A Collaborative Digital Platform for Green Charcoal Production Data Management

Kevin Aber [1*], Daniel Ogenrwot [2], Benedict Oyo [3], Geoffrey Olok Tabo [4], Lone Dirckinck-Holmfeld[5]

[1] Assistant Lecturer, Department of Computer Science, Gulu University, Uganda
[2]Assistant Lecturer, Department of Computer Science, Gulu University, Uganda
[3] Assoc. Professor, Department of Computer Science, Gulu University, Uganda
[4] Senior Lecturer, Department of Computer Science, Gulu University, Uganda
[5] Professor, Department of Communication and Psychology, Aalborg University, Denmark
*k.aber@gu.ac.ug: Kevin Aber

Abstract

Green charcoal offers a potential alternative to traditional biomass fuels in Uganda, yet its value chain remains fragmented, ineffective, and undigitized. The study presents the design and development of a collaborative, modular digital platform aimed at improving coordination, traceability, and data-driven decision-making in the green charcoal value chain. Participants consultations through Future Workshops and focus group discussions were used to derive system requirements. The elicited requirements were processed and then transformed to design a microservices-based architecture, with role-based access controls and implemented with lightweight, open-source technologies suitable for low-resource environments. The platform models production efficiency, support compliance monitoring, and training and policy intervention. Phased pilot implementation is planned to assess usability, data accuracy, and system adoption with the help of specific capacity-building initiatives. It serves as an open and flexible platform, a model suitable for advancing sustainability and innovation in the green charcoal sector in Uganda and driving digital transformation in low-resource value chains. The modular architecture can be extended with the addition of IoT sensors, mobile payment systems and predictive analytics, allowing the platform to continue to be relevant and influential in the long run.

Keywords: Green Charcoal, Digital System, Microservice Architecture, Participatory Design

1. Introduction

Charcoal remains a cornerstone of Uganda's energy ecosystem, serving as the primary cooking fuel for nearly 90% of households (Ali et al., 2019; Bamwesigye et al., 2020; UBOS, 2020). This widespread reliance underscores its critical role in both household energy and rural economic activities (Mainimo et al., 2022). However, the dominant methods of charcoal production, marked by unsustainable tree harvesting, rudimentary carbonization techniques, and weak regulatory enforcement, have significantly contributed to deforestation, land degradation, and biodiversity loss (FAO, 2020; Mugabi & Kisakye, 2021). These environmental consequences threaten ecological systems and the livelihoods of communities that depend on natural resources for survival.

In light of Uganda's commitment to the Sustainable Development Goals (SDGs), notably SDG 7 (Affordable and Clean Energy) and SDG 13 (Climate Action), there is growing national momentum to transition toward cleaner and more sustainable bioenergy sources. Among these, green charcoal (briquettes), a renewable biofuel derived from agricultural residues and other organic materials, has emerged as a promising alternative (Ibrahim et al., 2020; Njenga et al., 2019). It offers not only environmental benefits as a low-emission substitute for traditional charcoal but also economic advantages by promoting circular production systems and income opportunities for rural producers.

Despite its promise, the green charcoal sector in Uganda remains highly fragmented. It is primarily composed of small-scale producers with limited technical skills, inadequate market access, and weak institutional support (Mahoro et al., 2022; Mugabi & Kisakye, 2021). The lack of a robust digital infrastructure further hampers progress. Most production processes are either manual or undocumented, and poorly coordinated, leading to operational inefficiencies and inconsistent product quality (Yustas et al., 2022).

Additionally, key stakeholders, producers, researchers, local governments, and market actors struggle to access reliable data on production inputs, outputs, and performance metrics. The absence of a centralized, digital platform for collaboration, knowledge exchange, and performance monitoring impedes both innovation and policy support

Digital technologies, when designed with participatory principles, offer a powerful mechanism for addressing these barriers. A well-structured digital system can enhance production coordination, provide real-time data visibility, and support informed decision-making based on evidence. By embedding data capture, role-based dashboards, and performance reporting into a digital platform, small producers can strengthen quality control, researchers can access field data, and policymakers can evaluate the sector's socio-environmental impact.

To this end, the paper presents the design and development of a participatory digital data management platform tailored to the specific needs of Uganda's green charcoal production sector. It explores the potential of digital systems, when informed by participatory engagement, to support operational improvements, facilitate better coordination among stakeholders, and increase access to relevant production data. The platform offers a replicable model that contributes to ongoing conversations on sustainable energy innovation, particularly in advancing locally driven solutions and supporting transitions in community-based energy practices. The study is arranged as follows: Section two presents UPCHAIN project as a case and describes the data collection and analysis method, section three discusses the results and the system design, section four explores the functional capabilities of the system and section five and six concludes the paper with expected limitations and how to overcome them and discussing the potential future research directions.

2. Methodology

The design and development of the data management system use UPCHAIN (Unlocking the Potentials of Green Charcoal Innovation to Mitigate Climate Change in Northern Uganda) project as the empirical case study and development context. Using a participatory, user-centered approach, the methodology leveraged the project's inherent data management challenges across its six Work Packages (WP), particularly the heterogeneous data generated from WP1 (production), WP3 (marketability), WP5 (geospatial modeling), and WP6 (innovation methodologies), as the foundation for system requirements and design specifications. The development process unfolded through participants engagement with UPCHAIN researchers, requirements elicitation based on their diverse data needs, system specification addressing cross WP interoperability challenges, and iterative prototype development informed by real project constraints and workflows.

To contextualize system design within actual user experiences and production landscape, three Future Workshops (Jungk & Mullert, 1987; Kevin et al., 2024 forthcoming) were conducted in Gulu City, Amuru District, and Adjumani District. Participants were purposively selected to reflect the diversity of the green charcoal value chain. These included producers, consumers, local council leaders, students, environmental officers, stove artisans, and entrepreneurs involved in the supply of raw materials. The workshops aimed to elicit participants' experiences, identify value chain bottlenecks, and co-develop solutions that digital innovation could address. Through structured group dialogue, stakeholders jointly identified critical functional domains in the value chain, such as raw material sourcing, production technologies, marketing, community sensitization, and government/institutional support. These workshops co-created ideas and expectations for a system designed to enhance coordination, visibility, and sustainability within green charcoal initiatives. Participant's concerns for year-round sensitization campaigns especially at the grassroot level as a way of empowering community to take ownership, create market links and reinforce and expand the long-term adoption of green charcoal pave way for designing a repository where stakeholders can find training manuals, video demonstration on green charcoal production as well as the interactive boards to share local innovations or local knowledge on production. Further, their concerns on high-cost machines, limited access to efficient technology, need for local fabricators and knowledge for repair, need for tailored technological innovation to the local needs, for example, a participants voice *"the machines are too heavy and break down often"* didn't sound as a technical complaint but a requirement need for maintenance logging, machines catalogue and, feedback loop and also the need to create local fabrication network to connect producers to artisans or university for co-design and servicing.

Two Focus Group Discussions (FGD) were conducted with the production team, involving eight participants. The sessions lasting between one hour to three, documented core features and workflows and, examined data types, performance metrics, and user roles in depth. It provided a thick descriptions of practical production realities with a more granular view of how the team experience production, machine operations, raw material handling and quality concerns in green charcoal value chain. The gathering of user experiences, new insights made it a valuable method to ensure that the system design aligned with the user needs (Adekola & Olumati, 2023; Yayeh, 2021). The sessions were transcribed and analyzed thematically using NVivo, resulting in clear functional and non-functional requirements. The analysis discloses concerns around traceability, quality and consistency of the green charcoal which was treated as a design requirement to auto generate readable batch codes through the production process so that complaints be traced and weak or poor quality be recalled, and a quality assurance layer within the collaborative platform to link the production inputs to test to market.

The prototype was built using a microservices architecture with a shared database to ensure modularity, scalability, and ease of maintenance (Laigner et al., 2021), advantages not offered by monolithic designs (Velepucha & Flores, 2023). Each production stage, including carbonization, milling, mixing, briquetting, drying, packaging, and marketing was considered as a module. Additionally, the prototype uses lightweight, open-source technologies optimized for low-resource and low-bandwidth environments. The backend is developed using PHP version 8 programming language due to its low cost, wide developer familiarity, and efficient server-side processing. The frontend is powered with React.js version 18.2 JavaScript library, offering modern reusable components design with responsive and scalable interface across web and mobile platforms. MySQL version 10.4 serves as the database Management System, providing reliable, structured data management with minimal resource demands. To ensure inter-service communication, token-based authentication and future integration between modules, a RESTful API architecture is adopted. This stack balances cost-effectiveness, scalability, and ease of maintenance, making it ideal for rural and peri-urban deployment.

3. Results and System Design

This section presents key insights from the Future Workshop (FW) and follow-up FGD, which identified challenges in data coordination, traceability, and digital literacy within green charcoal production. These findings directly guided the development of a modular digital platform designed to manage research data more effectively. Informed by the FW report, Kevin et al., (2024), and the requirements specification document developed from the FGD the system features microservices, role-based access, and batch tracking tools tailored to stakeholder needs and real-world conditions.

3.1. Insights from the Future Workshop and Focus Group Discussion

Engagements during the Future Workshop and subsequent focus group discussions surfaced three critical themes: the need to improve community sensitization and digital skills; the absence of reliable data on production and distribution; and the demand for product traceability and quality control. Participants expressed concern over weak coordination among key actors, including producers, researchers, and implementing institutions, which hampers effective collaboration and data use. In response, the system incorporates a batch-tracking microservice that records each production lot from the point of raw material intake to the final packaging stage, addressing supply chain visibility gaps. To strengthen coordination, a shared dashboard was developed, offering producers, researchers, and project coordinators access to real-time data on production activities, field logs, and delivery schedules. Recognizing the digital capacity limitations among users, the platform includes multilingual support and intuitive data entry workflows tailored to varying literacy levels. These features directly reflect user-identified needs, ensuring that the platform is grounded in locally informed challenges and priorities.

3.2. Modular Microservices and Batch Tracking

The core functionality of the system is delivered through a suite of modular microservices, each mirroring a distinct stage in the production value chain. A unified batch tracking mechanism underpins all modules, ensuring that every input, process step, and output is tagged with a unique batch identifier for end-to-end traceability and real-time data validation. At the start of the workflow, raw materials arriving via the Transport Module are assigned a batch number, which accompanies them through each subsequent service. This flow is depicted in Figure 1.

IJBEST ISSN (2959-586X) and ISBN (978-9970-9943-4-2)

1. The Transport Service monitors the delivery of raw materials to the production site, capturing key data such as vehicle type, fuel use, distance, and material weight. It enables tracking of logistics and environmental impact while supporting planning through auto-calculated fuel and emissions estimates. Timestamped entries and personnel records enhance transparency and accountability in resource mobilization.
2. Carbonization Service receives the tagged raw biomass with a batch number. It logs the type of feedstock, carbonization method (e.g., drum, pit kiln), temperature profile, duration, and char yield. The resulting char inherits the batch ID, creating a continuous record from raw input to carbonized output.
3. Milling and Binder Preparation Services. Carbonized material and binders enter separate but parallel services. The Milling Service logs batch-specific parameters such as mill settings, particle size distribution, and storage conditions. Binders, when required, are also processed through this module. Simultaneously, the Binder Preparation Service captures binder source, type, formulation ratios, and viscosity, assigned sub-batch numbers, which are linked to the parent production batch, enabling flexible batching logic.
4. Mixing Service. Milled char and prepared binder converge under one batch ID. Users input mix ratios, mixing duration, and moisture measurements, while the system's built-in validations flag deviations from optimal thresholds. This is to ensure consistency in feed mix formulation before moving to compaction.
5. Briquetting Service. The mixed material is then processed, and extrusion pressure, temperature (if applied), throughput volume, and the number of briquettes produced, tagged with the originating batch number, are tracked. Machine performance metrics and any line stoppages are also logged against this batch, enabling root-cause analysis of yield losses.
6. Drying Service. Wet briquettes transfer to the Drying Service. This module logs drying method (sun or mechanical), duration, ambient environmental conditions, and post-drying moisture content. Any deviations from optimal drying curves are flagged, and results are logged under the active batch.
7. Packaging Service. Finally, dried briquettes enter the Packaging Service, where each batch is assigned packaging details-such as pack type, weight per unit, labeling information, and storage location. This marks the completion of the production cycle for that batch for traceability and reporting.

Together, these modules form a digitally linked chain, where the batch number acts as a central reference. At each stage, user input forms are preloaded with the batch ID, reducing duplication, minimizing error, and maintaining a unified data thread. This allows producers, researchers, and regulators to trace any production run from end to end, identify inconsistencies, and assess efficiency over time.

IJBEST ISSN (2959-586X) and ISBN (978-9970-9943-4-2)

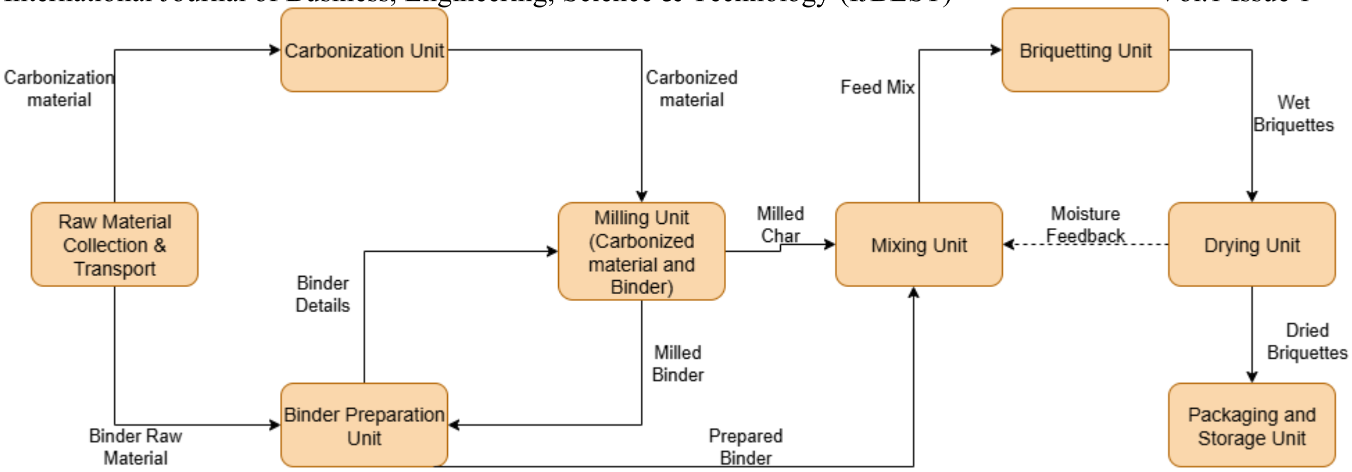

Figure 1: Illustrate the batch-tracked process flow of Green Charcoal Production across the modular microservices

3.3. System Architecture

The platform adopts a layered, modular architecture designed for scalability, security, and real-time data flow (Laigner et al., 2021). Users access role-specific dashboards via web or mobile, with secure authentication managed centrally. Functional modules, covering each production stage, operate as independent microservices connected through RESTful APIs. Between the microservices and the API gateway, the platform is configured with a load balancer to manage in- and out-going traffic load. The is particularly important for scalability and reliability of the platform. A centralized data storage layer configured with a database to supports batch-level data tracking and system logging, ensuring efficient operations and a secure, streamlined user experience. Figure 2 is an illustratration of the microservice architecture.

3.4 User Access Interface

As illustrated in Figure 3, the system provides a responsive, multilingual interface with flexible role-based access for producers, researchers, regulators, marketers, and administrators. The system accommodates users with multiple or overlapping roles by allowing administrators to assign combined permissions, enabling access to relevant tools across different functional areas. While each user group primarily sees tools most relevant to their role, the interface dynamically adapts based on assigned secondary roles, minimizing information overload while maintaining comprehensive access. The system outputs (reports and others) also have configurable visibility settings and this enables configuration of granular data access among user groups and maintaining confidentiality levels required. This flexible approach supports efficient task execution across all devices while accommodating the interconnected nature of stakeholder relationships in the UPCHAIN project.

3.5 Mobility and Offline Data Capture Workflows

Most of these online systems assume constant connectivity which is impractical in the rural area where network coverage is poor and data bundle plans are expensive. The emphases of the participants to have a system that works reliably in the offline setting prompted the creation of a similar version of the mobile system that has offline capabilities and delayed synchronization workflow. The producers/researchers records/capture data, stores then locally on their device (mobile or desktop particularly in the established centers) and wait to be synchronized. After loading data or gaining connection to the internet, they automatically upload and reconcile the records with the central server through light weight synchronization technique. It was so as to strike the balance between flexibility of field work and centralized reporting and monitoring.

3.6 Architectural Rationale, Security, and Extensibility

The microservices architecture ensures scalability, modularity, and fault tolerance, allowing independent updates and smooth integration via RESTful APIs. Security is enforced through role-based access control and data encryption, safeguarding sensitive information. Its modular design also supports future expansion as user needs evolve.

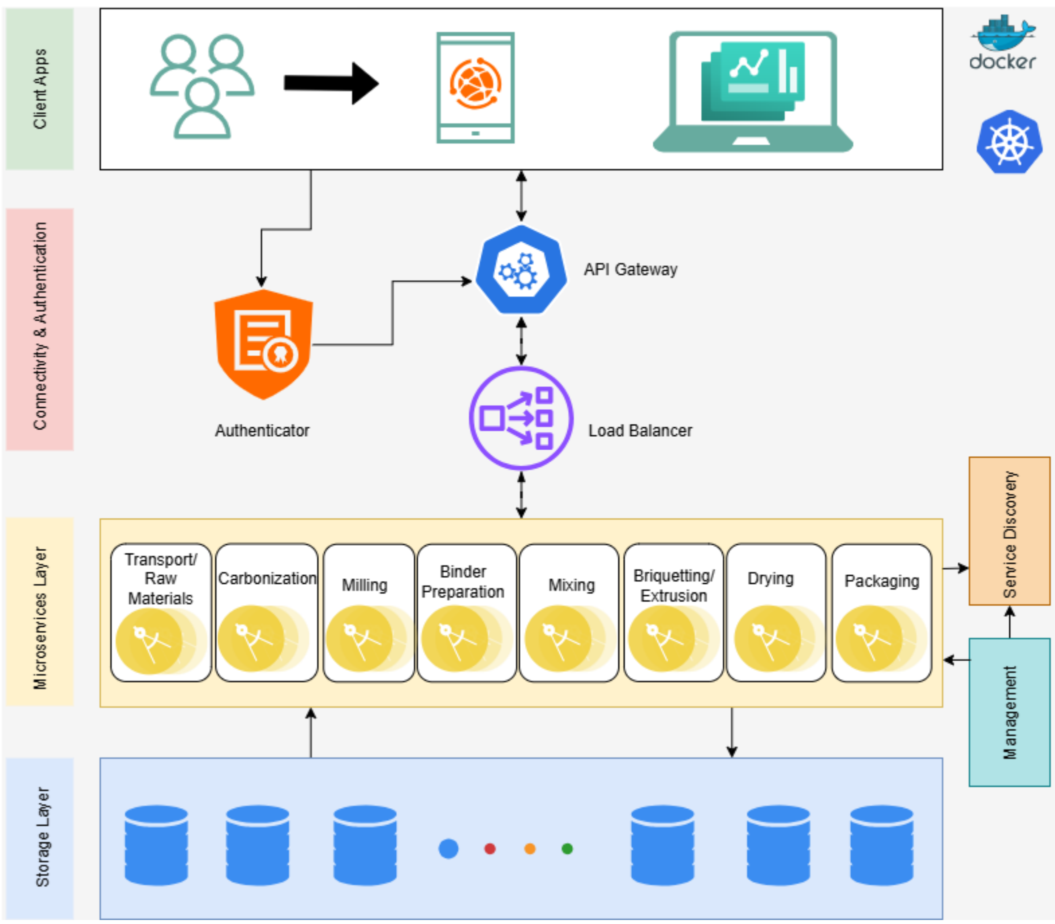

Figure 2: A Microservice Architecture for Green Charcoal Production

IJBEST ISSN (2959-586X) and ISBN (978-9970-9943-4-2)

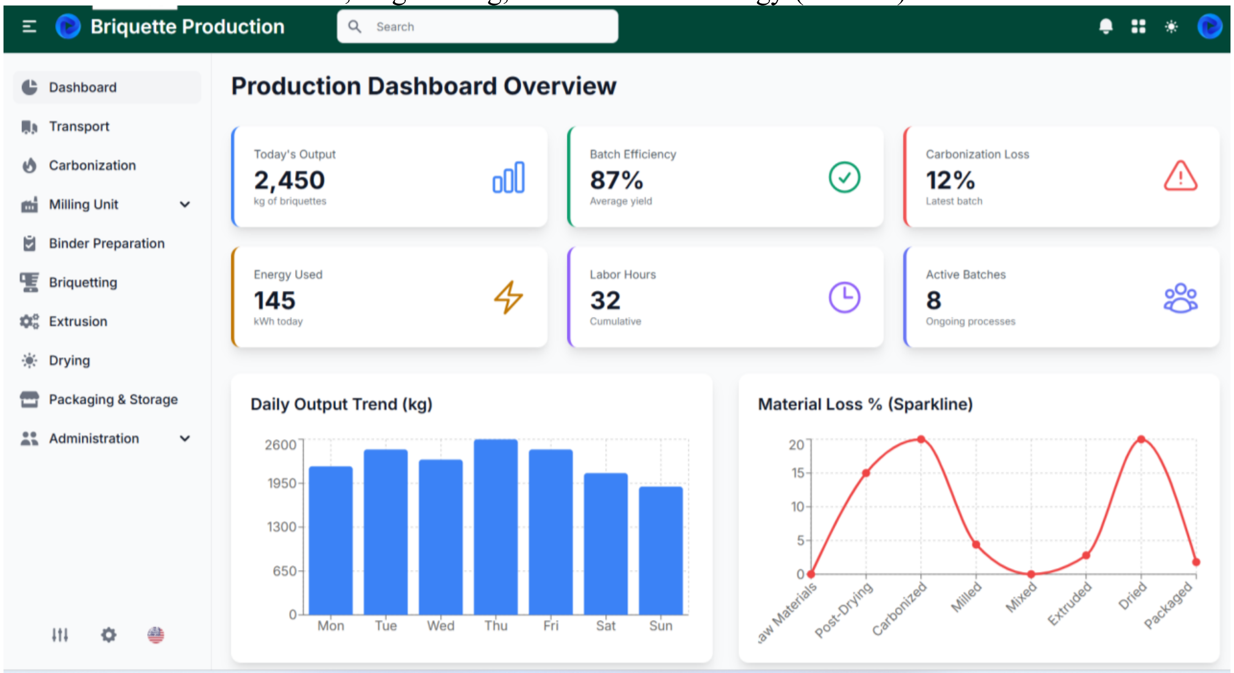

Figure 3: A Dashboard for Green Charcoal Production Data Management System

4. Discussions

The development of the Collaborative Platform for Green Charcoal Production Data Management should be considered not only from the perspective of the technical design but also its alignment to the broader ecosystem of digital platforms for biomass monitoring and environmental monitoring. Across the bioeconomy, a range of platforms have sprung up to support functions such as traceability, supply chain optimization, carbon accounting and geospatial monitoring. These efforts illustrate the promise of digital tools, but all too often they are targeted to narrow domains, industrial contexts or driven by donors. Positioning our platform within this landscape is important in order to underscore both the intersections and the gaps that the platform aims to fill.

Körner et al., (2025)describes a digital Monitoring, Reporting and Verification (dMRV) systems that combine sensor data to produce reports for environmental and carbon accounting but these depend on constant connectivity and therefore are not suitable for smallholder briquette producers. Le, (2022) outlines a big data architecture where data on biomass is aggregated with Hadoop and analytics done at-scale, but there are no offline workflows or mobile interfaces as producers considered essential. Bastos, Matias, et al., (2025; Bastos, Nunes, et al., (2025) demonstrate marketplace tools for optimization of biomass logistics and linking suppliers with buyers, while the Biochar App demonstrates the potential of mobile tools for recording pyrolysis data, calculating carbon credits and supporting MRV. But both approaches do prioritize financial accounting over the day-to-day realities of small producers. Similarly, Atmosfair's biochar monitoring system tracks household production of biochar for carbon credit schemes, but is donor- and registry-driven. At the industrial level, ICT-BIOCHAIN platform and Digital twin biomass energy for energy processes provide regional policy and industry coordination digitalization (instead of decentralized context), predictive maintenance, real-time sensor integration and energy optimization (Akhator & Oboirien, 2025; Dapkute et al., 2024), but these architectures require continuous telemetry and stable infrastructure hardly existing in village briquette production All, when compare, it becomes clear that most of the highlighted platforms remain either industrial oriented, donor-driven carbon markets, leaving the small holders' producers under served.

Against this background, a unique contribution of the Collaborative Platform is the translation of locally expressed challenges (e.g., inconsistencies in quality, downtime of machines, fluctuations in raw material prices, limited connectivity) into digital functions with a stronger focus on producer empowerment, the offline-first use, and collaborative market linkages. This comparative positioning gives us the basis to explore the fundamental dimensions of the platform, which are covered in the sections that follow: System Capabilities and Intended Use, Functional Modules and Operational Capabilities, Data Reporting and Community Insights, Modeling Production Efficiency and Innovation, and Future Validation and Impact Strategy.

4.1. System Capabilities and Intended Use

The system represents a transformative approach to enhancing the efficiency and sustainability of the green charcoal value chain, integrating advanced data management techniques with participatory design to empower stakeholders, producers, researchers, and regulators. This section explores the functional capabilities of the system, its reporting mechanisms, and the intended uses that collectively foster innovation and improve coordination within the industry.

4.2. Functional Modules and Operational Capabilities

Each microservice within the developed system is designed to generate targeted outputs that support data-driven decision-making, operational monitoring, and performance optimization across the green charcoal production process. This modular approach aligns with current system design principles, where microservices are preferred for their scalability, flexibility, and ability to support distributed, domain-specific development (Bai & Song, 2024; Lyu et al., 2020). The carbonization module, for instance, produces batch-linked logs that help assess feedstock suitability, char yield, and emissions, reinforcing findings by Chen et al. (2020) on the role of real-time monitoring in improving fuel efficiency and carbon retention. Qu et al., (2024) further demonstrate how integrated observational data, such as satellite inputs, can enhance accuracy in biomass emission tracking. The milling and binder preparation modules track granule uniformity and binder formulation, ensuring upstream input quality, which Yirijor & Bere, (2024) and Saeed et al., (2021) highlight as critical for densification and briquette durability. The mixing module captures data on formulation ratios and moisture levels, aligning with best practices outlined Obi et al., (2022), who note the importance of moisture control for briquette structure and combustion efficiency. Briquetting and drying modules generate mechanical and environmental parameters necessary for maintaining product consistency and minimizing energy consumption, echoing the findings of (Obi et al., (2022) and thermogravimetric analyses by Saeed et al., (2021) on degradation profiles. Finally, the packaging module maintains traceability by linking final products to their original batches, an approach consistent with agri-food traceability frameworks Aung & Chang, (2014) and emission accountability systems in biomass processing (Singh & Singh, 2025).

IJBEST ISSN (2959-586X) and ISBN (978-9970-9943-4-2)

Collectively, these microservices produce a transparent, real-time data ecosystem that allows producers to identify inefficiencies, enables researchers to model performance, and equips regulators to monitor compliance. Unlike monolithic systems, this batch-tracked architecture enhances coordination, supports continuous learning, and fosters adaptive innovation, traits essential to digitally enabled bioenergy transitions (Sorrell, 2018).

4.3. Data Reporting and Community Insights

The system transforms routine production data into real-time, actionable insights through tailored visual dashboards and reports. It captures data at every production stage and generates role-specific analytics, such as batch efficiency, production volumes, char quality trends, and user activity logs, to support informed decision-making, transparency, and operational improvement. Producers, researchers, and regulators each access customized reports suited to their needs, enabling performance tracking, resource planning, and quality monitoring. Designed for inclusivity, the dashboard accommodates varying digital literacy levels and promotes participatory engagement. Overall, these tools foster a culture of data-driven decision-making, collaboration, and continuous learning within the green charcoal ecosystem.

4.4. Modeling Production Efficiency and Innovation

The system collects detailed data on feedstock properties, processing conditions, and output quality, enabling in-depth analysis of production efficiency. It allows researchers and producers to evaluate performance metrics like char yield per kilogram of biomass, binder-to-char conversion efficiency, and moisture reduction during drying across various techniques, equipment configurations, or raw materials. Scenario analysis tools help explore hypothetical situations, assessing potential impacts on yield and processing time. This data-driven decision-making helps optimize inputs, minimize waste, and predict production performance across different operational setups. The system promotes ongoing innovation by grounding experimentation and learning in reliable data. It enables communities to pinpoint successful batches linked to specific locations or processing methods and replicate or modify those approaches in future production cycles. The accumulation of data allows trend tracking and predictive analysis, encouraging producers to refine processes, test alternative feedstocks, or adopt emerging technologies. This platform not only optimizes current practices but also builds a culture of digital fluency and collaborative development, advancing sustainable livelihoods and environmental responsibility within Uganda's green charcoal industry.

4.5. Future Validation and Impact Strategy

The system, developed based on user input, will be piloted in three stakeholder regions to validate usability, functionality, and adoption among producers, researchers, and local authorities. It is designed to support green charcoal innovation by enhancing coordination, training, and evidence-based decision-making. Future integration with mobile money, IoT sensors, and national sustainability systems is envisioned. Overall, the system offers a comprehensive, community-driven approach to improving efficiency and transparency in green charcoal production. With its modular design and strong emphasis on stakeholder engagement, it holds the potential to strengthen Uganda's green energy sector and contribute to inclusive digital transformation.

A phased rollout with pilot deployments is recommended to test system performance under real-world conditions and inform refinements in mobile usability, data validation, and offline capabilities.

Capacity-building efforts, such as user training and helpdesk support, should accompany implementation. Technically, future development should prioritize database decoupling, service mesh integration, and asynchronous data handling to support system scalability. Collaboration with policymakers and funders is essential to align outputs with national standards and sustainability frameworks, ensuring long-term relevance and impact.

5. Limitations

Although the microservices architecture simplifies data management and enhances traceability, it has drawbacks because it relies on a common MySQL database. This design was selected due to its simplicity, low cost, and suitability to integrate during the prototyping phase, yet has technical limitation including, lack of scalability, lower flexibility of unstructured information and bulky synchronization. It was a practical solution to the immediate pilot system requirement but technically can be scalable and adaptable to large scale deployments. Its modular structure can eventually be migrated to more advanced data backend such as (PostgreSQL, NoSQL), as needed. The system, too, is not as yet extensively tested in the live production settings, and accordingly, its applicability and functionality in the context of various users need to be confirmed. This represents the staged development approach with greater emphasis on codesigning and translating user needs into a working digital platform and the implementation will occur in subsequent stages with pilot performed in chosen production facilities.

6. Conclusion

This study presented the design and development of a collaborative, modular digital system tailored to the green charcoal production value chain. Informed by Future Workshops and focus group discussions, the system integrates stakeholder needs into a microservices-based platform that supports batch-level tracking, role-based access, and real-time analytics. It enhances coordination, visibility, and operational efficiency in a fragmented, low-resource sector.

The architecture and design choices offer immediate practical benefits while also laying a foundation for scalable, adaptive growth. Looking ahead, future system enhancements may include integration with mobile money platforms, GIS-based tools, IoT sensors, and predictive analytics using machine learning. These additions will strengthen the platform’s capacity to support digital transformation, climate resilience, and inclusive green energy development in Uganda.

7. Funding

This project was funded by the Ministry of Foreign Affairs of Denmark through the 2021 development research grants (Project No. 21-02-AAU), administered by the Danida Fellowship Centre. The views expressed are solely those of the authors and do not necessarily represent those of the MFA or DFC.

8. Data Availability

The data supporting this study, including workshop reports, recordings, and transcriptions, are stored in a restricted UPCHAIN Google Drive and are not publicly available due to ongoing project work and confidentiality. Access may be granted upon reasonable request to the corresponding author.

IJBEST ISSN (2959-586X) and ISBN (978-9970-9943-4-2)

References

Adekola, G., & Olumati, E. S. (2023). *Focus Group Discussion : A Research Method in Community Development*. *VII*(2454), 392–399. https://doi.org/10.47772/IJRISS

Akhator, P., & Oboirien, B. (2025). Digitilising the energy sector: A comprehensive digital twin framework for biomass gasification power plant with CO2 capture. *Cleaner Energy Systems*, *10*(October 2024), 100175. https://doi.org/10.1016/j.cles.2025.100175

Ali, N. U., Nina, P. M., J.V, P. T., Nakanwagi, R., J.O, E. K., Nur, A.-L. A., & Chanda, P. (2019). Assessment of Biomass Briquette Use As Alternative Source of Renewable Energy in Kampala District. *African Journal of Environment and Natural Science Research*, *Volume 2*(1), 68–76.

Aung, M. M., & Chang, Y. S. (2014). Traceability in a food supply chain: Safety and quality perspectives. *Food Control*, *39*(1), 172–184. https://doi.org/10.1016/j.foodcont.2013.11.007

Bai, R., & Song, X. (2024). Research on Information System Architecture Based on Microservice Architecture. *2024 5th International Conference on Information Science, Parallel and Distributed Systems, ISPDS 2024*, 606–610. https://doi.org/10.1109/ISPDS62779.2024.10667519

Bamwesigye, D., Kupec, P., Chekuimo, G., Pavlis, J., Asamoah, O., Darkwah, S. A., & Hlaváčková, P. (2020). Charcoal and wood biomass utilization in uganda: The socioeconomic and environmental dynamics and implications. *Sustainability (Switzerland)*, *12*(20), 1–18. https://doi.org/10.3390/su12208337

Bastos, T., Matias, J., Nunes, L., & Teixeira, L. (2025). Technology for Boosting Sustainability: A Web App-Based Information Model for Boosting Residual Biomass Recovery. *Land*, *14*(7), 1–20. https://doi.org/10.3390/land14071332

Bastos, T., Nunes, L. J. R., & Teixeira, L. (2025). Smart Residual Biomass Supply Chain: A Digital Tool to Boost Energy Potential Recovery and Mitigate Rural Fire Risk. *Sustainability (Switzerland)*, *17*(17), 1–21. https://doi.org/10.3390/su17177863

Dapkute, A., Siozinys, V., Jonaitis, M., Kaminickas, M., & Siozinys, M. (2024). Enhancing Industrial Process Control: Integrating Intelligent Digital Twin Technology with Proportional-Integral-Derivative Regulators. *Machines*, *12*(5). https://doi.org/10.3390/machines12050319

FAO. (2020). The State of the World's Forests. In *Geographical Review* (Vol. 14, Issue 1). https://doi.org/10.2307/208372

Ibrahim, M., S, B., & A, I. (2020). Biomass Briquettes as an Alternative Source of Cooking Fuel towards Green Recovery Post COVID-19. *Saudi Journal of Engineering and Technology*, *5*(6), 285–290. https://doi.org/10.36348/sjet.2020.v05i06.005

Jungk, R., & Mullert, N. (1987). *Future Workshops: How to Create Desirable Futures*. Institute for Social Inventions, 24, Abercorn Place, London NW8 9XP.

Kevin, A., Geoffrey, T. O., Opiyo, E. A., & Lone, D.-H. (2024). *Co-Creating Sustainable Solutions : A Report on the Future Workshop for Green Charcoal Adoption in*.

Körner, M. F., Leinauer, C., Ströher, T., & Strüker, J. (2025). Digital Measuring, Reporting, and Verification (dMRV) for Decarbonization. *Business and Information Systems Engineering*. https://doi.org/10.1007/s12599-025-00953-3

Laigner, R., Zhou, Y., Salles, M. A. V., Liu, Y., & Kalinowski, M. (2021). Data management in microservices: State of the practice, challenges, and research directions. *Proceedings of the VLDB Endowment*, *14*(13), 3348. https://doi.org/10.14778/3484224.3484232

Le, Y. (2022). Research on data resource management of biomass energy engineering based on data mining. *Energy Reports*, *8*, 1482–1492. https://doi.org/10.1016/j.egyr.2022.02.048

Lyu, Z., Wei, H., Bai, X., & Lian, C. (2020). Microservice-Based Architecture for an Energy Management System. *IEEE Systems Journal*, *14*(4), 5061–5072. https://doi.org/10.1109/JSYST.2020.2981095

IJBEST ISSN (2959-586X) and ISBN (978-9970-9943-4-2)

Mahoro, B. G., Eniru, I. E., Omuna, D., Akiyode, O., & Danson, M. (2022). *Adoption of Briquettes of Organic Matter as an Environmentally Friendly Energy Source in Uganda Department of Biological & Environmental Sciences , Renewable cooking , water heating , and heating production processes has been expanding by the Kampala . Fa*. *01*(01), 23–30.

Mainimo, E. N., Okello, D. M., Mambo, W., & Mugonola, B. (2022). Drivers of household demand for cooking energy: A case of Central Uganda. *Heliyon*, *8*(3), e09118. https://doi.org/10.1016/j.heliyon.2022.e09118

Mugabi, P., & Kisakye, D. B. (2021). *STATUS OF PRODUCTION , DISTRIBUTION AND DETERMINANTS OF BIOMASS BRIQUETTE ACCEPTABILITY IN KAMPALA CITY ,*. *2021*(23), 1–8. https://doi.org/10.4067/s0718-221x2021000100413

Njenga, M., Gitau, J. K., Iiyama, M., Jamnadassa, R., Mahmoud, Y., & Karanja, N. (2019). Innovative biomass cooking approaches for sub-Saharan Africa. *African Journal of Food, Agriculture, Nutrition and Development*, *19*(1), 14066–14087. https://doi.org/10.18697/AJFAND.84.BLFB1031

Obi, O. F., Pecenka, R., & Clifford, M. J. (2022). *A Review of Biomass Briquette Binders and Quality Parameters A Review of Biomass Briquette Binders and Quality Parameters*. *March*. https://doi.org/10.3390/en15072426

Qu, G., Shi, Y., Yang, Y., Wu, W., & Zhou, Z. (2024). Methods, Progress and Challenges in Global Monitoring of Carbon Emissions from Biomass Combustion. *Atmosphere*, *15*(10), 1–14. https://doi.org/10.3390/atmos15101247

Saeed, A. A. H., Harun, N. Y., Bilad, M. R., Afzal, M. T., Parvez, A. M., Roslan, F. A. S., Rahim, S. A., Vinayagam, V. D., & Afolabi, H. K. (2021). Moisture content impact on properties of briquette produced from rice husk waste. *Sustainability (Switzerland)*, *13*(6). https://doi.org/10.3390/su13063069

Singh, V., & Singh, A. (2025). Briquetting Technologies for Minerals and Metallurgical Applications: A Review. *Mineral Processing and Extractive Metallurgy Review*, *00*(00), 1–20. https://doi.org/10.1080/08827508.2025.2496512

Sorrell, S. (2018). Explaining sociotechnical transitions: A critical realist perspective. *Research Policy*, *47*(7), 1267–1282. https://doi.org/10.1016/j.respol.2018.04.008

Soylemez, M., Tekinerdogan, B., & Tarhan, A. K. (2024). *Microservice reference architecture design: A multi-case study* (pp. 58–84). WILEY. https://doi.org/10.1002/spe.3241

UBOS. (2020). UGANDA BUREAU OF STATISTICS, 2020 Statistical Abstract. *Uganda Bureau of Statistics*, *1*, 303. http://www.ubos.org/onlinefiles/uploads/ubos/pdf documents/abstracts/Statistical Abstract 2013.pdf

Velepucha, V., & Flores, P. (2023). A Survey on Microservices Architecture: Principles, Patterns and Migration Challenges. *IEEE Access*, *11*(August), 88339–88358. https://doi.org/10.1109/ACCESS.2023.3305687

Yayeh, F. A. (2021). Focus Group Discussion as a data collection tool in Economics. *Daagu International Journal of Basic & Applied Research*, *3*(1), 52–61. www.daagu.org

Yirijor, J., & Bere, A. A. T. (2024). Production and characterization of coconut shell charcoal-based bio-briquettes as an alternative energy source for rural communities. *Heliyon*, *10*(16), e35717. https://doi.org/10.1016/j.heliyon.2024.e35717

Yustas, Y. M., Tarimo, W. M., Mbacho, S. A., Kiobia, D. O., Makange, N. R., Kashaija, A. T., Mukama, E. B., Mzigo, C. K., & Silungwe, F. R. (2022). *Toward Adaptation of Briquettes Making Technology for Green Energy and Youth Employment in Tanzania : A Review*. 74–93. https://doi.org/10.4236/jpee.2022.104006

IJBEST ISSN (2959-586X) and ISBN (978-9970-9943-4-2)