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Research on World Agricultural Economy

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ARTICLE

Financial Feasibility Analysis of Spent Coffee Grounds Briquettes as Alternative Renewable Fuel in South West Region of Aceh

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ABSTRACT

This study evaluates the commercial feasibility of producing briquettes from spent coffee grounds (SCG) in the South West Region of Aceh, Indonesia, where cafe clusters generate a steady and concentrated residue stream suitable for decentralised valorisation. A ten-year discounted cash-flow model at a 12% discount rate is integrated with operational, process-engineering, and market insights to assess whether a compact, MSME-scale densification line can achieve financial viability. The nominal plant processes 816 kg/day and produces 254,592 kg/year of briquettes at an assumed ex-factory price of IDR 4500/kg. Baseline modelling yields an annual operating cash flow of IDR 285.36 million, a Net Present Value (NPV) of IDR 73.52 million, an Internal Rate of Return (IRR) of 13.13%, a Net Benefit–Cost Ratio (Net B/C) of 1.05, and a payback period of 5.46 years. Sensitivity analysis identifies realised price as the dominant determinant of feasibility, followed by utilisation rates and key variable-cost components such as binder and labour. Qualitative extensions incorporate the feasibility of multi-plant network configurations, the economic implications of seasonal moisture variability, and refinements to binder–labour op-

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ARTICLE INFO

Received: 16 Ocotber 2025 | Revised: 8 December 2025 | Accepted: 16 December 2025 | Published Online: 11 June 2026
DOI: https://doi.org/10.36956/rwae.v7i2.2813

CITATION

Aulia, M.R., Azrani, U., Hartini, et al., 2026. Financial Feasibility Analysis of Spent Coffee Grounds Briquettes as Alternative Renewable Fuel in South West Region of Aceh. Research on World Agricultural Economy. 7(2): 725–744. DOI: https://doi.org/10.36956/rwae.v7i2.2813

timisation informed by local practice. A hypothetical carbon-finance scenario indicates potential for raising IRR if monitoring costs and verification burdens decrease. Overall, the findings show that SCG briquettes can be commercially viable under disciplined pricing, utilisation above 96%, and consistent quality assurance, offering a practical circular-economy pathway for reducing waste burdens and substituting conventional solid fuels in West Aceh.

Keywords: Spent Coffee Grounds; Biomass Briquettes; Feasibility Analysis; Circular Bioeconomy; Small and Medium Enterprises

1. Introduction

Global momentum toward low-carbon energy systems has revived interest in solid biofuels that can be produced and consumed near the point of waste generation. Densified biomass in the form of briquettes or pellets is attractive because densification overcomes three endemic limitations of raw residues, namely low bulk density, poor handling characteristics, and inconsistent combustion performance, by producing a uniform fuel that can be stacked, transported, and burned with predictable behaviour in household and small and medium enterprise (SME) stoves [1]. In both coffee-producing and coffee-consuming regions, spent coffee grounds (SCG) represent a stable and concentrated residue stream that is commonly landfilled or openly dumped despite containing energy-rich biopolymers such as lipids, lignin-derived aromatics, and polysaccharides [1]. This combination of continuous availability and favourable chemical composition has positioned SCG as a promising feedstock for solid biofuel production.

Recent experimental and applied studies indicate that SCG can be successfully upgraded into briquettes or pellets with heating values in the mid-teens MJ/kg and with mechanical durability compatible with conventional handling, provided that moisture content and binder proportions are appropriately controlled. Combustion and emission characteristics of solid briquettes in household stove contexts have been documented in the wider solid-fuel literature, providing benchmarks for acceptable thermal performance and emissions behaviour [2].

Detailed characterisation and pelletisation experiments have demonstrated clear linkages between SCG physicochemical properties, densification performance, and combustion emissions [3]. In addition, the use of SCG as an additive in biomass briquettes has been shown to improve mechanical quality and handling stability under controlled processing conditions [4].

Further supporting evidence highlights that SCG-based densified fuels can satisfy practical requirements for household and micro-enterprise energy use when basic process parameters are optimised, thereby opening additional pathways for value addition and waste valorisation within coffee-based agro-industrial systems [5]. Studies on solid biofuel production from SCG report stable combustion behaviour and acceptable fuel characteristics under optimised compaction and drying regimes [6]. Field-validated densification studies in Aceh and comparable settings also confirm that agricultural and organic residues can be compacted into durable briquettes with stable handling properties and acceptable performance when moisture and binders are properly managed [7, 8].

Beyond technical feasibility, sustainability and systems-level assessments reinforce the rationale for SCG valorisation.

At the global level, this rationale is increasingly embedded within coffee diplomacy and circular economy initiatives, which promote climate resilience, waste valorisation, and low-carbon transformation across coffee value chains through multi-stakeholder platforms such as the Center for Circular Economy in Coffee (C4CEC) [9]. In this context, circular economy–oriented interventions in coffee value chains, including the valorisation of spent coffee grounds as alternative solid fuels, are increasingly viewed as part of a broader low-carbon transition strategy aimed at reducing energy intensity and decoupling economic growth from environmental degradation, particularly particulate emissions such as $PM_{2.5}$ [10].

Life-cycle assessment studies indicate that SCG pellets can achieve favourable environmental profiles compared with fossil or traditional solid fuels, particularly when supply chains are localised and drying energy is optimised [11]. Complementary work on circular-economy implementation in coffee-based production systems further underscores the potential role of residue valorisation in strengthening sustainability outcomes in coffee-growing regions, including Indonesia [5, 12].

At the same time, the global coffee sector continues to expand and remains vulnerable to supply–demand imbalances and climate-related shocks, which together shape residue availability and intensify the urgency of valorisation pathways. According to the most recent annual review of the International Coffee Organization, global trade volumes remain high, and price volatility has been pronounced in recent seasons, renewing attention to the sector's waste footprint and circular-economy opportunities [9]. Parallel environmental–economic analyses show that energy consumption, economic growth, foreign direct investment, and rapid urbanisation significantly exacerbate $PM_{2.5}$ concentrations in emerging economies, highlighting the need for cleaner and more decentralised energy systems [10].

In this context, locally sourced solid biofuels such as SCG briquettes represent more than a waste-management option. Their adoption offers a dual benefit by reducing organic waste burdens while partially displacing charcoal or fuelwood used for cooking and small-scale processing. Such substitution pathways align with broader energy-transition objectives while addressing local air-quality concerns and resource-efficiency goals.

However, translating laboratory-scale promise into viable business models depends critically on economic performance. Techno-economic assessments and supply-chain optimisation studies consistently demonstrate that realised selling price, plant utilisation rates, capital intensity, and the cost of capital are the dominant determinants of Net Present Value (NPV) and Internal Rate of Return (IRR) in biomass densification systems [13]. Comprehensive reviews further show that discount rates, operating scale, and logistics configuration can materially shift feasibility boundaries across agricultural and forest biomass pathways [14, 15]. Reviews focused on briquette binders and quality parameters also emphasise that fuel durability and handling characteristics directly influence operating costs and market acceptance, thereby shaping overall project bankability [16].

Indonesia provides a compelling context for SCG valorisation. Rapid expansion of café culture in urban centres and secondary cities has generated steady SCG streams throughout the year, while major coffee-growing regions also host roasting and brewing activities that further concentrate residues. In such settings, compact and semi-mechanised briquetting lines that collect, pre-dry, bind, press, and cure SCG can be located close to both feedstock sources and end users, including households, street food vendors, and micro-industries, thereby shortening logistics chains and improving supply reliability relative to more diffuse biomass resources.

Despite growing interest in SCG-based biofuels, a practical gap remains between materials-science studies of fuel properties and decision-ready business cases that integrate process design with market and financial analysis. This study addresses that gap by presenting a case-based financial feasibility assessment of an SCG briquette plant in Aceh Barat, Indonesia. Building on a conservative feedstock window derived from café clusters, the study evaluates a ten-year project using standard investment criteria, including NPV, IRR, Net Benefit–Cost ratio (Net B/C), and payback period, complemented by one-factor sensitivity analysis and qualitative assessment of operational and market conditions. The objective is to determine whether a modest MSME-scale briquetting line can be bankable under realistic local conditions and to identify the key levers that enhance financial resilience, particularly realised price, utilisation, labour and binder control, and cost of capital.

2. Materials and Methods

2.1. Study Area and Design

The case study was conducted in Kecamatan Meureubo, a sub-district located in Aceh Barat, on the western coast of Sumatra, Indonesia, between August and December 2024. This region was chosen for its significant coffee production, with smallholder farmers predominating the landscape, which makes it an ideal location for studying the valorisation of spent coffee grounds (SCG). Aceh Barat is known for its high-quality Arabica coffee, which is widely cultivated in the area. However, the large quantities of waste, particularly spent coffee grounds, which are typically landfilled or discarded, remain a significant challenge to waste management. SCG, despite containing valuable energy-rich biopolymers, including lipids, lignin-derived aromatics, and polysaccharides, has not been fully utilised for energy production.

The research employs a mixed-methods design, integrating both quantitative and qualitative components to provide a comprehensive assessment of the feasibility of converting SCG into solid biofuels, specifically briquettes. The quantitative component uses a discounted cash-flow (DCF) model, a standard financial evaluation tool for long-term investment projects. This model computes key financial indicators such as Net Present Value (NPV), Internal Rate of Return (IRR), Net Benefit-Cost ratio (Net B/C), and payback period over a ten-year project horizon using a 12% discount rate. These metrics are crucial for determining the economic viability of establishing an SCG briquette production line in Aceh Barat. The NPV provides insight into whether the investment will yield a positive return over time, while the IRR measures the annual return that the project is expected to generate. The Net B/C ratio is used to assess the overall economic efficiency of the project, and the payback period provides information on how long it will take for the initial investment to be recovered through the revenue generated from SCG briquettes.

This combined framing extends beyond purely plant-level analysis by incorporating aspects of distributed residue generation and small-scale biomass systems that are typical of MSME contexts in Indonesia. Similar mixed techno-economic approaches have been applied in previous studies examining biomass briquetting systems, binder effects, and portable or decentralised densification pathways, providing a methodological precedent for integrating financial modelling with operational considerations [15–17].

In addition, a hypothetical carbon-finance scenario is incorporated to explore whether avoided emissions from charcoal substitution and reduced landfill methane (CH_4) emissions could enhance IRR under realistic assumptions regarding monitoring, reporting, and verification costs. This approach is consistent with life-cycle and sustainability assessments of biomass and SCG-based solid fuels that consider both energy and environmental performance dimensions [11].

2.2. Feedstock Window, Seasonal Variability, and Line Sizing

A rapid census of café clusters in Aceh Barat indicates that approximately 8.5 t/day of spent coffee grounds (SCG) are generated across the study area. To avoid optimistic assumptions regarding feedstock availability and logistics, only 9.6–10% of this stream is assumed to be consistently recoverable under current collection and handling conditions. This conservative assumption yields a nominal single-plant processing capacity of 816 kg/day, equivalent to 254,592 kg/year at 312 operating days.

Building on this conservative sizing approach, prior studies on coffee and biomass residues underscore the importance of aligning feedstock scale, pre-treatment choices, and economic realism. In the case of coffee husks in Brazil, large theoretical energy potentials have been identified, yet techno-economic assessments reveal that high moisture content and low bulk density necessitate intensive pre-treatment, particularly drying, which often dominates both capital and operating costs and renders many bioenergy scenarios economically unviable despite substantial residue availability [18, 19]. This evidence reinforces the rationale for adopting modest, decentralised capacities in early-stage SCG valorisation systems, where controlling drying conditions and avoiding capital-intensive combustion technologies are critical to cost containment.

From a process perspective, densification plays a pivotal role in improving the handling, storage, and energy performance of biomass residues, but the literature also highlights persistent challenges related to product quality assessment and standardisation. Key parameters such as mechanical durability, abrasion resistance, moisture adsorption, and density are highly sensitive to feedstock properties and processing conditions, while the absence of universally applied standards introduces uncertainty in performance comparisons and scale-up decisions [20]. For SCG-based fuels, this implies that conservative throughput assumptions must be complemented by careful control of densification parameters to ensure consistent fuel quality under local operating conditions.

Insights from integrated torrefaction–pelletisation systems further demonstrate how plant scale, feedstock cost, and conversion yield fundamentally shape economic outcomes. Techno-economic analyses show that minimum selling prices of torrefied pellets remain strongly dependent on feedstock prices and process yields, although moderate scale increases can reduce unit costs through economies of scale [21]. In the context of Aceh Barat, the relatively small annual throughput implied by recoverable SCG volumes suggests that non-torrefied or lightly upgraded densified fuels may represent a more appropriate transitional pathway, prioritising logistical feasibility and cost control over high-capex thermal upgrading technologies.

Seasonal variability in SCG moisture content is a critical operational consideration. Field observations indicate typical moisture levels of approximately 58–65% during the rainy season and 48–54% during the dry season. These seasonal fluctuations have two principal cost implications: (1) increased thermal or passive drying requirements, which raise operating expenditure (OPEX), and (2) reduced effective throughput caused by longer drying cycles and handling delays. Both effects are explicitly incorporated into the sensitivity analysis framework, consistent with prior techno-economic evaluations of biomass briquetting systems that identify moisture variability as a key determinant of cost and performance [22, 23].

In addition to the single-plant base case, a distributed configuration involving two to three micro-scale briquetting units co-located near dense café clusters is qualitatively assessed. This approach aims to reduce collection distances, minimise moisture-related storage losses, and stabilise effective utilisation rates. The conceptual basis for this networked configuration draws on findings from supply-chain optimisation and portable densification studies, which show that decentralised systems can improve logistics efficiency and feedstock reliability in residue-rich regions [13, 15].

2.3. Process Route, Quality Control, and Cost-Control Extensions

The semi-mechanised production route adopted in this study consists of pre-drying, mixing spent coffee grounds with approximately 8% molasses binder on a weight basis, hydraulic pressing, curing to storage moisture, and packaging into 10–25 kg units. Quality-control procedures monitor key parameters, including moisture content, bulk density, mechanical durability, and ash composition. Where required, optional third-party testing of calorific value and emissions is assumed to ensure compliance with user requirements and applicable fuel standards.

Experimental and applied studies demonstrate that binder proportion, moisture control, and compaction conditions strongly influence the mechanical durability and handling quality of SCG briquettes. Prior work has shown that SCG can function effectively as an additive or primary feedstock in biomass briquettes when these parameters are properly controlled, leading to improved resistance to breakage and stable handling characteristics [3, 4].

To strengthen operational robustness and cost control, the analysis incorporates locally observed optimisation practices that influence variable costs. These include molasses dosing windows of approximately 6.5–8.5% to minimise rework and fines, two-shift labour rotation patterns commonly used in micro-densification units to reduce idle press time, and the use of rain-shelter drying racks to stabilise moisture levels during wet periods. Field observations indicate that such measures can reduce moisture variability by roughly 8–12%, thereby lowering binder demand and shortening press cycle durations.

Mechanical durability testing follows ISO 17831-1, which provides a standardised procedure for evaluating briquette resistance to abrasion and fragmentation during handling and transport [18]. In addition, techno-economic and process-modelling studies of coffee-residue pretreatment and densification are used to parameterise the model's sensitivity to drying temperature, airflow, and bed height, each of which has a measurable effect on throughput efficiency and operating expenditure [19, 20].

2.4. Financial Model, Carbon-Finance Layer, and Decision Criteria

The financial analysis evaluates a ten-year project life using a discount rate of 12%, straight-line depreciation over ten years, and a corporate tax rate of 22%. Baseline assumptions include an ex-factory selling price of IDR 4500/kg; variable production costs of IDR 2415/kg covering binder, electricity, labour, routine maintenance, packaging, and outbound transport; fixed OPEX of IDR 150 million per year; total capital expenditure (CAPEX) of IDR 1.5 billion; and working capital equal to 5% of annual sales, which is recovered in Year 10.

Project feasibility is evaluated using standard investment criteria, including Net Present Value (NPV), Internal Rate of Return (IRR), Net Benefit–Cost ratio (Net B/C), and simple Payback Period. One-factor sensitivity analysis is conducted to assess the impact of variations in key parameters around the baseline scenario. These evaluation metrics and sensitivity practices are widely applied in techno-economic assessments of biomass briquetting and pelletisation systems and are consistent with established methodologies in the bioenergy literature [15, 16].

$$\text{PV:PVt} = \text{x} = \frac{\text{CF}t}{(1+\text{i})} = 12\%$$

Financial feasibility analysis of briquettes:

$$\text{NPV} = \sum_{t=0}^{n} \frac{\text{CF}t}{(1+\text{i})\text{t}}$$

where: CFt—gross social benefits of the project in year t, which consists of all types of non-financial revenues or benefits received in year t; Ct—gross social costs in year t, all types of expenditure, both capital and routine.

The following are the decision guidelines for the NPV assessment:

(a) If the NPV is greater than zero (NPV $>$ 0), the project is feasible or acceptable to perform since it may bring benefits, and the project is at the break-even point.

(b) NPV = 0 indicates that the project returns exactly the amount of social opportunity capital factor.

(c) If NPV $<$ 0, the project is not worth working on and should be rejected.

$$\text{Net B/C ratio} = \frac{\text{PV net benefit positif}}{\text{PVnet benefit negati}}$$

The ratio provides an estimate of how many times benefits outweigh costs; projects with Net B/C $\geq$ 1 are acceptable in this framework.

$$\text{IRR} = \text{i} + \frac{\text{NPV1}}{(\text{NPV1} - \text{NPV2})} \times (i_2 - i_1)$$

where i_1 and i_2 are discount rates that yield NPV1 and NPV2, respectively; interpolation of IRR and use of simple Payback alongside NPV and Net B/C are common in TEA for briquetting and pelletisation.

$$\text{Payback Period} = (x+a)^n = \frac{\sum_{i=1}^{n} - \bar{I}_i - \Sigma_{i=1}^{n} \bar{B}_{iC_{P-1}}}{\bar{B}_P}$$

C_{P-1}—the year before payback period, I—the amount of investment that has been discounted,

$\bar{B}_{iC_{P-1}}$—the number of benefits that have been discounted before the payback period,

$\bar{B}_P$—number of benefits in the payback period.

To extend the analytical scope, a hypothetical carbon-finance layer is included to estimate the potential impact of carbon-revenue streams on financial performance. The assessment considers three parameters:

(1) a charcoal displacement factor whereby one tonne of SCG briquettes corresponds to approximately 1.4 tCO_2e (tonnes of CO_2 equivalent) emissions;

(2) landfill methane reduction potential estimated at 0.18–0.24 tCO_2e per tonne of SCG diverted;

(3) representative voluntary carbon-market prices in the range of USD 4–7 per tCO_2e.

While carbon revenue is not incorporated into the baseline cash-flow model due to uncertainties in verification and monitoring costs, these parameters enable a structured estimation of potential IRR uplift under low-cost certification pathways.

Decision rules follow established techno-economic assessment practice, whereby the project is considered financially feasible if NPV is positive, IRR exceeds the discount rate, and the Net B/C ratio is equal to or greater than one. The full discounted cash-flow model, sensitivity analysis, and supporting datasets are provided in the **Supplementary Materials**.

3. Results

3.1. Base-Case Outcomes

Annual sales reach IDR 1,145,664,000, and steady-state operating cash flow equals IDR 285,362,074 per year. Investment cash flows are: $t_0 = -$IDR 1,557,283,200 (CAPEX + working capital), $t_{1-9} = +$IDR 285,362,074 per year, $t_{10} = +$IDR 342,645,274 (operating cash flow plus working-capital recovery).

The resulting criteria are NPV (12%, 10 years) = IDR 73,519,817, IRR = 13.13%, Net B/C = 1.05, and Payback ≈ 5.46 years. These figures indicate a borderline-positive case that can become robust with modest improvements in realised price or utilisation, consistent with techno-economic assessments of biomass densification where unit margin, utilisation, and capital cost are dominant value drivers [14–16, 21]. The elasticity of value with respect to realised price and operating hours mirrors prior TEA patterns in which incremental gains in unit margin or effective uptime generate disproportionate effects on NPV and payback because many annual costs are semi-fixed [15, 21].

Beyond the project-level financial indicators, the broader literature on coffee-waste valorisation provides important context for interpreting the borderline-positive economics observed here. Comprehensive reviews show that spent coffee grounds (SCGs) are increasingly recognised as strategic feedstocks within bio-circular economy pathways, particularly for biofuels and bioenergy applications, due to their wide availability at the downstream end of the coffee value chain and their suitability for large-scale upcycling relative to other coffee residues [24]. However, despite strong technical potential and diverse application routes, industrial deployment remains limited, largely due to commercialization barriers related to process efficiency, market access, and scale alignment—factors that directly influence realised prices and utilisation rates, which are also the most elastic value drivers in the present analysis.

At the local level, empirical evidence from community-based initiatives in West Aceh further demonstrates that non-technical interventions can materially improve the economic robustness of SCG briquette systems. Participatory capacity-building programs combining technical training, cleaner production principles, and digital marketing have been shown to increase production efficiency, reduce material and water waste, and expand market reach for SCG-based briquettes, thereby improving unit margins and stabilising demand [25]. These findings support the argument that modest improvements in realised price and effective operating hours—achieved through skills upgrading, waste minimisation, and market integration—can shift borderline techno-economic outcomes toward clearly viable business cases.

From a fuel-performance perspective, studies on coffee-based pellets also indicate that binder composition and densification parameters significantly affect key quality attributes, including density, moisture content, ash fraction, fixed carbon, and thermal efficiency [26]. Optimised formulations using common binders such as tapioca flour and molasses have been shown to produce pellets with adequate energy efficiency and combustion characteristics for household-scale applications, reinforcing the feasibility of decentralised SCG densification systems. Taken together, these strands of evidence suggest that the financial performance reported above is not solely a function of feedstock scale, but is closely intertwined with process optimisation, institutional support, and market development—consistent with broader trajectories observed in coffee-waste-based bioenergy systems [24–26].

The baseline results in **Table 1**, therefore, indicate thin but positive financial feasibility, reflecting a typical MSME-scale densification profile where profitability hinges on sustaining throughput, controlling unit costs, and maintaining a viable price floor [14–16, 21].

Technically, spent coffee grounds briquettes deliver mid-teens megajoules per kilogram and high mechanical durability under routine control of moisture and binder, providing a defensible ex-factory price and supporting adoption in household and SME markets. Experimental evidence reports stable briquette properties and acceptable combustion performance when basic process controls are enforced, particularly drying discipline, compaction conditions, and binder dosing [3, 4, 27].

Table 1. Baseline financial inputs.

Item	Assumption	Note
Ex-factory price	IDR 4500/kg	Base selling price
Variable cost	IDR 2415/kg	Binder 640; electricity 225; labour 900; maintenance 150; packaging 200; outbound 300
Fixed OPEX	IDR 150,000,000/year	Supervision, rent, misc
CAPEX (Year 0)	IDR 1,500,000,000	Equipment, building works, light truck, installation
Working capital	5% of annual sales	Recovered in Year 10
Project life; DF; tax	10 y; 12%; 22%	Straight-line depreciation 10 y

The assumed variable-cost structure also aligns with quality and binder reviews showing that moisture content, particle size, and binder proportion are primary levers shaping bulk density, durability, and handling performance, which in turn affect breakage losses and unit cost per kilogram [16, 20]. Management investment in straightforward quality procedures and preventive maintenance for dies and hydraulics, therefore translates directly into higher effective utilisation without raising CAPEX, strengthening the operating annuity that drives discounted value [14, 15].

Strategically, the pronounced sensitivity to realised price implies the need to protect a price floor through simple offtake arrangements, subscription bundles, or product–stove bundling during early rollout. This pattern matches prior densification cases in which specification assurance and reliable quality control enable modest price premia and improved investment performance [14–16].

From a sustainability perspective, life-cycle assessments of SCG pellets indicate competitive environmental profiles relative to traditional solid fuels when supply chains are localised and drying energy is optimised, supporting the feasibility of maintaining modest and defensible premia when paired with clear quality assurance and performance communication [11].

Overall, the alignment between SCG briquette technical performance, a controllable cost structure through SOP-based quality, and cross-study TEA evidence reinforces the claim that the project is financially viable at baseline and can become more comfortably bankable through stronger price realisation, utilisation near nameplate capacity, and disciplined control of binder and labour costs [3, 4, 11, 14–16, 20, 21, 27].

The study's core contribution lies in coupling realistic process parameters with a financial framework widely used in densification studies and mapping both to a West Aceh context that offers continuous SCG supply and nearby end-user markets. By translating bankability into concrete operating targets—minimum realised price and minimum daily output at the baseline price—the analysis provides actionable benchmarks for plant managers and local policy actors [14–16, 21].

Limitations include a single plant size, simplified drying energy assumptions, and the absence of verified carbon-credit scenarios. Future work should further refine moisture–throughput dynamics and explore alternative drying configurations that could widen margins and reduce cash-flow volatility, consistent with TEA findings for integrated thermal upgrading and densification systems [21].

3.2. Seasonal Moisture Variability and Cost Impacts

Field observations in Meureubo and surrounding café clusters show that SCG moisture content increases markedly in the rainy season, extending drying times and raising energy and labour requirements. In the financial model, seasonal moisture penalties are represented as incremental increases in variable cost and reductions in effective throughput. A simple extension of the base case indicates that when rainy-season moisture and associated handling losses raise total variable costs by approximately 8–10%, NPV moves close to zero, and the IRR converges toward the discount rate. This behaviour is consistent with briquetting TEAs and reviews identifying moisture variability as a key operational drawback that directly affects energy use, throughput, and economic performance [22, 23].

Operationally, this underscores the importance of low-cost moisture-management practices such as rain-shelter drying racks, thinner drying beds, and time-windowed pressing schedules. In MSME settings, these measures function as risk controls that stabilise press cycle time, limit binder overuse, and reduce rainy-season cost surges, thereby protecting discounted value under thin-margin conditions [22, 23].

3.3. Detailed Cash-Flow Profile and Managerial Implications

The cash-flow profile begins with a year-zero outlay that combines fixed investment and working capital, creating an initial negative base that must be recovered through operating surpluses. Years one through nine form a near-level operating annuity, so most of the project's present value is generated by repeatedly earning a stable margin on an essentially fixed annual throughput. This explains why realised price and utilisation dominate the economics: small gains in unit margin or effective uptime compound across multiple periods and raise present value more than one-off adjustments can, a pattern consistent with techno-economic assessments of densification projects [14, 15, 21].

Two mechanics in the terminal year are particularly important. First, the release of working capital in year ten increases the terminal inflow without affecting interim years, which is why the present value in year ten can exceed that of a single operating year despite heavier discounting. Second, straight-line depreciation affects cash only through taxes: reducing taxable income generates a tax shield that lifts after-tax operating cash flow and therefore NPV. Together, these effects produce the observed profile: a thin but positive NPV at a 12% hurdle, an IRR slightly above the discount rate, a Net B/C just over one, and a mid-horizon nominal payback—typical for compact briquetting lines operating with modest capital intensity and steady utilisation [14, 15, 21].

The discount factor column is computed as $1/(1+0.12)^t$ and should be shown to four decimals to reproduce the present-value column consistently. Using 0.8929, 0.7972, 0.7118, 0.6355, 0.5674, 0.5066, 0.4523, 0.4039, 0.3606, and 0.3220 for years one through ten follows standard discounted-cash-flow practice and supports transparency and repeatability in peer review.

Managerially, **Table 2** highlights that value is concentrated in the operating annuity rather than in speculative terminal values. Three priorities follow: protect unit margin through QA-backed pricing, prioritise uptime and preventive maintenance, and manage working capital tightly to improve early free cash flow, which is disproportionately valuable under discounting [15, 21].

Table 2. Detailed annual cash flows and present values (12%).

Year	Cash Flow (IDR)	Discount Factor (12%)	PV (IDR)	Cumulative Nominal CF (IDR)
0	−1,557,283,200.00	1.00	−1,557,283,200.00	−1,557,283,200.00
1	285,362,073.60	0.8900	254,787,565.71	−1,271,921,126.40
2	285,362,073.60	0.8000	227,488,897.96	−986,559,052.80
3	285,362,073.60	0.7100	203,115,087.46	−701,196,979.20
4	285,362,073.60	0.6400	181,352,756.66	−415,834,905.60
5	285,362,073.60	0.5700	161,922,104.16	−130,472,832.00
6	285,362,073.60	0.5100	144,573,307.29	154,889,241.60
7	285,362,073.60	0.4500	129,083,310.08	440,251,315.20
8	285,362,073.60	0.4000	115,252,955.43	725,613,388.80
9	285,362,073.60	0.3600	102,904,424.49	1,010,975,462.40
10	342,645,273.60	0.3200	110,322,607.74	1,353,620,736.00

Finally, the assumption of a stable operating annuity is supported by the technical credibility of SCG briquettes. Experimental studies report mid-teens MJ/kg energy content, high mechanical durability, and acceptable emissions when moisture and binder are routinely controlled, which underpins stable offtake and lowers rework or breakage losses [3, 4, 27]. When supply chains and drying energy are localised and optimised, LCA evidence for SCG pellets supports the sustainability rationale for modest and defensible price premia, strengthening the commercial case under disciplined quality assurance [11].

3.4. Multi-Plant Network Considerations

Although the primary financial model is built around a nominal processing capacity of 816 kg/day, this figure derives from the feedstock assessment conducted in Meureubo and surrounding café clusters and reflects a conservative capture rate under realistic logistics constraints. However, the café-cluster geography of West Aceh naturally lends itself to multi-plant configurations. A qualitative comparison between a centralised single-plant layout and a distributed network of two or three smaller units located near dense café clusters indicates a classic trade-off: while CAPEX and fixed OPEX rise moderately due to duplicated equipment and supervisory functions, collection and outbound transport costs fall, and feedstock security improves because each unit serves a smaller radius. In operational terms, shorter collection distances reduce storage losses and stabilise effective utilisation.

Although the present analysis does not include a full network-optimisation model, the conceptual logic is consistent with supply-chain optimisation and portable densification evidence showing that decentralised configurations can improve feedstock reliability and reduce logistics penalties in residue-cluster settings [13, 15].

3.5. Price Scenarios and Carbon-Finance Potential

Table 3 shows a direct and powerful linkage between realised selling price and project value. Raising the price from IDR 4500 to IDR 5500/kg converts the venture from a thin baseline into a highly attractive case, whereas reducing the price to IDR 3500/kg drives NPV deep into negative territory. This strong operating leverage is consistent with techno-economic evidence showing that realised price and effective utilisation dominate NPV and IRR in densification projects because margin is applied repeatedly across a largely fixed annual throughput [14, 15]. See **Figure 1** for the cumulative cash flow over the 10-year period.

Table 3. Scenario NPVs for selling price.

Price (IDR/kg)	NPV (IDR)
3500	−1,068,705,549
4500 (baseline)	73,519,817
5500	1,130,818,479

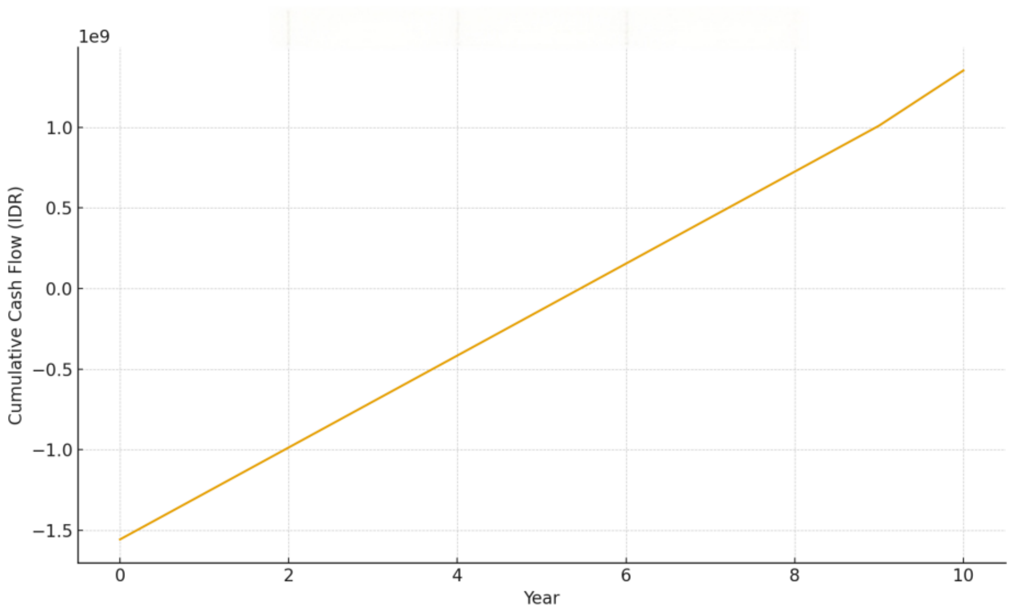

Figure 1. Cumulative cash flow—baseline (10 years, 12% discount).

Two practical takeaways follow for managers. First, establish and defend a price floor. Because unit margin compounds over the project horizon, small shortfalls in realised selling price can erode discounted value substantially. Second, make price premia credible through routine quality assurance. Experimental and applied studies show that SCG briquettes and pellets can achieve durable handling quality and stable combustion performance under disciplined moisture and binder control, supporting defensible pricing when specifications are communicated and verified [3, 4, 16, 27].

Price also interacts with utilisation. Throughput near nameplate capacity amplifies the benefit of any positive price deviation because the higher margin is applied to more tonnes, while downtime erodes gains hour by hour. This interaction explains why price and utilisation consistently rank as first-order drivers in densification TEA, with other levers (binder, labour, and maintenance) following behind [14, 15, 21].

Overall, **Table 3** converts abstract sensitivity into practical guidance. Protect unit margin, make the premium defensible through routine QA, and keep the line running close to planned output. Do these three things, and the project moves decisively from borderline feasible toward comfortably bankable.

Beyond market price effects, the analysis also considers a hypothetical carbon-finance layer. Life-cycle evidence indicates that SCG pellet/briquette pathways can provide favourable environmental profiles relative to conventional solid fuels when supply chains are localised and drying energy is optimised, supporting the plausibility of emission-reduction claims under appropriate accounting boundaries [11]. Although carbon revenue is not incorporated into the baseline cash-flow model due to uncertainty in verification and transaction costs, the scenario provides a structured estimate of potential IRR uplift under low-cost certification pathways.

As summarised in **Table 4**, the baseline scenario at IDR 4500/kg yields a borderline-feasible financial profile, with NPV = IDR 73.52 million, IRR = 13.13% (slightly above the 12% discount rate), Net B/C = 1.05, and a payback period of approximately 5.46 years. This outcome mirrors typical results reported for small-scale briquetting plants, where value creation depends on sustaining unit margin across a largely fixed annual throughput [14–16].

Table 4. Financial results (10 years, 12% discount).

Scenario	Annual Sales (IDR)	Operating CF (IDR/yr)	NPV (IDR)	IRR (%)	Payback (yr)	Net B/C
Baseline (IDR 4500/kg)	1,145,664,000	285,362,074	73,519,817	13.13	5.46	1.05
Low price (IDR 3500/kg)	890,072,000	—	−1,068,705,549	—	>10	<1
High price (IDR 5500/kg)	1,401,256,000	—	1,130,818,479	—	<4	>1

The downside price scenario at IDR 3500/kg is decisively uneconomic, producing a negative NPV, Net B/C below one, and a payback period exceeding the project horizon. Such outcomes are consistent with techno-economic evidence showing that when realised price approaches variable-cost levels, IRR collapses and discounted payback becomes unattainable in densification systems with semi-fixed cost structures [14–16].

In contrast, the upside scenario at IDR 5500/kg results in a strongly attractive investment profile, with NPV exceeding IDR 1.13 billion, payback below four years, and Net B/C comfortably above one. This "gear-up" response reflects the operating leverage inherent in briquetting systems, where modest increases in realised price translate almost one-for-one into operating cash flow and discounted value when utilisation is maintained [14, 15].

The plausibility of such a price premium is supported by technical evidence. Experimental studies consistently report that SCG briquettes can achieve mid-teens MJ/kg heating values, high mechanical durability, and acceptable emissions under routine moisture and binder control, enabling household and SME acceptance and supporting modest price premia when coupled with quality assurance or bundled offerings [3, 4, 27].

Finally, incorporating conservative emission-reduction factors suggests that carbon finance could further strengthen project economics. Assuming approximately 1.4 tCO_2e avoided per tonne of briquettes through charcoal displacement and 0.18–0.24 tCO_2e avoided per tonne of SCG diverted from landfill, the annual output could yield on the order of 400 tCO_2e of emission reductions. At indicative voluntary carbon prices of USD 4–7 per tCO_2e, this corresponds to potential gross revenues of approximately IDR 25–40 million per year. If verification costs can be kept low, discounted carbon revenue of this magnitude could increase NPV by roughly IDR 100–200 million and raise IRR by an estimated 1–2 percentage points, shifting the project from borderline feasible toward a more comfortably bankable range without altering the physical process [11].

3.6. Sensitivity Analysis and Operating Guardrails

Table 5 confirms that project value is dominated by unit margin and throughput. A ±20% swing in realised selling price shifts NPV by approximately ±IDR 1.0 billion, dwarfing the effects of other levers. This occurs because the selling price directly affects the per-kilogram margin applied to every tonne produced across the full project horizon, generating large discounted effects when compounded over time. Such sensitivity rankings are consistent with prior densification TEA and supply-chain optimisation reviews where price and effective utilisation are the principal determinants of bankability [14, 15]. See **Figure 2** for a visual representation of the NPV sensitivity to price changes.

Table 5. One-factor sensitivity (ΔNPV vs. baseline).

Parameter Change	ΔNPV (IDR)
Price +20%	+951,568,796
Price −20%	−1,006,430,816
Output +10%	+204,813,855
Output −10%	−204,813,855
Labor −20%/+20%	+201,965,622/−201,965,622
Binder −20%/+20%	+143,619,998/−143,619,998
Discount rate −2 pp/4+2 pp	+144,708,547/−126,869,651

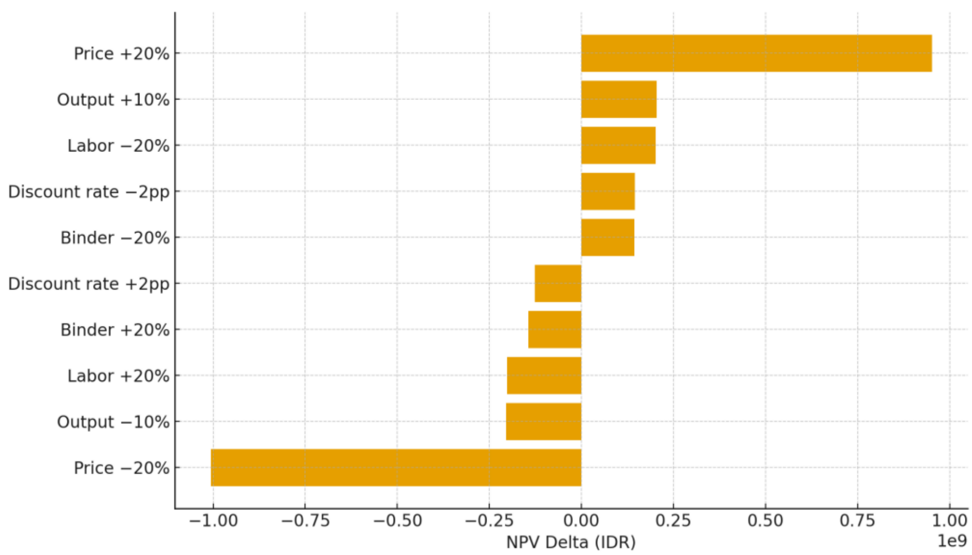

Figure 2. NPV sensitivity tornado (Δ vs. baseline).

By contrast, utilisation changes of ±10% shift NPV by roughly ±IDR 204.8 million because they scale the operating annuity without changing per-unit margin. Labour and binder costs remain material because they represent major components of variable cost, and their control improves resilience; however, their NPV impact remains smaller than that of price in thin-margin systems [16, 20]. The discount rate also affects value materially, reflecting financing and capital-cost risk; integrated TEA literature similarly reports that the cost of capital shifts feasibility thresholds even when operations are unchanged [21].

Two operating guardrails emerge from the sensitivity results: a price floor around IDR 4430/kg and a minimum daily output around 787 kg/day at the baseline price. Practically, this implies two priorities. First, protect realised price through QA-backed specifications, simple offtake or subscription arrangements, and clear communication of moisture and durability bands to reduce price slippage. Second, sustain utilisation near nameplate by stabilising moisture targets, ensuring consistent binder dosing, and prioritising preventive maintenance to minimise unplanned downtime. These levers align with prior findings that maintaining stable flow and specification compliance is the fastest route to stronger economics in densification systems [14–16, 20].

Because SCG briquettes can demonstrate mid-teens MJ/kg energy content, high mechanical durability, and stable handling when moisture and binder are controlled, the operational preconditions for holding price and utilisation are attainable under basic SOP-based quality assurance [3, 4, 27]. In that sense, the venture is "thin but steerable": disciplined pricing and uptime shift it from borderline-positive to more comfortably bankable.

3.7. Break-Even Thresholds and Local Evidence

Table 6 translates the model into two practical operating thresholds. The break-even price (NPV = 0) is IDR 4430.46/kg, which is only about 1.55% below the baseline assumed price of IDR 4500/kg. This narrow gap indicates that even modest slippage in realised price can push discounted value below zero, while a modest uplift can materially strengthen feasibility. This behaviour is typical of compact densification lines where semi-fixed annual costs mean that unit margin is amplified over repeated production cycles [14, 15].

Table 6. Break-even thresholds from the model.

Metric	Value
Break-even price (NPV = 0)	IDR 4430.46/kg
Break-even output (at IDR 4500/kg)	787/day

At the baseline price, the break-even output is approximately 787 kg/day, leaving only a small utilisation cushion relative to the 816 kg/day design rate. Sustained throughput below this threshold erodes value because fixed and semi-fixed costs dilute operating margin, whereas steady uptime increases NPV by strengthening the operating annuity. This tight capacity margin is consistent with densification TEA evidence, where reliable throughput and specification compliance determine whether small-scale plants remain bankable under realistic cost structures [15, 21].

Operationally, three actions follow. First, protect the price floor with QA-backed specifications and simple contracting tools so realised price does not drift below IDR 4430/kg; durable handling quality and mechanical integrity are central to maintaining that price floor, as shown in binder and durability research [16, 20]. Second, hold utilisation near design capacity by standardising moisture targets, binder dosing and mixing, press pressure and dwell time, and preventive maintenance for dies and hydraulics, consistent with densification quality-parameter reviews [20]. Third, reduce daily-output volatility through clustered collection practices and short drying loops to stabilise feedstock handling and press scheduling. Moisture variability remains a known operational drawback in briquetting systems with direct implications for energy use and throughput stability, so low-cost moisture-management practices function as downside-risk controls [22, 23].

These guardrails are credible because experimental evidence indicates that SCG briquettes can maintain high mechanical durability and acceptable combustion behaviour when moisture and binder are routinely controlled through basic quality assurance, supporting stable offtake at or above the break-even price [3, 4, 27]. In discounted terms, disciplined pricing and dependable utilisation operate as paired levers that move the project from thin feasibility toward robust bankability, consistent with the ranking of drivers reported across densification techno-economic assessments [14, 15, 21].

4. Discussion

The results support the central proposition of this study that a compact spent coffee grounds (SCG) briquette line in West Aceh can be financially viable, but only within a relatively narrow corridor defined by realised selling price and effective utilisation. Under baseline assumptions, the Net Present Value (NPV) is slightly positive, the Internal Rate of Return (IRR) marginally exceeds the 12% discount rate, and the Net Benefit–Cost ratio (Net B/C) is just above unity. This financial profile is characteristic of small- and medium-scale densification projects, in which value creation depends primarily on the ability to apply a stable unit margin repeatedly across a largely fixed annual throughput rather than on scale economies or technological sophistication [14–16, 21].

The one-factor sensitivity analysis reinforces this interpretation by showing that modest deviations in realised price and utilisation dominate the NPV response, whereas even relatively large changes in binder and labour costs have smaller proportional effects. This pattern is consistent with established techno-economic assessment (TEA) evidence for biomass briquetting and pelletisation systems, which consistently identifies selling price and uptime as first-order drivers of bankability under semi-fixed cost structures [14, 15, 21]. In practical terms, this means that managerial attention should prioritise price discipline and throughput stability over incremental cost optimisation, particularly in MSME-scale operations where margins are thin.

These findings align with broader techno-economic evidence on biomass briquetting systems, which demonstrates that feasibility outcomes are highly sensitive to feedstock characteristics, process stability, and market conditions. Recent assessments show that moisture variability, feedstock handling losses, and inconsistent utilisation can quickly erode financial performance, even when baseline scenarios appear viable [22, 23]. The present study extends this evidence by showing that SCG briquette ventures are not intrinsically unviable, but rather conditionally bankable, with realised price, utilisation, and moisture control emerging as decisive variables shaping discounted cash-flow outcomes in the West Aceh context.

From a technical perspective, the results reinforce the growing consensus that SCG constitutes a credible solid biofuel feedstock when processed under basic quality assurance. Experimental and applied studies consistently demonstrate that SCG briquettes can achieve mid-teens MJ/kg energy content, high mechanical durability, and stable handling characteristics when moisture content and binder proportions are carefully controlled [3, 4, 27]. These attributes underpin reliable combustion behaviour and reduce breakage and fines during handling and transport, which in turn support stable offtake and defensible pricing in household and SME markets.

The linkage between technical performance and financial outcomes is particularly important in this context. Because the economic model is highly sensitive to realised price, even modest improvements in briquette durability and handling quality can have disproportionate financial effects if they enable the maintenance of a price floor or a small premium over lower-quality fuels. This helps explain why quality assurance, rather than purely cost-minimisation, emerges as a critical operational lever in the financial model [16, 20]. In effect, technical discipline translates directly into financial resilience by stabilising both price realisation and utilisation.

From an environmental and sustainability standpoint, the discussion further highlights the relevance of SCG briquettes within a circular bioeconomy framework. Life-cycle assessment evidence indicates that SCG pellet and briquette pathways can deliver competitive or superior environmental profiles compared with traditional solid fuels when supply chains are localised and drying energy is optimised [11]. In the West Aceh context, where SCG generation is geographically clustered around cafés and small processing units, such localisation is operationally realistic and strengthens the environmental rationale for valorisation.

The results also intersect with broader circular-economy and rural development objectives in coffee-producing regions. Evidence from Indonesian coffee cooperatives shows that residue valorisation initiatives can strengthen local economic resilience and reduce environmental burdens when supported by appropriate organisational and market arrangements [12]. The present study adds a finance-oriented perspective to this literature by demonstrating how such circular-economy concepts become investable only when operational discipline—particularly around moisture management, binder dosing, and utilisation—is translated into predictable cash-flow performance.

Seasonal moisture variability emerges as a critical contextual factor in this regard. The rainy-season scenarios show that relatively small increases in effective variable costs, on the order of 8–10%, are sufficient to push NPV towards zero and compress IRR towards the hurdle rate. This behaviour mirrors findings from other briquetting TEAs, where thin margins are rapidly eroded by higher drying energy requirements, handling losses, or unplanned downtime [15, 21]. However, field observations in West Aceh suggest that low-cost interventions, such as rain-shelter drying racks, thinner drying beds, and time-windowed pressing (can materially reduce moisture variability and rework). Viewed through a discounted-cash-flow lens, these practices function as risk-management tools rather than marginal technical refinements, helping to reduce downside volatility during wet seasons.

The exploratory carbon-finance analysis adds a further layer to the interpretation of bankability. By combining conservative emission-reduction factors for charcoal displacement and landfill diversion with indicative voluntary carbon prices, the study shows that even modest carbon revenues could meaningfully improve discounted financial indicators, potentially lifting NPV by IDR 100–200 million and raising IRR by 1–2 percentage points [11]. While carbon revenue is treated here as an upside option rather than a core pillar of feasibility, this finding suggests that improvements in monitoring, reporting, and verification (MRV) frameworks for small decentralised projects could materially de-risk borderline SCG briquette ventures in the future.

Taken together, the discussion supports a three-pillar interpretation of bankability for SCG briquettes in West Aceh. First, disciplined pricing and price-floor protection are indispensable, given the narrow gap between the break-even price and the baseline assumption. Second, dependable utilisation near the 816 kg/day design capacity is necessary to amortise fixed costs, which in turn depends on moisture management, preventive maintenance, and labour organisation that minimises idle time. Third, binder and labour optimisation, while second-order in the sensitivity ranking, provide additional resilience when embedded in standard operating procedures that reduce rework, fines, and wasted press cycles. These pillars are fully consistent with the ranking of drivers reported across densification TEAs and with emerging practice in MSME-scale biomass upgrading systems [16, 21].

Several limitations qualify this interpretation. First, the financial model developed in this study is deterministic and based on a single plant size, with uncertainty addressed only through one-factor sensitivity analysis. Deterministic models, while useful for initial feasibility screening, often fail to capture the full range of variability in key parameters such as feedstock availability, pricing, moisture content, and labour costs; in contrast, stochastic or scenario-based approaches explicitly model the joint variability of multiple uncertain factors, providing a more robust assessment of techno-economic performance under real-world conditions [28]. Stochastic optimization has been shown to outperform conventional approaches by incorporating uncertainties simultaneously within supply chain network design, leading to more resilient and realistic decision outcomes [29].

Moreover, the discussion of multi-plant configurations remains qualitative and would benefit from explicit spatial optimisation modelling. Spatial optimisation methods, including GIS-based multi-criteria planning and geographic optimisation of facility locations, can improve overall supply chain efficiency by identifying optimal plant siting and transport cost trade-offs across heterogeneous biomass availability landscapes [30]. Without such spatial analysis, qualitative discussions risk oversimplifying complex geographic and logistical interactions that influence system cost and performance.

In addition, the carbon-finance layer remains hypothetical, with further empirical work needed to quantify MRV (Measurement, Reporting, and Verification) costs, additionality, and permanence—critical elements in the credibility of carbon credit mechanisms for renewable projects. Challenges such as lack of permanence, non-additionality, and limited MRV standards have been identified as major obstacles for carbon contracting and carbon farming projects, reducing incentives and affecting market credibility [31]. Robust MRV protocols are especially important for small-scale biomass or bioenergy projects where measurement uncertainties can be proportionally larger [32].

Finally, although the analysis focuses primarily on financial metrics, it does not yet address broader distributional outcomes such as employment effects or household energy security. Renewable energy and bioenergy deployment have been linked with socio-economic outcomes, including job creation, income effects, and energy access improvements, yet these impacts are often under-quantified in traditional techno-economic assessments [33]. For example, ex-ante studies of bioenergy indicate that employment, income, and energy security effects are important socio-economic dimensions that warrant explicit inclusion in comprehensive project evaluations.

5. Conclusions

This study examined whether a compact spent coffee grounds (SCG) briquette production line in West Aceh can be financially bankable under realistic local conditions. The core conclusion is that the project is conditionally feasible. Under baseline assumptions, it delivers a thin but positive Net Present Value (NPV), an Internal Rate of Return (IRR) slightly above the 12% discount rate, a Net Benefit–Cost ratio (Net B/C) marginally greater than one, and a mid-horizon payback period. However, financial viability depends critically on maintaining a narrow corridor of realised selling price and effective utilisation. In this sense, SCG briquettes are not a guaranteed investment outcome, but they can become financially attractive when basic commercial and operational discipline is consistently applied.

From a technical standpoint, the findings indicate that SCG briquettes can achieve fuel performance comparable to, or better than, conventional biomass fuels for household and SME stoves when moisture content and binder ratios are properly controlled. Mid-teens MJ/kg energy content, high mechanical durability, and acceptable combustion behaviour provide a credible basis for modest price premia over lower-quality fuels. The discounted cash-flow and sensitivity analyses clarify how these technical attributes translate into bankability: protecting unit margin through price-floor management, sustaining throughput near the 816 kg/day design capacity, and tightening control over binder and labour costs together shift the project from borderline-positive toward more robust financial performance.

The analysis also yields context-specific insights relevant to circular bioeconomy strategies in coffee regions. In West Aceh, café-cluster geography favours decentralised or networked production configurations that shorten collection distances, reduce moisture-related losses, and stabilise feedstock supply. Seasonal moisture variability emerges as a non-trivial operational risk, but one that can be mitigated through low-cost practices such as rain-shelter drying racks, thinner drying beds, early-morning pressing windows, and disciplined binder dosing. Exploratory carbon-finance calculations further suggest that, if monitoring and verification costs can be contained, modest carbon revenues could lift NPV and IRR sufficiently to materially de-risk otherwise borderline projects.

In the broader context of energy transition and rural development, these conclusions highlight SCG briquettes as a practical circular-economy instrument rather than a purely conceptual solution. By diverting SCG from landfill or open dumping and partially displacing charcoal and fuelwood use, the venture integrates waste management, local energy security, and climate objectives within a single MSME-scale model. Importantly, the results demonstrate that success hinges less on advanced technology and more on clear operating guardrails and simple, enforceable routines related to pricing discipline, utilisation, and quality assurance.

Finally, the study identifies clear directions for future research and policy. More detailed spatial and stochastic modelling could refine comparisons between single-plant and multi-plant configurations and better capture joint variability in price, feedstock availability, and moisture. Integrating life-cycle assessment, local air-quality impacts, and socio-economic outcomes would broaden evaluation beyond financial metrics alone. For policymakers and practitioners, the key message is straightforward: if realised price, utilisation, and basic quality assurance can be jointly safeguarded, SCG briquetting in West Aceh can move from a thin feasibility margin to a robust and scalable component of regional circular-bioeconomy strategies.

Supplementary Materials

The supporting information can be downloaded at: https://journals.nasspublishing.com/files/RWAE-2813-Supplementary-Materials.xlsx.

Author Contributions

Conceptualization, M.R.A. and U.A.; methodology, H.; validation, M.R.A. and A.N.; formal analysis, U.A.; investigation, M.R.A. and H.; resources, H.; data curation, A.N. and F.A.F.; writing—original draft preparation, U.A. and A.N.; writing—review and editing, M.R.A. and H.; visualization, U.A.; supervision, M.R.A.; project administration, F.A.F. All authors have read and agreed to the published version of the manuscript.

Funding

This work received no external funding.

Institutional Review Board Statement

Not applicable. This study did not involve human or animal subjects and therefore did not require approval from an Ethics Committee or Institutional Review Board.

Informed Consent Statement

Not applicable. This study did not involve human subjects and therefore did not require informed consent.

Data Availability Statement

Data supporting the findings of this study are available within the **Supplementary Materials**. Additional data, including extended operational records and moisture-variability logs, are available from the corresponding author upon reasonable request.

Acknowledgments

We are grateful to cafe owners, baristas, and waste collectors in Aceh Barat who shared access to spent coffee grounds and provided practical insights on collection logistics and consumer preferences. We thank fuel retailers and small stove users in Meulaboh and the surrounding sub-districts for participating in product trials and user interviews.

We acknowledge the support of colleagues at the University of Teuku Umar, particularly within the Faculty of Agriculture and the Faculty of Economics, for constructive input on study design and market analysis. Field enumeration and laboratory assistance from our student volunteers are gratefully recognized. We also appreciate the facilitation provided by local government offices in Aceh Barat for discussions related to waste management and MSME development. Helpful comments from academic peers during internal seminars improved the clarity of the manuscript; any remaining errors are our own. This research received no external funding. We are thankful to the anonymous reviewers for their careful reading and valuable suggestions that strengthened the paper.

Conflicts of Interest

The authors declare no conflict of interest.

Appendix A

Appendix A contains supplementary figures, tables, and equations that provide additional detail on the discounted cash-flow model, seasonal moisture sensitivity, operational elasticity, and alternative plant configuration scenarios.

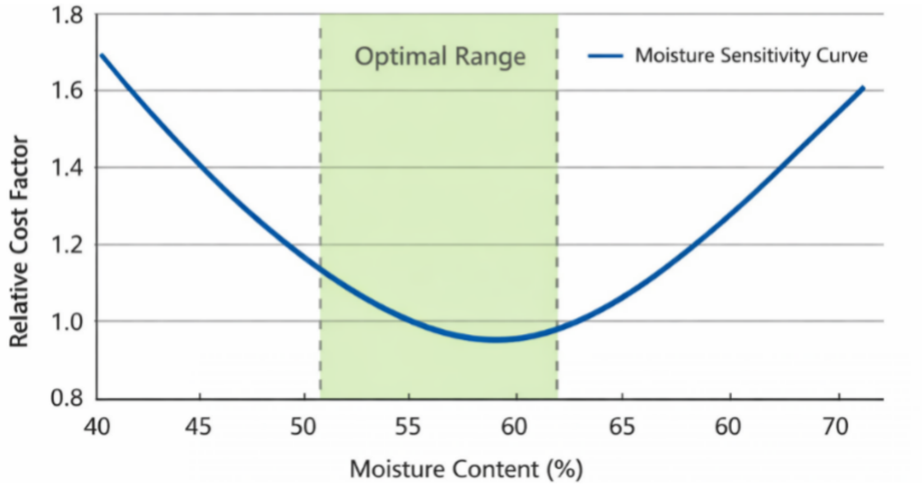

Figure A1. The moisture sensitivity curve applied in the seasonal cost modelling framework.

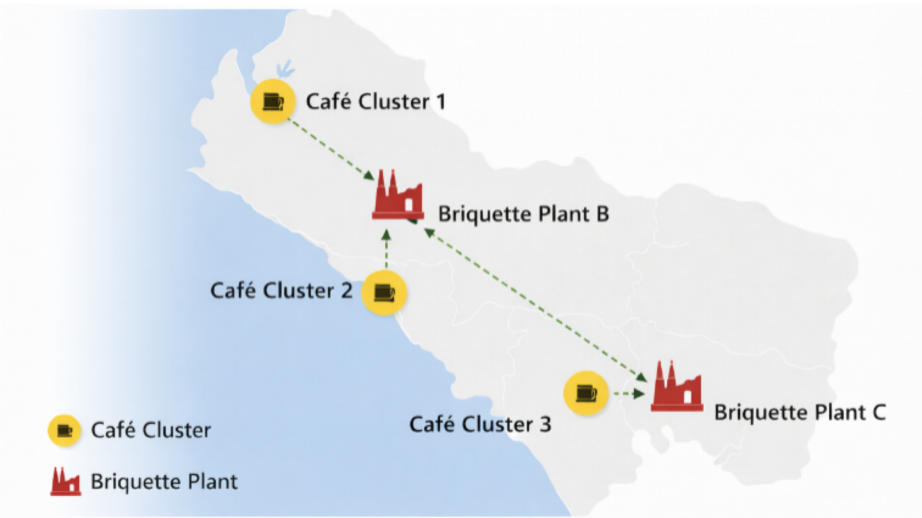

Figure A2. An alternative three-plant network layout for café clusters in West Aceh.

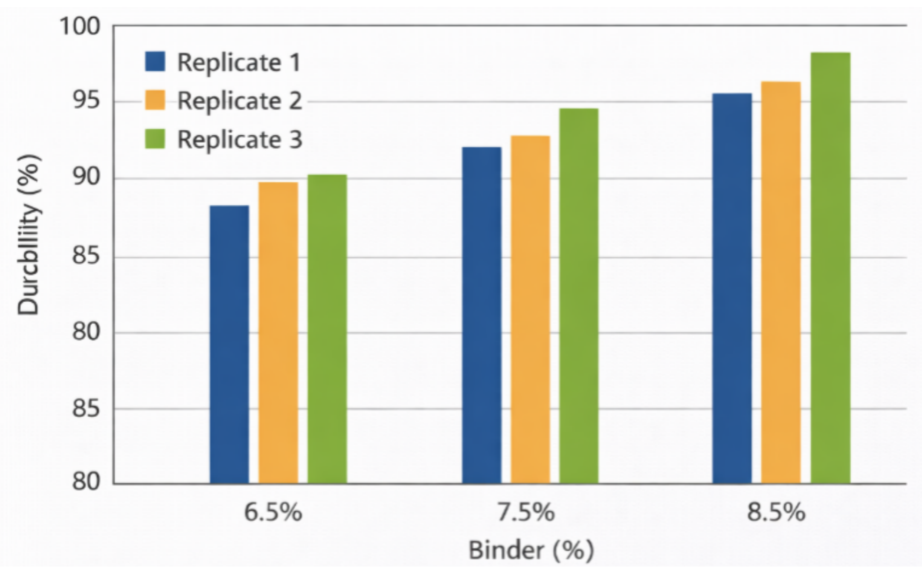

Figure A3. Replicate durability test results for SCG briquettes under different binder dosages.

Table A1. The parameter ranges used in the binder–labour optimisation scenarios.

No.	Parameter	Range
1.	Binder percentage	6.5%–8.5%
2.	Moisture content	48%–65%
3.	Press pressure	50–75 bar

Table A2. An extended comparison of CAPEX and OPEX components between single-plant and multi-plant configurations.

No.	Component	Single-Plant	Multi-Plant
1.	CAPEX (IDR)	1,500,000,000	2,000,000,000
2.	Fixed OPEX (IDR/year)	150,000,000	180,000,000
3.	Variable OPEX (IDR/kg)	2415	2000
4.	Maintenance costs (IDR)	25,000,000	30,000,000

Equation (A1) presents the discount-factor computation formula applied in the cash-flow analysis:

$$DF_t = \frac{1}{(1+r)^t}, \quad r = 0.12 \tag{A1}$$

References

[1] Atabani, A.E., Mahmoud, E., Aslam, M., et al., 2023. Emerging Potential of Spent Coffee Ground Valorization for Fuel Pellet Production in a Biorefinery. Environment, Development and Sustainability. 25(8), 7585–7623. DOI: https://doi.org/10.1007/s10668-022-02361-z

[2] Otieno, A.O., Home, P.G., Raude, J.M., et al., 2022. Heating and emission characteristics from combustion of charcoal and co-combustion of charcoal with faecal char-sawdust char briquettes in a ceramic cook stove. Heliyon. 8(8), e10272. DOI: https://doi.org/10.1016/j.heliyon.2022.e10272

[3] Colantoni, A., Paris, E., Bianchini, L., et al., 2021. Spent coffee ground characterization, pelletization test and emissions assessment in the combustion process. Scientific Reports. 11(1), 5119. DOI: https://doi.org/10.1038/s41598-021-84772-y

[4] Brunerová, A., Roubík, H., Brožek, M., et al., 2019. Valorization of Bio-Briquette Fuel by Using Spent Coffee Ground as an External Additive. Energies. 13(1), 54. DOI: https://doi.org/10.3390/en13010054

[5] Rahmah, D.M., Faojiah, R.S., Dewi, M.S., et al., 2025. Dynamic modelling of circular economic implementation towards sustainable coffee agroforestry in Indonesia. Discover Sustainability. 6(1), 1243. DOI: https://doi.org/10.1007/s43621-025-02039-2

[6] Lee, X.J., Ong, H.C., Gao, W., et al., 2021. Solid biofuel production from spent coffee ground wastes: Process optimisation, characterisation and kinetic studies. Fuel. 292, 120309. DOI: https://doi.org/10.1016/j.fuel.2021.120309

[7] Athaillah, T., Masykur, M., Husin, H., et al., 2024. Briquettes from a Mixture of Cow Menure, Rice Husks and Wood Dust as Alternative Fuel. Journal of Ecological Engineering. 25(2), 290–299. DOI: https://doi.org/10.12911/22998993/177194

[8] Agustiar, A., Bantacut, T., Romli, Moh., et al., 2023. The Potential of Bio-Try Briquettes for Biomass Power Plant in Aceh Province—Case Study in South West Aceh, Indonesia. Journal of Ecological Engineering. 24 (10), 115–124. DOI: https://doi.org/10.12911/22998993/170079

[9] International Coffee Organization (ICO), 2024. Coffee Year 2023/24: Paving the Way for a Sustainable Future through Coffee Diplomacy. ICO: London, UK.

[10] Bildirici, M., Çoban Kayıkçı, F., 2023. Energy Consumption, Energy Intensity, Economic Growth, FDI, Urbanization, PM2.5 Concentrations Nexus. Environment, Development and Sustainability. 26(2), 5047–5065. DOI: https://doi.org/10.1007/s10668-023-02923-9

[11] Rajabi Hamedani, S., Colantoni, A., Bianchini, L., et al., 2022. Environmental life cycle assessment of spent coffee ground pellet. Energy Reports. 8, 6976–6986. DOI: https://doi.org/10.1016/j.egyr.2022.05.031

[12] Dana Karningsih, P., Ciptomulyono, U., Suef, M., et al., 2025. Circular Economy Adoption on Coffee Production: Case Study of a Coffee Cooperatives Farmer in Indonesia. BIO Web of Conferences. 157, 04007. DOI: https://doi.org/10.1051/bioconf/202515704007

[13] Albashabsheh, N.T., Heier Stamm, J.L., 2019. Optimization of lignocellulosic biomass-to-biofuel supply chains with mobile pelleting. Transportation Research Part E: Logistics and Transportation Review. 122, 545–562. DOI: https://doi.org/10.1016/j.tre.2018.12.015

[14] Cambero, C., Sowlati, T., 2014. Assessment and optimization of forest biomass supply chains from eco-

nomic, social and environmental perspectives—A review of literature. Renewable and Sustainable Energy Reviews. 36, 62–73. DOI: https://doi.org/10.1016/j.rser.2014.04.041

[15] Sahoo, K., Bilek, E., Bergman, R., et al., 2019. Techno-economic analysis of producing solid biofuels and biochar from forest residues using portable systems. Applied Energy. 235, 578–590. DOI: https://doi.org/10.1016/j.apenergy.2018.10.076

[16] Obi, O.F., Pecenka, R., Clifford, M.J., 2022. A Review of Biomass Briquette Binders and Quality Parameters. Energies. 15(7), 2426. DOI: https://doi.org/10.3390/en15072426

[17] Agustiar, Romano, Aulia, M.R., et al., 2024. Mass balance of palm waste energy potential in palm oil processing in South West Aceh, Indonesia. IOP Conference Series: Earth and Environmental Science. 1297(1), 012076. DOI: https://doi.org/10.1088/1755-1315/1297/1/012076

[18] Gilvari, H., De Jong, W., Schott, D.L., 2020. The Effect of Biomass Pellet Length, Test Conditions and Torrefaction on Mechanical Durability Characteristics According to ISO Standard 17831-1. Energies. 13(11), 3000. DOI: https://doi.org/10.3390/en13113000

[19] E Silva, A.D.O., Dos Santos, I.F.S., Perazzini, H., 2026. Study on the Modeling and Simulation of the Pre-Treatment Process of Coffee Husks for Renewable Energy Production in the Brazilian Agro-Industrial Sector. Biomass and Bioenergy. 204, 108405. DOI: https://doi.org/10.1016/j.biombioe.2025.108405

[20] Gilvari, H., De Jong, W., Schott, D.L., 2019. Quality parameters relevant for densification of bio-materials: Measuring methods and affecting factors—A review. Biomass and Bioenergy. 120, 117–134. DOI: https://doi.org/10.1016/j.biombioe.2018.11.013

[21] Manouchehrinejad, M., Bilek, E.M.T., Mani, S., 2021. Techno-economic analysis of integrated torrefaction and pelletization systems to produce torrefied wood pellets. Renewable Energy. 178, 483–493. DOI: https://doi.org/10.1016/j.renene.2021.06.064

[22] Roghan, H.B., Sekar, I., Sivaprakash, M., et al., 2025. Techno-economic feasibility of biomass briquetting system for sustainable waste-to-energy generation. Plant Science Today. DOI: https://doi.org/10.14719/pst.7187

[23] Kpalo, S.Y., Zainuddin, M.F., Manaf, L.A., et al., 2020. A Review of Technical and Economic Aspects of Biomass Briquetting. Sustainability. 12(11), 4609. DOI: https://doi.org/10.3390/su12114609

[24] Pongsiriyakul, K., Wongsurakul, P., Kiatkittipong, W., et al., 2024. Upcycling Coffee Waste: Key Industrial Activities for Advancing Circular Economy and Overcoming Commercialization Challenges. Processes. 12(12), 2851. DOI: https://doi.org/10.3390/pr12122851

[25] Athaillah, T., Afrianda, S., Salsabila C., et al., 2025. Utilization of Coffee Grounds-Based Eco Briquettes as an Alternative Energy Source for Coffee Shop Enterprises in Aceh Barat Regency. Journal of Service Innovation. 1(1), 32–36. Available from: https://journalofserviceinnovation.com/jsi/article/view/7

[26] Harsono, S.S., 2024. Biomass Pellets Fuel from Coffee Peels as a Renewable Energy Source and Its Application in Low Emission Stove. IOP Conference Series: Earth and Environmental Science. 1356(1), 012061. DOI: https://doi.org/10.1088/1755-1315/1356/1/012061

[27] Seco, A., Espuelas, S., Marcelino, S., et al., 2020. Characterization of Biomass Briquettes from Spent Coffee Grounds and Xanthan Gum Using Low Pressure and Temperature. BioEnergy Research. 13(1), 369–377. DOI: https://doi.org/10.1007/s12155-019-10069-8

[28] Lo, S.L.Y., How, B.S., Teng, S.Y., et al., 2021. Stochastic techno-economic evaluation model for biomass supply chain: A biomass gasification case study with supply chain uncertainties. Renewable and Sustainable Energy Reviews. 152, 111644. DOI: https://doi.org/10.1016/j.rser.2021.111644

[29] Mohagheghi, O., Rezvani, S., Hassannayebi, E., 2024. Stochastic Optimization Approaches to Biomass-to-bioenergy Supply Chain Network Design under Demand Uncertainty. Research Square. DOI: https://doi.org/10.21203/rs.3.rs-4159254/v1

[30] Jayarathna, L., Kent, G., O'Hara, I., 2021. Spatial optimization of multiple biomass utilization for large-scale bioelectricity generation. Journal of Cleaner Production. 319, 128625. DOI: https://doi.org/10.1016/j.jclepro.2021.128625

[31] Raina, N., Zavalloni, M., Viaggi, D., 2024. Incentive mechanisms of carbon farming contracts: A systematic mapping study. Journal of Environmental Management. 352, 120126. DOI: https://doi.org/10.1016/j.jenvman.2024.120126

[32] Thornbush, M., Govind, A., 2025. Monitoring, Reporting, and Verification (MRV) Protocols Used in Carbon Trading Applied to Dryland Nations in the Global South for Climate Change Mitigation. Sustainability. 17(24), 11001. DOI: https://doi.org/10.3390/su172411001

[33] Brinkman, M.L.J., Wicke, B., Faaij, A.P.C., et al., 2019. Projecting socio-economic impacts of bioenergy: Current status and limitations of *ex-ante* quantification methods. Renewable and Sustainable Energy Reviews. 115, 109352. DOI: https://doi.org/10.1016/j.rser.2019.109352