

CIRCULAR ECONOMY COCOA: FROM BEAN TO BAR



FINAL REPORT

DOCUMENTATION OF BIOCHAR CASE STUDY

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EXECUTIVE SUMMARY

This report consolidates the findings of the Biochar Case Study commissioned under the EU-Cocoa Project. It documents and assesses three interlinked solution streams demonstrated by the project: (i) gasification systems for clean heat supply to crop drying, (ii) low-tech pyrolysis systems for biochar and wood vinegar production, and (iii) soil improvement trials combining biochar with liming, humic substances and organic fertilizer.

The analysis shows that the project has already generated credible early evidence of technical feasibility and practical relevance. Gasification performed strongly as an energy-efficiency solution for drying operations, while pyrolysis performed strongly as a decentralized circular-economy solution that converts agricultural residues into value-added soil amendments. Soil-improvement trials indicate promising agronomic benefits, especially in acidic and cadmium-affected cocoa soils, although the current monitoring period is too short for definitive long-term impact claims.

- **Technical performance:** Kanai-800 gasification achieved stable flame temperatures of about 800-1,100°C, flexible drying temperatures of 60-300°C, and reduced fuel consumption by about 40-75% compared with conventional wood, gas or electricity-based systems. Improved pyrolysis kilns generated biochar yields in the range of about 41-68%, with some feedstocks achieving IBI Class 1 quality.
- **Economic viability:** the gasification business case is strongest where there is a sustained drying demand and expensive conventional energy. The pyrolysis business case is strongest where residues are readily available on-site and both biochar and wood vinegar can be valorized. Indicative project calculations suggest payback periods of around 9-12 months for gasification and under one year for pyrolysis under favorable assumptions.
- **Environmental and social value:** both technologies reduce open burning, odors and unmanaged residue accumulation. Pyrolysis additionally creates a durable carbon-rich product with carbon-storage potential and soil-rehabilitation value, while gasification reduces local air pollution and labor intensity in drying operations.
- **Adoption and scalability:** users were generally positive and willing to continue, but scale-up will depend on lower upfront costs, improved training, better kiln fit-for-purpose, clearer product use guidance, and development of a more reliable biochar market and MRV-ready operating system.

Overall, the case study concludes that the project has successfully demonstrated a strong circular-economy model with high relevance for agri-food value chains in Vietnam. Gasification should be positioned primarily as a clean heat and drying solution. Pyrolysis should be positioned primarily as a circular residue-management, soil-health and future carbon-market solution. A combined deployment strategy is likely to deliver the highest system-wide value.

- **Prioritize use-case matching:** deploy gasification where heat demand is continuous and deploy pyrolysis where residue conversion, soil improvement and carbon co-benefits are the main objective.
- **Strengthen operational quality:** improve feedstock drying protocols, operator training, kiln sizing, smoke control, wood-vinegar handling and product-use guidance.
- **Prepare for scale-up:** develop biochar market channels, a project-level monitoring plan, and a simplified MRV framework aligned with Carbon Registry for future carbon-credit readiness.

1. Introduction

1.1. Background

This report documents and independently assesses biochar-related solutions developed under the EU-Cocoa Project, Circular Economy Cocoa: From Bean to Bar. The assignment responds directly to the Terms of Reference, which call for evidence-based documentation of pyrolysis, gasification, and soil-improvement practices developed in the Central Highlands and the Mekong Delta, with a focus on lessons for replication and decision-making.

Across the project portfolio, biochar has been promoted as a circular economy solution that can convert agricultural by-products into higher-value outputs: biochar for soil or other uses, wood vinegar in some systems, and useful heat for drying in gasification systems. The expected value proposition combines waste reduction, reduced open burning, improved soil performance, additional farmer income opportunities, and the longer-term possibility of alignment with carbon removal standards.

This case study is not a full impact evaluation. It is a formative synthesis of available evidence from project reports, technical demonstrations, trial results, and stakeholder feedback. Its purpose is to consolidate what has been tested, what appears promising, where operational barriers remain, and what would be required to move selected models toward wider deployment or toward carbon-project readiness.

1.2. Objectives of the report

The overall objective is to document and analyse the biochar solutions developed under the EU-Cocoa Project and to provide an independent, practical assessment of their technical performance, early economic and environmental value, user feedback, and replication potential.

- Document the main biochar-related technical solutions, including three pyrolysis kiln versions, two gasification pathways, and soil-improvement formulas used in practice.
- Assess indicative technical, economic, social, and environmental performance using qualitative and semi-quantitative evidence.
- Capture user experience from farmers, cooperatives, enterprises, experts, and project partners.
- Review the current level of alignment of selected technologies with carbon removal standards, especially Global Artisan C-Sink and Puro Biochar Methodology 2025.
- Propose practical recommendations for operation, scale-up, and future carbon-readiness work.

1.3. Scope of assessment

Dimension	Scope covered in this report
Technologies	Gasification (Kanai-800 and related heat-transfer systems); Pyrolysis versions 1, 2 and 3; soil-improvement trials using biochar-based formulas
Geographic focus	Project demonstrations in Dak Lak, Gia Lai, Lam Dong, Khanh Hoa, Vinh Long, Kien Giang, Ho Chi Minh City and related supply-chain nodes

Dimension	Scope covered in this report
Stakeholders	Farmers, cooperatives, enterprises, project staff and technical experts
Assessment lens	Technical performance, economic viability, environmental and social effects, adoption barriers, scalability conditions and future C-sink readiness

2. Methodology and data sources

2.1. Methodological approach

The report follows a documentation-plus-assessment approach. It combines desk review of project and standard-setting documents with case comparison, extraction of operational evidence, and synthesis of interview findings. The assessment is independent in the sense that it distinguishes between demonstrated evidence, plausible interpretation, and items that remain uncertain.

2.2. Secondary data review

The document review covered: (i) The project reports on Trong Duc'gasifier, Kanai-800 gasifier for Nhat Tam Cooperative, economic-environmental assessment of Kanai-800, reports on pyrolysis kilns ver 1, 2 and 3; (ii) the cadmium reduction and soil-improvement reports; and (iii) standards and principles relevant to carbon-removal readiness, including Global Artisan C-Sink / CSI principles and Puro Biochar Methodology 2025.

2.3. Primary data collection

Primary evidence was assembled from the interview compilation provided for this assignment and from field-based observations described in the project reports. The consultation pool covers farmers, cooperatives, enterprises, technical experts, and project actors. Both on-site and online interviews are referenced in the source material.

2.4. Stakeholders consulted

Stakeholders consulted in the source material included cooperative managers, farmer-users of pyrolysis kilns, enterprises testing or receiving kilns, technology designers, technical experts on biochar and soil, and value-chain actors such as Marou. Their feedback is used in this report as qualitative evidence of implementation experience, operational fit, and user demand.

Evidence source	What it shows	Status	Notes / gaps
Reports: 1/ Report on the results of the survey on the current status of cocoa-growing areas, chocolate processing factories, and consulting on the treatment of by products and waste from cocoa pod	Drying performance, fuel use, cost savings, biochar co-product	Yes	Not designed as a carbon-project dossier

husks and farms by Cacao Trong Duc Co. Ltd. 2/ Report on the results of the implementation of a gasifier for heat supply to the rotary dryer system by Sai Gon Water and Environment Co., Ltd. 3/ Technical Description Document for the Kanai 800 Industrial Gasifier by Sai Gon Water and Environment Co., Ltd. 4/ Assessment of the Economic and Environmental Effectiveness of the Kanai-800 Gasifier by Sai Gon Water and Environment Co., Ltd.			
Reports: 1/ Report on the production and application of Biochar from Cocoa for Puratos Grand – Place Vietnam 2/ Report on the development and demonstration of a Cocoa – based biochar production model for Marou Chocolate Joint Stock Company in Vietnam 3/ Report on scaling up the Pyrolysis biochar kiln model in Vietnam’s agricultural and food sectors	Evolution of pyrolysis model, training, deployment, product quality	Yes	Operational monitoring uneven across sites
Reports: 1/ Report on Cadmium reduction solutions at the farm level for the Cococa – Chocolate supply chain of for Marou Chocolate Joint Stock Company in Vietnam 2/ Biochar: An Effective Solution for Improving Soil Quality and Increasing Productivity. Case Study: Biochar Application in the Cocoa-Growing Area of Chau Thanh, Ben Tre	Agronomic effects, pH and Cd response, role of NT3 and NT5	Yes	Long-term follow-up still limited
Interview compilation	Practical user feedback, barriers, willingness to continue	Partial	

Reports: Standard for Carbon Sink Certification for artisan biochar production Puro Biochar Methodology - Edition 2025	External carbon- readiness benchmark	Yes	Used as reference, not certification result
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2.5. Analytical methods

The report applies descriptive synthesis, cross-case comparison, indicative cost-benefit review, and qualitative assessment of enabling conditions and barriers. For carbon-readiness, the report uses a gap-based approach against key eligibility areas: technology, feedstock, emissions, monitoring, product quality, end-use traceability, and durability of storage claims.

2.6. Limitations

Several limitations affect the strength of conclusions. First, several demonstrations were still at an early stage at the time of interview, limiting evidence on sustained performance and adoption. Second, economic calculations in the project summary are partly assumption-based and should be read as indicative business cases rather than audited financial statements. Third, the agronomic trial period for soil improvement was short, so conclusions on durable yield, cadmium reduction and soil restoration remain provisional. Fourth, due to data gaps in CH₄/N₂O/CO emission profiles, H/Corg ratios, digitalized MRV and end-use traceability, any conclusions regarding 'carbon project readiness' should be interpreted strictly as a preliminary suitability assessment rather than a formal certification of standard compliance.

3. Overview of biochar solutions under the project

3.1. Role of biochar in the circular economy model

Within the EU-Cocoa Project, biochar functions as a circularity tool that converts agricultural residues into products and services with both local and climate-related value. In the project logic, residues that would otherwise be burned, left to decompose, or used at low value are redirected into biochar production. Depending on the technology pathway, the system may also deliver wood vinegar or clean heat for crop drying.

The circular economy case rests on four linked claims: residue management improves, useful outputs are generated, selected agronomic or energy costs can be reduced, and carbon can potentially be stored for longer periods if biochar is used in suitable end applications.

3.2. Main solution groups

- Gasification systems: systems designed primarily to provide clean hot air for drying while co-producing biochar.
- Pyrolysis kilns: small-scale, less complex systems designed to produce biochar, and also recover wood vinegar.
- Soil-improvement formulas: field-tested formulas using biochar alone or in combination with humic acid, organic fertilizer, and lime.

3.3. Geographic and implementation coverage

- Regarding gasification, the project generated two different levels of evidence. At Cacao Trong Duc Company, an early-stage gasification configuration was tested to explore the technical feasibility of converting cacao husk residues into heat for drying. However, this case should be treated as a pilot and learning case rather than an active operating model, as the first experimental configuration was not sufficiently stable, had limited capacity, and was not continued by the enterprise due to resource and investment-incentive constraints. By contrast, the Kanai-800 system at Nhat Tam Cooperative represents the main operational gasification case under the project, with clearer evidence of practical application, integration into drying operations, and user acceptance.
- The solutions have been implemented across various maturity levels: progressing from initial surveys, testing, and technology selection to equipment refinement and model scaling, culminating in the transfer of 19 pyrolysis units and field deployment across multiple sites in Dak Lak, Gia Lai, Lam Dong, Dong Nai, Kien Giang and Ho Chi Minh City.
- In terms of soil improvement, trials conducted at a 3-year-old cocoa plantation (Mr. Nguyen Van Chinh 's famer) and a 20-year-old plantation (Mr. Nguyen Van Bay's famer) in Ben Tre/Vinh Long provide the most robust agronomic evidence within the project's documentation portfolio.

4. Technical solutions

4.1 Gasification Systems

In response to business needs to:

1. Address the environmental pollution caused by discarded cacao husks and other biomass residues. Each year, Cacao Trong Duc company generates approximately 1,000 tonnes of cacao husk waste, while Nhat Tam Cooperative generates around 200 tonnes, excluding other agricultural residues.
2. Solve the challenge of preserving cacao materials and other agricultural products during the rainy season, when high humidity increases the risk of spoilage and mould.

Helvetas Vietnam supported the testing and development of gasification solutions at different levels of maturity. At Cacao Trong Duc Company, an early experimental gasification configuration was tested as part of the project's technology exploration process¹. At Nhat Tam Cooperative, the Kanai-800 system represents the more mature and operationally relevant gasification model, designed to provide controllable hot air for rotary drying while co-producing biochar². In practice, gasification was applied primarily as a clean heat solution for agricultural drying.

Early pilot at Cacao Trong Duc Company

¹ Report on the results of the survey on the current status of cocoa-growing areas, chocolate processing factories, and consulting on the treatment of by products and waste from cocoa pod husks and farms by Cacao Trong Duc Co. Ltd.

² Report on the results of the implementation of a gasification furnace for heat supply to the rotary dryer system by Sai Gon Water and Environment Co., Ltd.

Between March and June 2024, the project conducted field assessment and testing of gasification configurations at Cacao Trong Duc Company using cacao husk residues. The pilot generated useful technical learning on residue-based heat generation, flame stability, hot-air production, and biochar quality. Test results indicated that dried cacao husks could be gasified and that the system could produce useful heat for drying applications, while biochar samples showed potentially valuable characteristics for soil-related use.



Figure 1: A semi-industrial Torch Updraft Gasifier at Trong Duc Cacao Company

Main operational case: Nhat Tam Cooperative

The Kanai-800 system at Nhat Tam Cooperative should be regarded as the project's main operational gasification case, as it provides the clearest evidence of field application, practical drying use, user satisfaction, and continued interest in replication.

The Kanai-800 system was designed to convert dry biomass residues such as macadamia shells, cacao husks, rice husks, cashew shells, coffee husks, and biomass pellets into syngas and hot air for a rotary drying system (Figure 2).³

- Indicative technical specifications reported by the project include flame temperatures of 800-1100°C, fuel consumption of about 70 kg/h, a continuous burning time of about 2.5 hours per batch, airflow of about 30,000 m³/h, and drying temperatures adjustable between roughly 60 and 300°C.
- The system was reported to reduce fuel consumption by around 40-75% compared with wood, gas or electricity, while shortening drying time by around 10-15% and maintaining stable operation in all weather conditions.
- The gasification system also produced a biochar co-product with carbon content over 55%, creating an energy-material circularity loop rather than a single-output heat system.

³ Technical Description Document for the Kanai 800 Industrial Gasification Furnace by Sai Gon Water and Environment Co., Ltd.

From an assessment perspective, gasification use of agricultural residues, reduction of uncontrolled burning and potential co-production of biochar make it relevant to a broader circular-economy and low-emission strategy.

Ms. Nguyen Hong Thuong, Director of Nhat Tam Cooperative: "My neighbor stopped by while we were operating the system and asked in surprise, 'Where is all the smoke?'"



Figure 2: Kanai-800 system at Nhat Tam Cooperative

The project experience indicates that gasification adoption depends not only on technical feasibility, but also on system stability, appropriate capacity, feedstock preparation and user resources. The Cacao Trong Duc case provided useful early-stage technical learning, while the Kanai-800 system at Nhat Tam Cooperative provides stronger evidence of operational fit and practical application. Future replication of gasification should therefore prioritize sites where drying demand, biomass residue availability, operator capacity, and commercial motivation are clearly aligned.

4.2 Pyrolysis Systems

The project applied pyrolysis technology to convert biomass residues, particularly agricultural by-products, into biochar and wood vinegar under oxygen-free or oxygen-limited conditions. The kiln system was designed to combine direct and indirect pyrolysis, with the objective of improving carbon recovery efficiency and enhancing the quality of co-products.

This pyrolysis kiln utilizes a specialized design to produce biochar and wood vinegar.

Key features include:

Structure: a 1m³ cylindrical body containing 12 biomass canisters (named ‘pyrolysis boxes’, 1/3 total volume) positioned symmetrically around a central gas flue.

Carbonization Process: Additional biomass is packed into the gaps between the canisters burning this external material heats and carbonizes the biomass inside the sealed canisters.

Components: The kiln features a bottom air intake and a top-mounted wood vinegar collection unit.

Operation: Pyrolysis lasts 24–48 hours, regulated by the air intake opening and fan usage.

Conversion Rate: 41.4% to 67.8% of input biomass is converted into biochar, varying by feedstock type.



To optimize operational performance and product quality, the kiln technology was progressively improved through three major development stages (Figure 3).^{4,5,6}

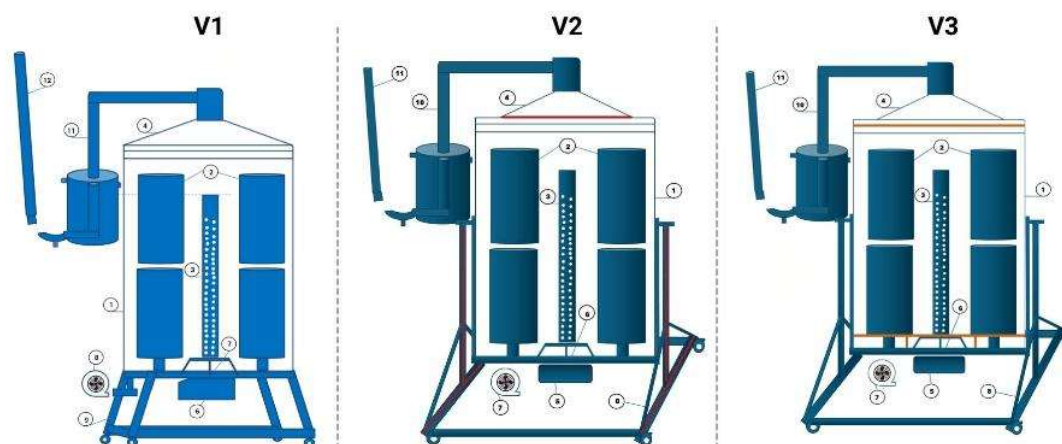


Figure 3: Pyrolysis Kiln models.

- Version 1

The first version featured a basic vertical kiln design capable of producing biochar while also recovering wood vinegar.

⁴ Report on the production and application of Biochar from Cocoa for Puratos Grand – Place Vietnam

⁵ Report on the development and demonstration of a Cocoa – based biochar production model for Marou Chocolate Joint Stock Company in Vietnam

⁶ Report on scaling up the Pyrolysis biochar kiln model in Vietnam’s agricultural and food sectors

However, this initial configuration had several limitations. The kiln height was too great, making biomass loading and biochar recovery difficult and labor-intensive. In addition, wood vinegar frequently leaked along the kiln wall, reducing collection efficiency and overall system performance.

- Version 2

The second version introduced important design improvements to address the operational constraints observed in Version 1.

First, the kiln base was redesigned to reduce the height of the kiln body (from 2.2m to 2.0m). The revised structure also allowed the kiln to tilt or rotate around its axis, which significantly improved installation, unloading, and biochar recovery.

Second, the kiln lid design was modified so that the lid opening was positioned inside the kiln body. This enabled condensed wood vinegar to flow directly into the collection system, rather than leaking outside the kiln, thereby improving recovery efficiency.

- Version 3

The third version represents the most advanced and technically refined design, with six major engineering improvements.

1. *CNC cutting and synchronized welding*

Manual cutting was replaced by CNC fabrication, resulting in a much higher level of precision and airtightness. This significantly reduced oxygen intrusion, thereby preventing partial combustion of biochar into ash.

2. *Internal suspension frame and load-bearing rotating shaft*

The kiln body was redesigned with an internal suspension frame concealed within the ceramic fiber insulation layer. This structure enables a single operator to tilt and rotate the kiln smoothly during unloading, reducing labor requirements and improving handling safety.

3. *Safety twist-lock mechanism for internal containers*

The 12 internal pyrolysis containers were fitted with removable lids equipped with a twist-lock mechanism, eliminating the risk of lid displacement or detachment during high-temperature operation.

4. *Stainless steel support rack for internal containers*

A stainless steel 304 support frame was added to secure the 12 containers in place and create uniform “thermal gaps,” allowing hot gases to circulate more evenly throughout the kiln.

5. *Reinforced kiln rim and improved lid sealing*

The kiln wall rim was made thicker to improve structural durability. At the same time, the lid was positioned inside the kiln opening, which helped eliminate wood vinegar leakage and improve sealing performance.

6. *Dedicated accessory box*

A stainless steel 304 accessory box was added to store the air blower and battery, reducing the risk of misplaced components and improving operational convenience.

Overall, the three kiln versions show a clear progression from a basic manually fabricated system to a high-precision, operator-friendly, and better-sealed design. Among that, version 3 achieved the highest level of technical maturity, with improved airtightness, safer internal container handling, better thermal circulation, greater durability, and more convenient operation.

From a technical perspective, the transition from manual fabrication to CNC-based construction, together with structural and sealing improvements, substantially increased system reliability and reduced the risk of oxygen ingress, which is critical for stable pyrolysis and high-quality biochar production. The improved pyrolysis kiln has an approximate volume of 1 m³, can process multiple types of biomass, and integrates direct and indirect heat transfer in one batch. It is designed with stainless steel 304, ceramic insulation, detachable parts, and mobility features to enable use at farm or cooperative level.

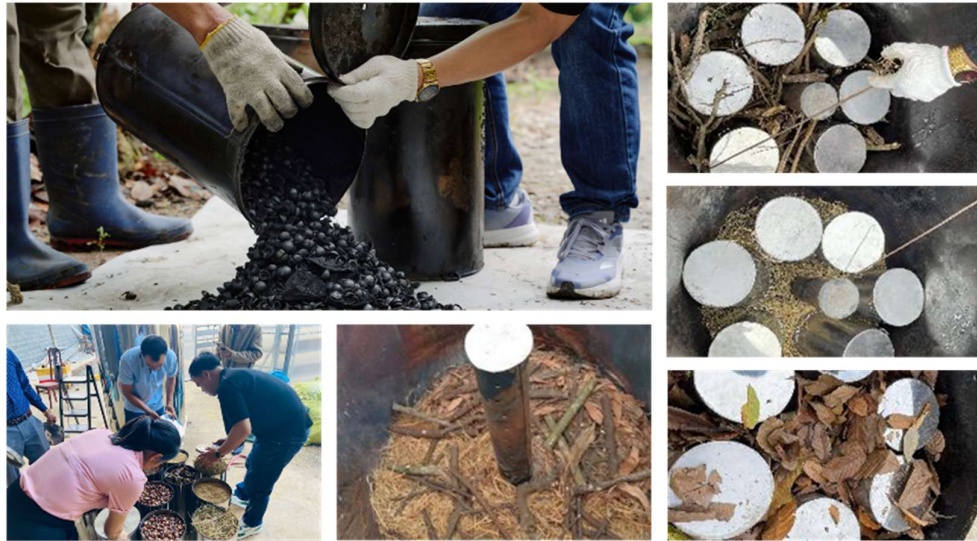


Figure 4: Feedstock and operating condition

The pyrolysis kilns were tested with cocoa pod residues and a wider range of agri-biomass, including rice husk, macadamia shell, coffee husk, coconut residues, straw, branches, and medicinal residues depending on site context (Figure 4). Reports consistently note the importance of drying feedstock before use. In practice, moisture, seasonality, and feedstock heterogeneity were recurring operational constraints.

- The project reports biochar recovery rates ranging from about 41.44% to 67.85%, depending on feedstock.
- Macadamia shell and woody biomass generated the highest-quality biochar, reaching IBI Class 1, while cocoa pod, coffee husk, leaf biomass and rice straw mostly achieved IBI Class 2, and rice husk and bottom-char fractions were lower quality.
- Kiln also enabled collection of wood vinegar, which users viewed as a potentially valuable co-product for pest management and soil-related applications, although practical guidance remains insufficient.

Mr. Nguyen Dinh Thien (Dong Tien Cooperative) noted: "Since I started spraying wood vinegar, I've noticed a significant drop in pests and diseases."

4.3 Soil Improvement Trials

The soil-improvement component tested biochar-based formulas in cocoa plots affected by acidity and cadmium-related concerns in Vinh Long. The most notable formula combined biochar, humic acid, microbial organic fertilizer and lime (commonly referred to in the project materials as NT5).^{7, 8}

- The project materials report that NT5 improved both physico-chemical properties of the soil and cocoa productivity, while contributing to reduced cadmium uptake in beans through pH improvement and stabilization mechanisms.
- Trial results after six months suggest pH improvement and yield gains in the range of about 19.4% to 28.8% for NT5 relative to conventional practice in the studied plots.
- Expert interviews, however, stress that the trial duration is too short to confirm durable soil-restoration effects and that long-term follow-up of at least one to three years is still required.



Figure 4: Demo farms in Vinh Long.

Mr. Nguyen Van Bay, farmer in Vinh Long: "Initially, I was quite hesitant. However, the results from the very first harvest after applying the biochar formula truly surprised me. Noticeable improvements in soil friability and crop yields."

5. Field observations and interview synthesis

5.1 Implementation Overview

The project supported one early-stage gasification pilot at Cacao Trong Duc Company and one more mature Kanai-800 gasification system at Nhat Tam Cooperative, alongside the fabrication and transfer of 19 pyrolysis kilns to partner units across Dak Lak, Lam Dong, Gia Lai, Dong Nai and Kien Giang. Training was delivered both in-person and online, with specific modules on biochar, wood vinegar and kiln operation.

⁷ Report on Cadmium reduction solutions at the farm level for the Cococa – Chocolate supply chain of for Marou Chocolate Joint Stock Company in Vietnam

⁸ Biochar: An Effective Solution for Improving Soil Quality and Increasing Productivity. Case Study: Biochar Application in the Cocoa-Growing Area of Chau Thanh, Ben Tre.

5.2 What Worked in Practice

Across multiple interviews, users consistently valued the ability of these systems to transform biomass residues that were previously discarded, openly burned, slowly composted, or left to decompose into biochar and wood vinegar with practical and economic value.

Users of the gasification systems reported clear practical benefits for agricultural drying, including improved product quality, lower operating costs, reduced smoke emissions, and labor savings. In detail,

According to Ms. Nguyen Hong Thuong, Director of Nhat Tam Cooperative:

- The gasification kiln, using residues such as cacao husks, macadamia shells, has enabled the cooperative to dry a wide range of agricultural products, including coffee beans, cacao beans, pepper, cashew, rice, and maize.
- Previously, drying 4–5 tonnes of raw materials typically cost around VND 4.5 million. With the gasification system, this expense can now be almost avoided.
- The biochar generated from the gasifier kiln is used as bedding material in cattle housing, helping to reduce odor. After use, the bedding is applied to cooperative farms, and it can also be sold at approximately VND 15,000 per kg.
- Since adopting the gasification kiln provided through the HELVETAS-supported initiative, the working environment and surrounding neighborhood conditions have improved noticeably. Nearby residents have not perceived any negative impacts, such as smoke, whether the system is in operation or not.
- Local authorities have also proposed working with the cooperative to identify solutions for pollution caused by residues such as diseased durian peels and fruits, and to convert these waste streams into value-added products. As the cooperative continues to expand in scale and capacity, Ms. Thuong is investing a second gasifier and is also considering upgrading to a larger-capacity system.

Ms. Nguyen Hong Thuong commented: "Better product quality, lower costs, reduced smoke, and significant labor savings... I am ordering a second gasifier."

According to Mr. Duong Van Truc, Director of Sai Gon Water and Environment Co., Ltd.:

- The gasification systems successfully address two critical needs identified by enterprises and cooperatives: (1) the management of biomass residue pollution at large production sites, and (2) the demand for agricultural drying solutions during the rainy season.
- He also emphasized that the most important factor for scaling up the model is leadership with an innovation-oriented mindset, willing to learn and apply science and technology in production. He cited Ms. Thuong of Nhat Tam Cooperative as a strong example of a leader committed to combining production efficiency with environmental protection and maximizing the value of by-products.

Users of the pyrolysis systems frequently highlighted a cleaner production environment, less smoke compared with open burning, improvements in soil structure, increases in crop productivity, reductions in pests and diseases, and the potential to generate additional income from biochar, wood vinegar, and organic fertilizers. In detail:

Mr. Le Quang Truong, staff member of Nhat Tam Cooperative, reported that:

- In the past, broken branches and pruned woody biomass had to be openly burned during farm maintenance, causing smoke and environmental pollution. Since the pyrolysis kiln was introduced, these materials have been productively used instead, reducing uncontrolled burning while generating biochar.
- In addition to using biochar with fertilizers to improve soil conditions within the cooperative's own farm, he also sold 200 kg of biochar for VND 4 million

Mr. Le Quang Truong said: "I can earn money from biochar generated from agri-residuals "

Mr. Nguyen Dinh Thien, Director of Dong Tien Cooperative, noted that:

- Since using the pyrolysis kiln, the environment has become cleaner and no longer affects surrounding neighbors, contributing positively to health and well-being. He also saved time, as the kiln could operate while he continued carrying out other farming activities. Biochar applied in the farm made the soil more friable and reduced irrigation needs.
- Wood vinegar, a co-product of the pyrolysis process, was reported to be highly effective in reducing plant pests and diseases.
- Neighbors and surrounding farmers who observed the kiln expressed interest in adopting the model in order to obtain wood vinegar and biochar, although some remained concerned about the relatively high capital cost of the kiln.
- He affirmed that this is a suitable model for continued implementation by the cooperative in the coming years and also a practical demonstration model to introduce to members both within and outside the cooperative.

Mr. Nguyen Dinh Thien shared: "Operating the kiln is convenient and doesn't take much time; each batch requires only about 2.5 hours. It takes 1.5 hours for loading and 1 hour for harvesting."

Ms. Nguyen Thi Bang, Director of An Phuc Khang Medicinal Cooperative, stated that:

- She was very satisfied with the pyrolysis kiln. Previously, residues and hard plant stems remaining after hydrolysis were typically discarded in the garden. With the kiln, residue management became more convenient, cleaner, and less smoky, while also producing biochar for crop use.
- The biochar was mixed into soil for seedling production. She also observed that biochar application improved soil looseness and supported better plant growth. Although no exact figures were available, she estimated that fertilizer costs could be reduced by up to 30%.

Mr. Nguyen Van Hoang, a farmer in the Marou Coffee system in Binh Duong, shared that:

- The kiln was convenient to use and required little time. When operated near livestock housing, it also helped repel mosquitoes and insects. The biochar produced could be used as animal bedding and was found to significantly reduce livestock odour.

Mr. Nguyen Van Bay Chinh, a farmer participating in the Vinh Long biochar crop trial group, reported that:

- Fertilizer blended with biochar made the soil more friable and increased fruit production. He expressed strong satisfaction with the use of biochar-based fertilizer.
- Because his farm generates substantial residues such as woody branches and leaves, he hoped to receive a kiln through the project in order to produce biochar directly for his own farm.

Mr. Nguyen Van Bay, another farmer in the Vinh Long biochar application trial group, explained that:

- He clearly understood the role of biochar in improving soil quality, increasing soil moisture retention, reducing fertilizer needs, and increasing crop productivity. Since soil preparation is required after every harvest season, he considered biochar use to be highly necessary.
- He noted that many biochar products are currently available on the market, but their quality is often uncertain. By contrast, residues available in his own farm, including leaves and pruned branches, are abundant, with around 30% of branches and leaves pruned annually and currently underutilized. He therefore expressed a strong interest in receiving a kiln through the project so that he could produce biochar directly for farm application.
- His family is already producing organic fertilizer for farm use, using soybeans fermented with microbial inoculants. If needed, he would even be willing to purchase feedstock to produce biochar, because self-production would allow better control over product quality.

Across the interviews, users clearly expressed a willingness to continue using these systems for at least the next 3–5 years and to recommend them to others. This suggests not only user satisfaction, but also the emergence of a stronger foundation for broader replication and long-term adoption. Beyond their technical function, these systems are increasingly seen as practical tools for turning agricultural residues into cleaner production, healthier farming environments, and new value streams for rural communities.

5.3 Main User Concerns

From an independent assessment perspective, the overall user response to the project is positive; however, several recurring concerns should be recognized as material constraints to broader adoption and scale-up. The most prominent concern is the high upfront capital cost of the systems, particularly for cooperative- or enterprise-scale technologies. Users acknowledged the practical value of the equipment, but repeatedly indicated that expansion would be difficult without continued financial support. At Dong Tien Cooperative, Mr. Thien noted that wider uptake would be much more likely if the kiln price were reduced to a level affordable for farmers, while other user as Ms. Thuong similarly highlighted that the current cost remains a barrier to replication.

A second major concern is the lack of a clear and reliable market outlet for biochar if production is scaled up beyond own-farm use. While users generally recognized the agronomic value of biochar, some expressed uncertainty regarding who would purchase it on a regular basis, especially at larger volumes. This indicates that future project expansion may depend not only on technology dissemination, but also on parallel development of downstream market channels and buyer networks. This concern was explicitly reflected in Mr. Truong feedback calling for “a unit to purchase biochar” as a condition for wider adoption.

Another frequently cited concern relates to the limited practical knowledge on wood vinegar utilization. Several users successfully recovered wood vinegar, but were still unsure how to use it effectively, how to optimize its recovery, or how to translate it into a stable commercial product. This suggests that, although the technology has demonstrated potential, post-installation technical support remains necessary to ensure that users can capture the full value of all outputs. One user stated plainly that the current difficulty was that they “did not yet know how to use wood vinegar effectively.”

Operational concerns were also reported, particularly under real farm conditions. These included smoke generation, odour, long batch duration, and operational inconvenience when feedstock conditions are not optimal. In the case of Nam Truong Son Cooperative, the user reported that the system was “very smoky and had an odour” and specifically requested design improvements to reduce smoke. Ms. Bang noted that the systems could be slow, especially where pyrolysis cycles extend over 48 hours, and that performance may be reduced when biomass is wet or inconsistent.

A related issue is feedstock suitability and input requirements. Some users reported that they did not always have sufficient biomass to run the kiln efficiently at full capacity, while others had to purchase supplementary materials such as rice husk or macadamia shell, increasing operating cost and reducing convenience. In practice, this means that system viability depends not only on the kiln itself, but also on the regular availability of appropriately dry and suitably sized feedstock. One respondent noted that, because available residues were mainly small quantities of pruned branches, they would prefer “a smaller kiln” better matched to actual feedstock availability.

Users also identified a number of design and durability limitations that warrant further technical refinement. Reported issues included difficulty in removing char safely, loose seals and the need for improved heat-resistant materials for gasification system as Ms. Thuong mention. Mr. Thien said that it is insufficient chamber size of pyrolysis system. These observations suggest that, while the systems are functional and generally well accepted, further engineering improvements would enhance safety, user convenience, and operational robustness.

Finally, the duration of field-based agronomic observation still limited duration of field-based agronomic observation. Although users and technical experts reported encouraging early signs, including improved soil friability, reduced irrigation needs, and potential fertilizer savings, but the trial period need to continue to confirm longer-term impacts on yield, soil rehabilitation, or sustained cost reduction. From an independent assessment perspective, this is a reasonable concern, as stronger longitudinal evidence will be important for supporting broader user confidence and investment decisions.

Overall, the evidence suggests that the principal user concerns are associated with affordability, market certainty, operational practicality, technical optimization, and the need for longer-term proof of agronomic performance, rather than with fundamental rejection of the technology itself. On the contrary, most concerns appear to reflect a desire to see the systems become more economically accessible, more user-friendly, and more clearly validated under real production conditions.

6. Analysis

6.1 Gasificaton System

6.1.1. Technical assessment

The Kanai-800 was developed as a medium-scale gasification unit integrated with a layered heat exchanger for agricultural drying. In the documented implementation, the system was designed to convert agricultural residues such as cacao husks, macadamia shells, coffee husks, and rice husks into a

clean thermal energy stream for drying, while also recovering biochar as a co-product. The system was specifically configured to connect with an existing rotary drum dryer at Nhat Tam Cooperative, allowing hot gases from the gasifier to be mixed with ambient air and supplied at adjustable temperatures depending on drying requirements.

From an engineering standpoint, this is an important feature. Many biomass systems perform well as standalone combustion devices but encounter practical limitations when retrofitted into real processing lines. In contrast, the Kanai-800 appears to have been intentionally designed for functional integration into an existing drying operation, which significantly strengthens its practical relevance in commercial agro-processing conditions.

Based on the implementation report, the Kanai-800 demonstrated stable thermal performance under field conditions. Reported operating parameters include a flame temperature of 800–1,100°C, fuel consumption of approximately 70 kg/h using dry macadamia shell or cacao biomass, continuous combustion for around 2.5 hours per batch with a loading capacity of 250 kg, hot air flow of about 30,000 m³/h, and adjustable drying temperatures ranging from 60 to 300°C. The system was also reported to reduce fuel consumption by 40–75% compared with wood, gas, or electricity, while shortening drying time by 10–15%. These values indicate that the Kanai-800 is technically positioned as a productive heat-delivery system rather than merely a waste-treatment unit. This distinction matters. In independent assessment, a system that only disposes of biomass residues has limited strategic value. A system that transforms residues into a controllable, high-temperature heat source for post-harvest processing creates direct operational value and is more likely to be adopted and sustained.

The heat-exchanger arrangement is also a notable strength. The layered unit was designed to stabilize the secondary flame, blend hot and cool air streams, and regulate final drying temperature according to product needs. This increases process flexibility and reduces the risk of overheating sensitive crops. The provision for separating entrained char before heat enters the dryer is another positive design feature, as it improves product cleanliness and reduces contamination risks in food-related applications.

From an independent perspective, one of the strongest attributes of the Kanai-800 is its fit-for-purpose design at cooperative scale. The system was described as compact, mobile, easy to reposition, and relatively convenient to maintain. It was also successfully tested in multiple runs and linked to the cooperative's existing drying infrastructure, suggesting that it has moved beyond prototype logic and into practical operational use.

The report itself notes the importance of operator training and recommends that the fuel moisture content be kept below 15% to maintain stable gasification. This is a crucial condition. Gasification systems are generally more sensitive than simple combustion units to feedstock quality, air control, and operator discipline. Therefore, while the Kanai-800 is technically promising, its performance is still conditional on good operating practice, trained staff, and reasonably consistent feedstock preparation.

The replication potential of Kanai-800 is high, but not universal. The system is especially well suited to sites that meet four conditions: 1/ steady demand for drying; 2/ sufficient locally available dry biomass residue; 3/ has basic technical capacity to operate and maintain the system; 4/ management is willing to adopt a more integrated and innovation-oriented production model.

In conclusion, the Kanai-800 should be regarded as a strong and credible cooperative- or enterprise scale gasification technology for agricultural drying, with additional circular-economy benefits from biomass residue utilization and biochar recovery. Its principal strength lies in delivering practical, controllable, and cost-saving heat under real agro-processing conditions. It is particularly well suited for enterprises

and cooperatives that treat drying as an operational bottleneck and already have access to biomass residues that can be prepared to suitable moisture levels.

6.1.2. Economic Analysis

The gasification case is compelling where residues are already available and drying services or energy substitution produce measurable savings. The indicative analysis suggests that Kanai-800 is financially attractive under both scenarios. In Scenario 1, where the system generates value from biochar and avoids outsourced drying costs, the estimated annual net benefit is VND 938 million, with a simple payback period of about 0.33 years and an estimated 5-year IRR of 298.8%. In Scenario 2, where the system generates value from biochar and drying service revenue, the estimated annual net benefit is VND 338.0 million, with a payback period of about 0.93 years and an estimated 5-year IRR of 104.8%. It should note that the drying service revenue used in Scenario 2 is not intended to represent a benchmark market price. It reflects a relationship-based charge applied to regular customers for customer retention purposes and therefore should be interpreted as an effective net realized value rather than a full market-rate revenue assumption.

Item	Scenario 1: Biochar + Avoided External Drying Cost	Scenario 2: Biochar + Drying Service Revenue
A. Initial Investment		
Equipment cost (VND)	313,600,000	313,600,000
Total initial investment (VND)	313,600,000	313,600,000
B. Operating Scale		
Operating days per year	200	200
Batches per year	200	200
C. Annual Operating Costs		
Labor (200,000 × 200 days)	40,000,000	40,000,000
Fuel/feedstock cost (900,000 × 200 days)	180,000,000	180,000,000
Electricity (30,000 × 200 days)	6,000,000	6,000,000
Total annual operating cost (VND)	226,000,000	226,000,000
D. Annual Revenues / Benefits		
Biochar revenue (132 kg/day × 200 days × 10,000 VND/kg)	264,000,000	264,000,000
Avoided external drying cost (4,500,000 × 200 batches)	900,000,000	0

Item	Scenario 1: Biochar + Avoided External Drying Cost	Scenario 2: Biochar + Drying Service Revenue
Drying service revenue (1,500,000 × 200 batches)	0	300,000,000
Total annual revenue / benefit (VND)	1,164,000,000	564,000,000
E. Financial Results		
Annual net benefit / cash flow (VND)	938,000,000	338,000,000
Simple payback period (years)	0.33	0.93
Simple payback period (months)	4.0	11.1
IRR (5-year project life)	298.8%	104.8%

6.1.3. Environmental Assessment

The project contributes positively to environmental protection by substituting conventional drying fuels with residue-based gasification and by converting agricultural by-products into useful heat and biochar. In the absence of the project activity, such residues would likely remain underutilized, be openly burned, or disposed of in ways that contribute to air pollution and waste accumulation. The gasification system provides a cleaner combustion pathway than direct wood firing, with very low particulate emissions, significantly lower carbon monoxide emissions, minimal smoke after start-up, and lower ash-related impacts, while also recovering approximately 25% high-quality biochar under suitable operating conditions. Ms. Nguyen Hong Thuong (Nhat Tam Cooperative) reported that since the gasification kiln was introduced under the HELVETAS-supported initiative, both the workplace environment and the surrounding community conditions have improved significantly. Residents who stay nearby have not reported any adverse effects, including smoke emissions, either during operation or when the system is not in use.

The project further contributes to climate change mitigation by displacing wood, gas or electricity use in drying operations. Based on the IPCC emission factors⁹ and greenhouse gas (GHG) emission factor of Vietnam's power grid in 2025¹⁰ provided for project assessment, each ton of wood displaced may avoid approximately 2.2 tCO₂e, while electricity displacement may be assessed using the Viet Nam grid emission factor of 0.6235 tCO₂e/MWh, with an operating capacity of 200 days per year, one gasification system can annually reduce the consumption of 200 tonnes of wood and 15.6 MWh of electricity and produce 26.4 tonnes of biochar, equivalent to an estimated emission reduction of approximately 231 tCO₂e per year.

6.1.4. Social Impact

The project creates social benefits primarily for cooperative and associated agro-processing operations by strengthening energy self-reliance, improving production efficiency, and enhancing technical capacity. The project includes training and technical transfer for company and cooperative personnel in

⁹<https://www.ipcc.ch/report/2019-refinement-to-the-2006-ipcc-guidelines-for-national-greenhouse-gas-inventories/>

¹⁰ <https://nnmt.net.vn/uoc-tinh-he-so-phat-thai-khi-nha-kinh-kinh-cua-luoi-dien-viet-nam-2025>

the operation of the gasification and heat exchange system, thereby improving local technical skills and supporting longer-term technology adoption. Through the technical handover and operator training for the Kanai-800 gasification system, the project has directly enhanced the local personnel's professional capacity in biomass energy management and biochar recovery. This impact is clearly evidenced by the Nhat Tam cooperative's ability to independently operate a complex system that reduces fuel consumption by up to 75% and generates an annual net benefit of up to VND 938 million. This shift extends beyond operational skills; it represents a crucial step in social empowerment, enabling the community to master an advanced, self-sustaining circular economy model and drive local climate mitigation efforts. Instead of being mere beneficiaries, Nhat Tam Cooperative has evolved into a knowledge hub for carbon farming, ready to contribute to the nation's sustainable development goals.

6.2 Pyrolysis system

6.2.1. Technical assessment

From an independent technical perspective, the pyrolysis kiln version 3 represents a significant improvement over earlier small-scale biochar kilns because it combines field practicality with a more clearly defined design standard. The reported design integrates both direct and indirect pyrolysis within a single batch, includes a wood vinegar recovery component, uses small-sized biomass as a smoke filtration layer, and is fabricated from SUS 304 stainless steel to improve corrosion resistance and durability under repeated high-temperature operation. The kiln is also described as modular, portable, and operable by a single worker, which constitutes a major advantage for decentralized deployment in rural areas.

The technical suitability of the system is further strengthened by its flexibility in feedstock utilization. The documentation indicates that the kiln can process a wide range of agricultural residues, including cocoa pod husks, cocoa leaves, cocoa branches, coffee husks, macadamia husks, coconut husks, straw, and rice husks. This is highly relevant to the agri-food context of Vietnam, where residue streams vary by crop type, season, and geography. A technology capable of accommodating such diversity has substantially greater scale-up potential than a kiln dependent on only one narrowly defined feedstock type.

The strongest evidence of technical effectiveness comes from the reported biochar quality results. The November 2025 report recorded biochar yields ranging from 41.44% to 67.85%, depending on the feedstock. Biochar derived from macadamia husks and branches achieved IBI Grade 1 quality, while biochar produced from cocoa residues, coffee husks, coconut husks, straw, and rice husks achieved IBI Grade 2 quality. Reported pH values ranged from 7.7 to 9.28, indicating that the material is generally suitable for soil improvement, particularly under acidic soil conditions. The report also identifies different functional characteristics among biochar, including improvement of soil physical properties, adsorption capacity, interaction with heavy metals, and support for acidic soil remediation.

Nevertheless, the technology remains highly dependent on operator practice, feedstock moisture content, and feedstock type. Interview evidence from users at Nam Truong Son Cooperative indicates that when biomass with moisture content above 15% is used during the rainy season, smoke emissions become high. In addition, according to feedback from Dong Tien Cooperative and farmer Nguyen Van Hoang in Di An (HCMC), certain feedstocks such as large branches or coconut coir are not well suited to the current pyrolysis drum size and require an additional pre-processing step before use. Interviews with several households also indicated that the external packing material must be of small particle size, such as rice husk or coffee husk, which constitutes another operational bottleneck for kiln use.

Overall, the third-generation pyrolysis kiln can be assessed as a technically reliable and practically improved conversion system that has moved beyond the experimental demonstration stage and entered the early phase of replicable application.

6.2.2. Economic Analysis

The pyrolysis case is smaller in scale but more decentralized. An indicative cost-benefit analysis was conducted for Pyrolysis Kiln Version 3 based on an annual operating schedule of 200 days per year, equivalent to 100 batches per year at a cycle of two days per batch. The total initial investment was estimated at VND 20 million (~785 USD).

Annual revenue is estimated at VND 61.0 million from biochar and wood vinegar alone, and VND 84.1 million when potential carbon credit revenue is included. On an accounting basis, annual operating costs are estimated at VND 14.1 million, including depreciation over a 5-year equipment life. On a cash basis, excluding depreciation, annual operating costs are VND 10.1 million.

In the non-carbon scenario, the kiln generates an estimated annual net cash flow of VND 50.9 million, with a simple payback period of approximately 4.7 months and an estimated IRR of 252.2%. In the carbon-inclusive scenario, annual net cash flow increases to VND 74.1 million, reducing payback to approximately 3.2 months, with an estimated IRR of 369.3%.

Item	Biochar + wood vinegar (VND/year)	Biochar + wood vinegar + carbon credits (VND/year)
A. Initial investment		
Pyrolysis kiln purchase cost (VND)	20,000,000	20,000,000
Total initial investment (VND)	20.000.000	20.000.000
B. Operating assumptions		
Operating days per year (day)	200	200
Production cycle	2 days per batch	2 days per batch
Batches per year	100	100
C. Annual operating costs		
Labor (100,000 × 100 batches)	10,000,000	10,000,000
Electricity (per year)	100,000	100,000
Depreciation (20.000.000/ 5-year lifetime)	4,000,000	4,000,000
Total cash operating cost (including depreciation) (VND/year)	14,100,000	14,100,000

Item	Biochar + wood vinegar (VND/year)	Biochar + wood vinegar + carbon credits (VND/year)
Total cash operating cost (excluding depreciation) (VND/year)	10,100,000	10,100,000
D. Annual revenues/year		
Biochar sales (40 kg × 100 batches × 9,000 VND)	36,000,000	36,000,000
Wood vinegar sale (5 litres × 100 batches × 50,000 VND)	25,000,000	25,000,000
Carbon credit revenue (0.04 tonne biochar × 100 batches × 2.2 tCO ₂ e × 100 USD)	0	23,100,000
Total revenue (VND/year)	61,000,000	84,100,000
E. Financial performance comparison		
Annual accounting profit (VND)	46,900,000	70,100,000
Annual net cash flow (VND)	50,900,000	74,100,000
Simple payback period (years)	0.39	0.27
Simple payback period (months)	4.7	3.2
IRR, 5-year lifetime	252.2%	369.3%

Overall, the analysis suggests that Pyrolysis Kiln Version 3 remains economically viable even without carbon revenues. The strongest near-term business case is therefore based on regular kiln utilization and reliable sales of biochar and wood vinegar, while carbon revenue should still be treated as a potential upside contingent on future compliance with carbon certification requirements.

In addition, for biochar, the strongest commercial route is local sale as a soil amendment or as an input for biochar-based fertilizer. Existing commercial examples in Vietnam already demonstrate this pathway. For example, in the case of Nhat Tam Cooperative, biochar after being used as bedding can be sold for 15,000 VND/kg. UNIDO identifies BIFFA, Vinatap, and Mai Anh as active biochar producers. BIFFA reportedly produces 6,000 tonnes of biofertilizer per year with 20–30% biochar content, with reported prices of around USD 260/tonne (~ 6,800,000 VND/tonne) for biochar and USD 130/tonne (~ 3,400,000 VND/tonne) for organic fertilizer. Vinatap and Mai Anh were also reported to commercialize biochar products, with biochar prices in the range of USD 430–520/tonne (~11,200,000 – 13,600,000 VND/tonne). These examples show that a market for biochar already exists in Vietnam, although it remains limited and requires stronger market education.

For wood vinegar, the commercial opportunity is also meaningful. UNIDO describes wood vinegar as a saleable pyrolysis by-product that can be used as a natural agricultural input, including as a support product for crop protection, soil improvement, composting, and odour control, provided that correct dilution and handling are applied. In the present business case, wood vinegar is not a minor by-product: at 5 litres per batch and 100 batches per year, it contributes VND 25 million/year in revenue at VND 50,000/litre, making it a significant component of the kiln's annual income.

Overall, the kiln should not be viewed only as a waste treatment device, but as a small-scale production unit generating two marketable agricultural products. The strongest near-term business model is therefore based on regular kiln operation and reliable local sales of biochar and wood vinegar, while carbon revenue should be treated as a possible future upside rather than the primary commercial outlet.

6.2.3. Environmental Assessment

The Pyrolysis Kiln Version 3 generates positive environmental impacts by converting agricultural residues into biochar and wood vinegar instead of allowing those residues to remain underutilized or to be disposed of through open burning or unmanaged degradation. In practical terms, this supports cleaner biomass management, reduces local environmental pressure, and promotes a more circular use of agricultural by-products.

Many farming households like Mr. Le Quang Truong (Nhat Tam Cooperative), Mr. Nguyen Dinh Thien (Director of Dong Tien Cooperative) or Ms. Nguyen Thi Bang (Director of An Phuc Khang Pharmaceutical Cooperative) noted that the environment has become cleaner and no longer affects surrounding neighbors, contributing positively to health and well-being.

Other key environmental benefit of the model is its contribution to climate change mitigation through long-term carbon storage in biochar. Based on the project's indicative operating parameters, one kiln can produce around 40 kg of biochar per batch. Assuming 100 batches per year, one kiln can generate approximately 4.0 tonnes of biochar per year. Applying the project assumption that 1 tonne of biochar removes 2.2 tCO₂e, the estimated annual climate benefit of one kiln is therefore approximately 8.8 tCO₂e/year. This provides a practical and transparent basis for expressing the annual carbon removal potential of the third-generation pyrolysis kiln at unit level.

In addition to carbon removal, the model contributes to better soil and resource management. The project documentation indicates that biochar produced from the improved kiln can improve soil structure, support water retention, enhance nutrient retention, and reduce pressure on chemical fertilizer use. Mr. Nguyen Van Chinh (cacao farmer at Vinh Long) said that biochar-based fertilizer made the soil more friable and helped increase fruit production. He is very satisfied with the results. The November 2025 report also recorded biochar yields ranging from 41.44% to 67.85% depending on feedstock, with several biochar types meeting IBI Class 1 or IBI Class 2 quality levels. This indicates that the environmental contribution of the kiln is not limited to residue treatment alone, but also includes the production of a technically useful and agronomically valuable material for more sustainable farming systems.

Overall, the pyrolysis kiln makes a positive environmental contribution by improving residue management, supporting long-term carbon removal through biochar, reducing environmentally harmful disposal practices, and promoting more sustainable soil management in agricultural production systems.

6.1.4. Social Impact

The project is already demonstrating credible and visible social value at community level. Its social impact is not limited to awareness-raising; rather, it is being expressed through measurable outreach,

cleaner living conditions, improved farming practices, and new income opportunities linked to biochar and wood vinegar. A particularly important strength is that the project has moved beyond a purely technical demonstration and has started to influence user behaviour and local perceptions of agricultural residue management. Across project phases, at least 5 major training rounds were delivered, including in-person sessions and remote/online guidance, with 57 specifically recorded participants, excluding additional participants in online sessions during 2026. The documentation further states that 100% of trained participants gained sound practical awareness of biochar production and application from agricultural residues. This is a meaningful social indicator because it shows that the project is not only transferring equipment, but also building local human capacity for replication and longer-term adoption.

The most immediate social benefit reported by users relates to healthier and cleaner local environments. Interviewees repeatedly linked the project with reduced smoke, cleaner surroundings, and fewer disturbances to neighboring households compared with previous open burning practices. Mr. Nguyen Dinh Thien (Director of Dong Tien Cooperative) stated that since using the pyrolysis kiln, “the environment has become cleaner and no longer affects surrounding neighbors,” while also noting positive effects on health and well-being. This is socially significant because, in rural production settings, smoke exposure and nuisance from residue burning are often accepted as normal; the project is helping to change that baseline. The broader project narrative also confirms that avoided open burning contributes directly to improved community well-being through reduced smoke and airborne particulates.

A second major area of social value is the project’s contribution to livelihood improvement and rural economic opportunity. Evidence in the interviews shows that farmers and cooperatives do not see biochar only as an environmental product; they increasingly recognize it as a useful and marketable rural asset. Mr. Le Quang Truong of Nhat Tam Cooperative reported that, in addition to applying biochar on-farm, he had already sold 200 kg of biochar for VND 4 million. This is a particularly important proof point for investors because it demonstrates real, observed monetization rather than purely theoretical market potential. The project files also emphasize that the establishment of biochar production activities can create local income opportunities for rural households and that these benefits are not gender-exclusive, with both men and women able to participate directly or indirectly in project-related functions.

The social impact is further strengthened by evidence that the project is improving farm-level confidence, self-reliance, and practical knowledge. Several interviewees explicitly connected biochar use with improved soil workability, lower input needs, and stronger control over production quality. Ms. Nguyen Thi Bang, Director of An Phuc Khang Medicinal Cooperative, reported that residue handling became “cleaner and less smoky” and estimated that fertilizer costs could be reduced by up to 30% after applying biochar in seedling production. Mr. Bay from the Vinh Long trial group explained that he clearly understood biochar’s role in improving soil quality, moisture retention, fertilizer efficiency, and crop productivity, and expressed strong interest in producing biochar directly on-farm in order to control product quality. These testimonies matter socially because they show that beneficiaries are not passive recipients; they are learning, evaluating, and actively seeking to integrate the technology into their own production systems.

Another notable social outcome is the project’s role in stimulating local demonstration effects and peer-to-peer diffusion. The evidence suggests that surrounding farmers and neighbours who observed the kilns became interested in adopting the model themselves, especially to access wood vinegar and biochar. Mr. Nguyen Dinh Thien described the kiln not only as useful for his cooperative, but also as a practical demonstration model for members inside and outside the cooperative. This kind of interest is a critical early signal for scale-up because it indicates that the project is beginning to build social

legitimacy at local level. The interviews also record that users are willing to continue using the systems for at least 3–5 years and to recommend them to others, which suggests a stronger probability of sustained adoption rather than short-lived pilot enthusiasm.

The project also appears to contribute positively to quality of life and labour practicality in rural settings. Users noted that the kiln could operate while they continued other farming activities, reducing time pressure on households. Additional practical benefits were also reported, such as reduced livestock odour and fewer mosquitoes and insects when biochar was used near livestock housing. In this case, the technology is being perceived as useful in multiple dimensions of farm life.

Overall, from an independent perspective, the project demonstrates a credible and investable social impact profile. The strongest current evidence can be summarized in four points: (i) documented training outreach with at least 5 major training rounds and 57 recorded participants; (ii) direct community health and well-being benefits through reduced smoke and cleaner surroundings; (iii) early but tangible livelihood benefits, including actual biochar sales of 200 kg for VND 4 million and reported reductions in fertilizer costs of up to 30%; and (iv) strong social acceptance, with users indicating willingness to continue use for 3–5 years and to recommend the systems to others. Taken together, these findings suggest that the project is not only technically relevant, but also socially embedded and capable of generating practical benefits that rural communities can see, use, and value.

6.3 Strategic Positioning of the Two Technologies

Dimension	Gasification	Pyrolysis
Primary role	Clean heat and drying efficiency	Residue valorization, soil amendment and future carbon removal
Best-fit users	Residue-rich cooperatives, processors, drying facilities	Cooperatives, Farmers, small processors
Strength	Stable process economics where heat demand is strong	Higher material value and stronger climate narrative
Main constraint	High upfront capital cost	Operational variability and weak market pull for outputs
Scale pathway	Service or facility model	Distributed smallholder / cooperative model

6.4 Soil Improvement Trials

The project has demonstrated a profound multi-dimensional impact by transforming hazardous cocoa residues into high-value biochar to remediate soil and enhance productivity. Environmentally, the project successfully addressed heavy metal contamination, with 2 field trials in Ben Tre/Vinh Long recording a reduction in cocoa bean Cadmium (Cd) levels by 54% to 80%, effectively bringing them safely below the critical EU export threshold of 0.60 mg/kg. The application of biochar—particularly Macadamia shell biochar containing 80.7% Organic Carbon—raised soil pH from a highly acidic 3.55–

4.00 to a more productive 3.94–4.39, while immobilizing mobile Cd to levels as low as 0.021 mg/kg. Economically, these interventions yielded substantial returns, including a 19.4% increase in yield for young cocoa plantations and a 28.8% increase for mature gardens, with average fruit weights reaching up to 483g. Socially, the initiative has engaged farmers, fostering significant local empowerment and technical adoption. High levels of user satisfaction are reflected in direct testimonials, such as those from Mr. Nguyen Van Chinh, who reported that "fertilizer blended with biochar made the soil more friable and increased fruit production," and Mr. Nguyen Van Bay, who expressed a strong interest in self-production after using biochar because "self-production would allow better control over product quality". Ultimately, the project has created a robust foundation for long-term adoption, with farmers expressing a unanimous willingness to continue using these biochar to ensure healthier farming environments and new value streams.

7. Success factors, barriers, and lessons learned

7.1 Success factors

Several factors contributed to the positive results observed during project implementation.

First, the project responded to real operational needs rather than introducing technologies without a clear use case. In the case of gasification, the systems directly addressed two pressing problems faced by enterprises and cooperatives: the accumulation of agricultural residues and the need for reliable drying during the rainy season. At Nhat Tam Cooperative, gasification created immediate practical value by converting available biomass residues into useful heat for drying while also producing biochar. The Cacao Trong Duc pilot, meanwhile, provided useful early technical learning but also showed that gasification adoption requires sufficient system stability, capacity, internal resources, and investment incentives. This close alignment between technology and actual production needs was a major success factor.

Second, the project benefited from a stepwise technology development approach, particularly for the pyrolysis systems. The progression from pyrolysis kiln Version 1 to Version 3 shows that technical refinement was informed by field experience. Improvements in kiln height, loading and unloading, wood vinegar collection, airtightness, safety, thermal circulation, and operator convenience significantly increased the practical usability of the system. This iterative approach reduced design weaknesses and improved the maturity of the technology over time.

Third, training and technical transfer played a critical role. The project did not stop at equipment delivery, but also provided in-person and online guidance on kiln operation, biochar production, and wood vinegar use. This helped users develop practical understanding and increased their confidence in operating the systems. The documentation records at least five major training courses with 57 specifically recorded participants, indicating that capacity building was an integral component of implementation rather than an afterthought.

Fourth, the project achieved stronger results where there was active local leadership and commitment. Interview evidence suggests that the most effective adopters were cooperatives or enterprises with leaders willing to experiment, learn, and integrate the technology into daily operations. Nhat Tam Cooperative is a clear example, where management linked the technology not only to residue treatment but also to drying services, cattle bedding, organic fertilizer production, and future expansion plans. This suggests that technology adoption was strongest where leadership saw the systems as part of a broader production strategy rather than a standalone pilot.

Finally, early success was reinforced by the fact that users could observe visible and immediate benefits. Across the interviews, these included cleaner surroundings, less smoke than open burning, improved soil friability, lower irrigation needs, reduced odour in livestock areas, time savings, and early signs of fertilizer cost reduction. The presence of these visible benefits helped build user confidence and social acceptance.

7.2 Barriers

Despite these positive outcomes, the project also encountered several barriers that constrained performance and may limit wider adoption if not addressed.

The most significant barrier was high upfront investment cost, especially for larger or more sophisticated systems. The Kanai-800 gasification unit was considered effective, but users noted that commercial purchase without project support would be difficult. Even for smaller pyrolysis kilns, affordability remains a concern for many farmers and cooperatives. This indicates that capital cost remains a major obstacle to wider dissemination.

A second barrier was feedstock-related variability. Both gasification and pyrolysis systems performed best when biomass was dry, suitably sized, and consistently available. In practice, however, feedstock quality varied by season and site. Wet biomass, especially during the rainy season, increased smoke and reduced operating quality. Some users also reported that the kilns required supplementary materials such as rice husk or small-sized biomass packing layers, which increased complexity and cost.

A third barrier was the limited practical knowledge on by-product utilization, especially wood vinegar. Although users recognized wood vinegar as potentially valuable, many were still uncertain about how to use it effectively, how to increase recovery, or how to commercialize it. This reduced the ability of users to capture the full economic value of the technology.

Another important barrier was the lack of a strong downstream market for biochar, particularly beyond on-farm use. While some users applied biochar directly or sold small quantities, market channels for larger-scale commercialization remain weak and fragmented. Wider replication will therefore depend not only on technical success, but also on stronger market development.

Technical and operational limitations were also reported. These included smoke and odour under suboptimal conditions, long batch durations for pyrolysis, limited chamber size, inconvenience in loading and unloading, and insufficient design optimization for certain feedstocks. These issues did not invalidate technology, but they did affect ease of use and user satisfaction.

Finally, a barrier from an evidence perspective is that the agronomic trial period remains relatively short. Although early results from soil improvement trials are promising, the available observation period is not yet sufficient to confirm long-term effects on yield, soil restoration, fertilizer reduction, or durable cadmium stabilization under different farm conditions.

7.3 Lessons learned

Several important lessons emerge from the implementation experience.

The first lesson is that technology must match user context. Gasification is most suitable where there is both abundant biomass and a continuous drying demand, such as at cooperatives or processing enterprises. Pyrolysis, by contrast, is more adaptable for decentralized use at cooperative or farm scale, especially where the main objective is residue valorization, biochar production, and local soil application. A single technology model is therefore unlikely to fit all users equally well.

The second lesson is that technology transfer must go beyond equipment handover. Users need repeated training, follow-up support, and practical guidance on operation, maintenance, feedstock preparation, and product application. This is particularly important for technologies such as pyrolysis, where performance is sensitive to moisture, feedstock type, and operational technique.

The third lesson is that co-products matter. The viability of these systems is strengthened when users can generate value not only from residue treatment but also from useful outputs such as clean heat, biochar, wood vinegar, cattle bedding, compost inputs, or organic fertilizers. Future interventions should therefore treat these systems as part of a value chain, not only as waste management devices.

The fourth lesson is that visible short-term benefits help drive adoption, but long-term evidence is still needed to sustain confidence. Cleaner surroundings, lower smoke, time savings, and improved soil friability and crop productivity were strong motivators for users.

The fifth lesson is that replication requires both technical and market ecosystems. Successful scaling will depend not only on improving kiln performance, but also on facilitating finance, strengthening after-sales support, providing quality assurance, and building clearer market pathways for biochar and wood vinegar.

8. Scalability

From an independent assessment perspective, the project demonstrates meaningful potential for scale-up, but the scalability of the two technology pathways differs substantially and should be considered separately.

8.1 Scalability of Gasification Systems

The gasification model shows strong scalability potential in cooperative and enterprise settings where three conditions are met: a large and steady supply of biomass residues, an ongoing need for drying, and sufficient technical capacity to operate and maintain the system. Under these conditions, the technology can create immediate operational and financial value by substituting conventional fuels, reducing drying costs, stabilizing product quality, and generating biochar as a co-product. The documented performance of the Kanai-800 at Nhat Tam Cooperative provides the strongest evidence that gasification can be technically credible and commercially relevant where drying is a core production function.

However, gasification is not universally scalable at household level because it requires higher capital investment, more disciplined feedstock preparation, and a more organized operational environment. Its strongest pathway for scale-up is therefore through service-oriented or facility-based models, including cooperatives, agro-processors, and residue-rich enterprises. In such contexts, gasification could be replicated as a circular-economy solution that links waste management, renewable heat, and biochar generation.

Future scalability of gasification would be strengthened by concessional finance, demonstration at additional processing sites, operator training, and policy or carbon-finance mechanisms that improve the investment case.

8.2 Scalability of Pyrolysis Systems

The pyrolysis model shows broader geographical and social scalability because it is more decentralized, lower-cost, and more adaptable to household and cooperative settings. The project already demonstrated this through the transfer of 19 pyrolysis kilns across multiple provinces and a wide range of biomass types, including cocoa residues, coffee husks, rice husks, macadamia shell, straw, coconut

residues, branches, and medicinal residues. This flexibility is a major strength for replication in diverse agricultural landscapes.

Version 3 of the kiln, in particular, has reached a level of technical maturity that supports wider dissemination. Its improved airtightness, durability, operator convenience, and safety features make it more suitable for practical field use than earlier versions. User interviews also suggest strong interest in continuing use and recommending the model to others, which is a positive signal for horizontal spread through farmer networks and cooperatives.

Nevertheless, scalability of pyrolysis remains conditional on several factors. These include lower equipment cost, improved design for ease of loading and unloading, reliable access to dry and appropriately sized biomass, stronger guidance on wood vinegar use, and clearer market outlets for biochar where self-use is insufficient. Without these supporting conditions, diffusion may remain limited to motivated early adopters rather than wider farmer uptake.

8.3 Overall Scalability Outlook

Overall, the project has established a credible foundation for scale-up, but replication should follow a differentiated pathway.

Gasification should be prioritized for residue-rich cooperatives, drying facilities, and agro-processing enterprises where thermal demand is continuous and the economic case is strongest.

Pyrolysis should be prioritized for cooperatives, farmer groups, and decentralized rural applications where the objective is residue management, biochar production, soil improvement, and gradual value creation at local level.

From a strategic perspective, the highest scalability may come from combining both pathways within a broader circular agriculture model: gasification for enterprise-scale clean heat and drying, and pyrolysis for distributed biomass valorization and soil application. This would allow the project model to serve multiple user groups while responding to different residue streams, economic conditions, and agricultural needs.

At the same time, broader scale-up will require enabling conditions beyond the technology itself. These include:

- Affordable financing or subsidy support for initial investment,
- Continued technical extension and after-sales support,
- Stronger market development for biochar and wood vinegar,
- Longer-term agronomic validation, and
- Policy recognition of the role of these systems in circular economy, low-emission agriculture, and climate mitigation.

In conclusion, the project technologies are scalable, but not automatically self-scaling. Their successful replication will depend on pairing technical dissemination with finance, training, market development, and context-specific deployment models.

9. Risk assessment

From an independent assessment perspective, the project is technically promising and has generated positive early results, but several practical risks remain relevant for long-term performance and scale-up.

The first key risk is operational variability under field conditions. Both gasification and pyrolysis systems depend on suitable feedstock quality, especially low moisture content, appropriate particle size, and consistent preparation. In practice, agricultural residues are often seasonal and heterogeneous, particularly during the rainy season. Under such conditions, users reported increased smoke, odour, longer processing time, and reduced efficiency. This means that actual performance may vary significantly across sites if feedstock management is weak.

A second major risk is high upfront investment cost, especially for gasification systems and for wider replication without external support. Interview evidence shows that users generally value the technology, but many consider the purchase cost too high for independent adoption at current price levels. Even for pyrolysis systems, affordability remains a limiting factor for many smallholders. Without concessional finance, subsidy support, or phased investment mechanisms, scale-up may remain slower than user interest would suggest.

The third risk concerns market uncertainty for biochar and wood vinegar. Although both products have demonstrated practical value, market channels remain weak and inconsistent, especially beyond self-use or small local sales. Several users expressed concern about the absence of reliable buyers for biochar if production increases. Wood vinegar faces an additional challenge: users still require clearer guidance on how to use it effectively and how to commercialize it. As a result, the full economic potential of co-products may not yet be realized in all locations.

Another important risk is dependence on operator skill and technical support. These systems are not fully plug-and-play. Their safe and efficient use depends on training, correct loading practices, proper air-flow control, and understanding of output applications. If future replication focuses mainly on equipment distribution without sufficient training and follow-up support, operational quality and user confidence may decline.

Overall, the main risks are linked to affordability, feedstock quality, operator capacity, market development, and limited long-term validation rather than to any fundamental rejection of the technology. These risks are real but manageable. They suggest that successful scale-up will require not only improved equipment, but also stronger training, financing access, market linkage, and longer-term performance monitoring.

10. Limitations

The report is based on the best available evidence provided through project documents and interview notes, but several limitations remain. First, a substantial part of the evidence is early-stage and qualitative. Second, some financial calculations are indicative rather than audited. Third, agronomic effects from biochar application require a longer observation period than currently available. Fourth, the report assesses future carbon-certification relevance using CSI principles and artisanal biochar requirements, but it does not constitute a validation, verification or eligibility opinion under any formal carbon standard.

11. Recommendations

Based on the available evidence, the project should move from a pilot toward a scale-up strategy centered on technology fit, affordability, and carbon-finance readiness. Three recommendations are proposed.

First, adopt a differentiated technology pathway rather than relying on a single equipment model. For cooperative- and enterprise-scale applications with continuous drying demand, the gasifier remains appropriate. However, for household and smallholder replication, on technology, the project should continue improving and deploying the existing pyrolysis systems, while also considering the addition of Kon-Tiki as a complementary option for selected smallholder contexts. The current project has already generated meaningful results from the pyrolysis pathway, and the progressive improvement from Version 1 to Version 3 shows that this technology can be refined into a more practical and reliable system for decentralized biomass conversion. At the same time, the project may consider adding Kon-Tiki kilns as a supplementary technology for farmer groups and households that work with more diverse, bulky, or larger-sized dry biomass such as branches, woody pruning residues, coconut fibre, and cocoa husks. Kon-Tiki is widely regarded as a practical controlled-flame pyrolysis technology in which the pyrolysis gases pass through a flame curtain, thereby reducing smoke and limiting oxidation of the produced char. It is often considered a bridging technology for developing-country conditions because it is simpler, lower-cost, and easier to replicate at farm level. In the context of this project, Kon-Tiki should not replace the current pyrolysis systems, but rather complement them where the feedstock type and farmer conditions make the existing kiln less convenient or less economical. This is particularly relevant for users such as Mr. Nguyen Van Hoang (cacao farmer in Di An, HCMC) and other households with larger branch-type residues or irregular feedstock sizes.



Kon-tiki Kiln

The advantage of this approach is that it builds on the project's current technical foundation rather than restarting from a new direction. The existing pyrolysis kilns remain the core technology, while Kon-Tiki can be piloted as an additional option to improve flexibility and widen adoption. A dual approach of this kind would allow the project to better match technology choice to feedstock conditions, user capacity, and investment level. For smallholders, this is important because affordability and operational simplicity

were repeatedly identified as key barriers to wider uptake. Kon-Tiki, a lower-cost technology, is in the range of approximately VND 7–8 million per unit, with around 100 kg of feedstock input, 30 kg of biochar output, and an operating cycle of roughly 4 hours per batch, may offer a more accessible entry point for replication, provided that their performance is validated under local conditions.

Second, build a financing model around farmer groups and carbon-project aggregation. Rather than expecting individual households to invest independently, the project should consider organizing participating households into clustered producer groups that can be aggregated into a future carbon project. This would reduce the financial barrier for individual farmers, improve training and monitoring efficiency, and create a more bankable basis for carbon-credit generation. Carbon revenue should not be treated as the only business case, but it can serve as an important additional income stream and behavioural incentive. At the moment the carbon price range of USD 100–200 per credit may be used as an upside scenario, subject to methodology, certification pathway, quality, and market conditions.

Third, position the project more explicitly toward Vietnam’s emerging carbon-market context. Vietnam’s carbon market is no longer only a future concept. The Prime Minister approved the national scheme for establishment and development of the carbon market under Decision 232/QĐ-TTg dated 24 January 2025, and the Government later amended Decree 06/2022/ND-CP through Decree 119/2025/ND-CP, which took effect on 1 August 2025. This policy direction strengthens the strategic relevance of projects that combine measurable emission reduction or carbon removal with rural development benefits. For this reason, the project should begin preparing not only for technical dissemination, but also for future MRV, producer grouping, and carbon-finance structuring.

12. Conclusions

The project has demonstrated that both of gasification and pyrolysis technologies can provide practical and relevant solutions for agricultural residue management in the cocoa and broader agri-food context. The project has moved beyond conceptual demonstration and has shown real field-level application across enterprises, cooperatives, and farming households. In particular, the Kanai-800 gasifier proved effective where there is a strong drying demand and sufficient biomass residue supply, while the pyrolysis systems showed good potential as decentralized solutions for residue valorization, biochar production, and local soil improvement.

The project generated clear environmental, economic, and social benefits.

- Environmentally, it reduced uncontrolled biomass disposal and open burning, while converting residues into useful outputs such as clean heat, biochar, and wood vinegar.
- Economically, both technology pathways showed promising business cases under suitable operating conditions, especially where biochar use, drying cost savings, or service revenues could be captured.
- Socially, the project improved local technical capacity, supported cleaner and healthier production conditions, and created early opportunities for livelihood improvement through the productive use of agricultural residues.

At the same time, the project also showed that successful adoption depends heavily on context. Performance was strongest where feedstock was available and well prepared, where users received sufficient training, and where local leadership was willing to integrate the technology into day-to-day operations. By contrast, high capital costs, variable feedstock quality, limited market development for biochar and wood vinegar, and the still short duration of agronomic trials remain important constraints to broader replication.

The Biochar Case Study demonstrates that the EU-Cocoa Project has successfully piloted a credible portfolio of circular-economy solutions around agricultural residues.