no longer smokes. This is added to briquettes to improve the flame they produce; and (B) clay and water are combined to form a solution which acts as a binder for the briquettes. Each comprise roughly 2.5% of the final product and are mixed with the processed charcoal until a homogeneous mixture is achieved. The material is then fed into a diesel-powered screw extrusion press, which compacts the mixture under high pressure and extrudes it through a mould to form cylindrical briquettes. The briquettes undergo a final drying stage lasting five to six days before they are ready for distribution and sale. Overall, the biomass undergoes three sequential reductions in volume during processing: firstly, through larval digestion, secondly, through carbonization, and thirdly, through water removal and mechanical densification during briquette formation.

## Results

*Briquettes as an Alternative to Traditional Charcoal*

***Revenue streams and fixed operating costs.*** *Briquette du Kivu* collects approximately 30 metric tons of organic waste from local markets each month. During the initial digestion stage, BSF larvae reduce the volume of this waste by 70-80%, producing roughly 9 tons of frass). Of this, 92% (i.e., 8.28 tons) is directed to charcoal production, while the remaining 8% (i.e., 0.72 tons) is used as fertilizer in *BdK*'s tree nursery. The 8.28 tons of frass processed for fuel production undergo pyrolysis, during which the mass is reduced by approximately 60%, yielding about 3.3 tons of charcoal briquettes after drying. With an input processing capacity of 240 kg frass per hour, *BdK*'s six carbonizers require approximately 34.5 operating hours per month to convert this material into charcoal.

The briquettes are sold for approximately 1000 Congolese Francs per kilogram (or ~0.40 USD/kg), generating an estimated 1,325 USD in monthly revenue from charcoal sales. In parallel, the BSF larvae production system yields 500-750 kg of larvae per month, which are sold as animal feed for 1 USD $kg^{-1}$, generating (500-750 USD in monthly revenue). The 0.72 tons of frass retained for agricultural use supports *BdK*'s tree nursery, where seedlings are cultivated in moulded pots woven from banana leaves. The nursery has an average production capacity of approximately 2,500 grafted trees per month, each sold for 1 USD to a combination of individuals, businesses, churches, schools, NGOs and government entities, generating about 2,500 USD in monthly revenue. Taken together, these activities generate approximately 4,325–4,575 USD in total monthly revenue (~4,450 USD on average). This exceeds the enterprise's fixed monthly operating costs of approximately 4,200 USD, which include 3,670 USD in salaries for 32 employees and 530 USD in rent for the production site.

***Business case.*** In local markets, low- and high-quality wood charcoal are often visually difficult to distinguish, although higher-quality charcoal is typically denser and heavier to the touch. Charcoal is commonly sold in small bags for around 0.50 USD, which by volume often corresponds to less than 1 kg. Lower-quality charcoal, frequently produced from younger wood, typically burns for 1–2 hours, often producing heat with limited flame, while charcoal produced from mature wood may burn for up to 2.5 hours. By comparison, *BdK*'s briquettes burn for approximately four hours, producing both sustained heat and strong flames (although this may not be necessary if 1-2 hours of cooking time is sufficient). Rather, more important is price saliency. Sold at 0.40 USD $kg^{-1}$, *BdK* therefore offers a longer-burning and competitively priced fuel, providing greater cooking efficiency per unit of fuel consumed and money spent. Moreover, the charcoal is available from organic waste produced within the city and so should be continuously available compared to wood that must be sourced from the countryside, which is a supply chain threatened with security issues. This model enables *BdK* to supply an affordable alternative cooking fuel while reducing pressure on surrounding forests by lowering demand for wood-derived charcoal. The revenues generated help support broader local employment and community-based activities.

*Social-Economic and Environmental Impacts*

***Food Security.*** Most food produced in the eastern DRC (including cassava, plantains, sugarcane, oil palm fruit, maize, rice, root vegetables, bananas, sweet potatoes and groundnuts), is consumed locally (Miriti 2025b). Despite this, domestic production remains insufficient to meet the needs of the region's growing population. In 2024, approximately 70% of the country's food supply was imported (Miriti 2025a), continuing a long-standing reliance on external markets that costs the DRC an estimated USD 3 billion annually. In addition to its trade deficits, with e.g. the United States, the DRC imports many agricultural staples from the European Union, Zambia, South Africa, China, India and Namibia (Miriti 2025a). Much of this trade enters the region through the port of Dar es Salaam, before being transported inland. Because eastern DRC is geographically separated from the western part of the country and lacks direct access to maritime trade routes, the Kivu provinces rely primarily on cross-border trade with Rwanda, Uganda and Burundi. Even under stable conditions, this dependence significantly increases transportation costs. During periods of conflict, however, border crossings may be restricted or controlled by armed groups, making food security a persistent and acute concern.

In this context, the fruit trees produced by *BdK*'s nursery contribute to local food security while also providing households with a potential source of income. Trees sold to families supply fruits for household consumption and allow surplus produce to be sold in local markets. For example, a regime of bananas may sell for approximately 29,000 Congolese Francs (~10 USD), while a single avocado typically sells for about 1,000 Congolese Francs (~0.40 USD). Income generated from such sales can support a range of household needs. For instance, 10 USD is sufficient to purchase a basic mobile phone, pay school fees for three children (approximately 3 USD per child per month, over a nine-month school year), cover basic medical consultations, or pay monthly rent in some peripheral neighbourhoods of Bukavu. By enabling households to generate small but meaningful income streams, *BdK*'s tree nursery contributes not only to local food availability and dietary diversity but also to household economic resilience in a region where access to stable markets and services is often constrained.

***Socio-economic context.*** In the eastern DRC, charcoal constitutes a major component of household energy consumption. The regional charcoal market has been estimated at approximately USD 60 million annually (UNCDF 2019), and energy-related expenditures can account for up to 30% of household income. In urban areas, households typically purchase charcoal or firewood from local markets, whereas in rural areas, families often collect fuelwood directly from surrounding forests.

Fuelwood collection has traditionally been shaped by gendered divisions of labour. Men generally cut trees, while women are responsible for collecting and transporting the wood to the household. In practice, however, these roles are often fluid and shaped by broader economic and social dynamics. In many communities, increasing participation of men in the artisanal mining sector (Stoop and Verpoorten 2021), including the extraction of gold, coltan, cassiterite and other minerals, has shifted household responsibilities. As a result, women and children frequently assume a greater share of tasks related to energy, water collection and household management, (Stoop et al. 2026). Conversely, the presence of armed groups and paramilitary actors in parts of the region has drawn some young men into cycles of violence or instability (Stoop and Verpoorten 2021), further complicating household labour structures.

Improved access to clean-burning charcoal briquettes (by being able to purchase more for less) can reduce the time and labour required to secure cooking fuel (or the money to buy it), as well as decrease security risks of having to travel and work in areas of conflict. Moreover, by turning urban waste into a business opportunity (described above), this system may allow households, particularly women, to safely engage in economically productive activities. For example, in Bukavu many women participate in village savings and loan associations, locally known as *associations de crédit*, where members collectively save money and provide small loans to support micro-enterprises. These initiatives often finance activities such as selling surplus fruit, agricultural products, or other locally produced goods in village markets. Alternative energy sources such as briquettes may therefore contribute not only to household energy security but also to women's economic participation and community-level resilience.

***Environmental Impacts.*** Although the precise energetic performance of *BdK*'s briquettes relative to conventional wood charcoal has not yet been formally quantified, their production offers several clear environmental advantages. Rather than relying on the harvesting of living trees (which are carbon sinks), *BdK*'s briquettes are produced from insect frass derived from organic waste streams that would otherwise remain unutilized, decompose and/or contribute to pest proliferation. At the most immediate level, *BdK* diverts approximately 30 metric tons of organic waste per month from unmanaged disposal pathways, equivalent to around 360 tons annually. When organic waste is processed through BSF larvae, a substantial portion of its nutrients and energy can be recovered. Previous studies indicate that BSF larval bioconversion can reclaim up to ~55% of the substrate's energy, 41% of its carbon, 38% of its nitrogen and 86% of its potassium in the larval biomass (Perednia et al. 2017; Parodi et al. 2020). In addition, approximately 55–75% of the substrate's carbon may remain sequestered in the frass (Wu et al. 2024). These values are context-dependent and may differ under *BdK*'s operational conditions, particularly given variations in substrate composition and processing parameters. Nevertheless, they illustrate the broader potential of BSF larvae systems to recover nutrients and carbon from organic waste streams. By converting frass into charcoal briquettes, *BdK* further extends this valorisation pathway by producing a substitute for wood-derived charcoal. With a current production capacity of approximately 3,300 kg of briquettes per month, *BdK* generates about 39.6 tons of charcoal-equivalent fuel annually. If 120 kg of conventional charcoal corresponds roughly to the biomass derived from five large trees, this level of production represents the potential displacement of charcoal obtained from approximately 1,650 trees per year.

Beyond reducing tree harvesting, this avoided deforestation helps maintain the ecological services provided by standing forests, including carbon sequestration, groundwater regulation, soil stabilization and habitat provision for biodiversity. Assuming typical forest densities of 100–250 trees per hectare, the avoided harvesting corresponds to roughly 6.6–16.5 hectares of forest biomass annually. Under conservative assumptions, this represents the equivalent of charcoal production from approximately 6–7 hectares of forest, compared with an estimated 300 hectares logged annually in the region. While these estimates are indicative and subject to refinement through detailed life cycle and energy analyses, they highlight how *BdK*'s model, by converting organic waste into cooking fuel, animal feed and fertilizer, can contribute simultaneously to waste reduction, forest conservation and local resource circularity.

## Discussion

*Limitations, Repeatability and Scalability*

Ideally, the objective of an life cycle assessment would be to quantify the environmental impact of a product and the process to make it (Smetana et al. 2025); however, limitations to research infrastructure in the DR Congo make the explicit quantification of some of these factors (such as the precise energy inputs and outputs) difficult. Instead, what has been compiled here is a qualitative assessment of *BdK*'s production process and the social-economic context of its business operations. Although imperfect, *BdK* makes great strides towards the energy transition to cleaner charcoal.

Moreover, because the highly dynamic political crisis that continues to occur in the Kivus, what is presented here is also just a snapshot of the company's activities in 2025–e.g., more recently, *BdK* is working on up-scaling to meet greater production demands though the utilization of a solar dryer which will accelerate this drying phase to around 3.5 days prior to packaging and distribution.

Because of the scale of the crisis in Bukavu, there is room enough for *BdK*'s methods to be adopted and implemented by other actors locally. Indeed, some of the company's trainees have created their own companies in Bukavu already (Amunazo, Pamela 2026). As for scalability to the broader region–the niche which *BdK* operates in is one of historic and continued crises. In other regions, especially those which have already adopted and have become dependent on utilizing fertilizers, it may not make sense to carbonize BSF frass into charcoal, especially since biochar has many other functional benefits when applied as a soil amendment such as improved carbon sequestration and crop yields (Sundberg et al. 2020; Oloruntoba et al. 2025). In this way, the situation in Kivu is unique in some regards. Operating within an urban area, there is little space for farming, and moreover there is little money or incentive to pay for additional farming inputs (i.e., fertilizer). Moreover, in the eastern DRC, farming is seen as a social activity rather than as a business, so there is rarely any monetary investment made in agriculture by farmers, no market for fertilizer, and no business case for selling frass. Historically, only NGOs have the means to buy and distribute the frass for use as fertilizer to rural farmers for free; but their doing so socially disincentivizes farmers from buying fertilizers on their own. This situation, coupled with the huge market demand for clean charcoal has given rise to *Briquette du Kivu's* business case of selling carbonized insect frass as clean cooking fuel, with the additional benefit of being able to sell products like BSF larvae for animal feed and nursery trees. Of course, such a need is not isolated to the Eastern DR Congo; and ~730 million people worldwide (mostly in Sub-Saharan Africa and Southeast Asia) do not have reliable access to electricity (Kohli et al. 2025). It is these regions where we foresee adoption of this or similar methods. Indeed, some of this effort is already underway. BdK has a history of hosting workshops to spread this innovation to neighbouring countries like Uganda, and small-scale rearing of BSF in Africa and the global south continues to be of great interest for countries to meet their food, energy and waste management needs (Barragán-Fonseca et al. 2025).

## Conclusion

*Briquette du Kivu*'s production model illustrates a localized circular bioeconomy in which urban organic waste streams are transformed into multiple essential resources. Market waste is first converted by BSF larvae into protein-rich biomass for animal feed and nutrient-dense frass, thereby recovering energy and nutrients that would otherwise be lost through unmanaged decomposition. The frass is then further valorised through pyrolysis to produce clean-burning charcoal briquettes, providing an alternative cooking fuel that can partially displace wood-derived charcoal. At the same time, a portion of the frass is applied as fertilizer in *BdK*'s tree nursery, enabling the production of fruit trees that enhance local food availability, household income and agroforestry practices. Through this integration of bioconversion of waste with biochar, *BdK* simultaneously addresses several interconnected regional challenges: organic waste accumulation, dependence on wood-based cooking fuels, limited access to affordable animal feed and declining forest resources. As such, these operations support the work for dozens of men and women, lead to regional capacity building and directly or indirectly addresses most (if not all) United Nations Sustainable Development Goals (SDGs) including but not limited to SG2: zero hunger, SDG7: clean energy, SDG11: sustainable cities and SDG15: life on land. Thus, by converting locally available waste into energy, food-system inputs and economic opportunities, the enterprise demonstrates how small-scale circular resource systems can contribute to environmental conservation while supporting livelihoods in resource-constrained contexts.

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