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Engineering Economic Analysis and Process Optimization of Waste-to-Food Conversion from Durian Seed Waste to Support the Sustainable Development Goals (SDGs)

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ABSTRACT

This study presents an engineering economic analysis and process optimization of waste-to-food conversion using durian seed waste as a value-added food product. The research integrates mass balance principles and engineering economic evaluation to assess the technical feasibility, scalability, and financial performance of a home-industry production model within a green technopreneurship framework. Process optimization focuses on improving material utilization, operational efficiency, and production workflow from raw durian seed waste to packaged chips. The economic assessment applies standard engineering indicators to evaluate investment feasibility, capital recovery, and long-term financial sustainability. The results indicate that durian seed waste can be effectively transformed into a commercially viable food product, providing a practical pathway for bio-waste valorization. Beyond economic performance, the proposed waste-to-food system supports circular economy principles and contributes to the Sustainable Development Goals (SDGs). This study offers a scalable engineering-based framework for sustainable agro-waste utilization.

1. Introduction

Recent developments in industrial and business systems increasingly emphasize the integration of technology-driven entrepreneurship and environmental sustainability. Technopreneurship has emerged as a key mechanism for enhancing productivity and competitiveness by combining technological capability with entrepreneurial practices [1]. In parallel, green entrepreneurship promotes environmentally responsible business models that emphasize resource efficiency, waste reduction, and sustainable production [2-5]. Green technology innovation, encompassing both

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product and process innovation, plays a critical role in improving sustainability performance across manufacturing and agro-industrial sectors [6-7].

Within this framework, green technopreneurship provides a strategic pathway for valorizing agricultural and food-processing waste into higher-value products while supporting circular economy principles and sustainable resource management [8-11]. Durian seed waste is generated in substantial quantities in many producing regions and is commonly underutilized or discarded, despite its potential nutritional and economic value. Transforming durian seed waste into food products such as chips offers an opportunity to reduce organic waste, enhance material efficiency, and create additional income streams at the household and small-industry levels.

Previous studies have examined waste-to-product and waste-to-energy systems using techno-economic and engineering economic analyses, highlighting the importance of indicators such as Internal Rate of Return (IRR), Payback Period (PBP), Net Present Value (NPV), and Break-Even Point (BEP) for assessing feasibility and scalability [12-18]. However, many existing studies focus on energy or material recovery pathways or provide generalized economic assessments, with limited integration between detailed process optimization and engineering economic evaluation for food-based waste valorization at a home-industry scale.

Accordingly, this study aims to conduct an integrated engineering economic analysis (EEA) and process optimization of durian seed waste conversion into food products within a green technopreneurship framework. The novelty of this research lies in: (i) the systematic integration of process engineering data, including material flow and unit operations, with comprehensive EEA; (ii) the development of a scalable home-industry waste-to-food model that bridges laboratory-scale concepts and practical commercialization; and (iii) the explicit positioning of waste-to-food conversion as an engineering solution that supports green technopreneurship rather than solely a socio-economic initiative. By combining technical feasibility, economic robustness, and scalability considerations, this study contributes to sustainable manufacturing practices and advances the Sustainable Development Goals (SDGs), particularly SDG 2 (Zero Hunger), SDG 8 (Decent Work and Economic Growth), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action).

2. Literature Review

Technopreneurship has been widely discussed in the literature as a form of entrepreneurship that integrates technological capability with entrepreneurial skills to create innovative and competitive business ventures. Early studies describe technopreneurs as technology-based or high-technology entrepreneurs who leverage technical expertise to develop new products, processes, or services [19]. More recent interpretations emphasize technopreneurship as a strategic fusion of technology and entrepreneurship that enables firms, particularly small and medium enterprises, to improve innovation capacity and market responsiveness [20].

Alongside technopreneurship, green entrepreneurship has emerged as an important approach for addressing environmental challenges through sustainable production and consumption practices. Green entrepreneurs focus on producing environmentally friendly products, minimizing operational costs, conserving natural resources, and implementing energy-efficient technologies [21]. Within the green technopreneurship framework, sustainable technopreneurs are expected to combine technological expertise with the ability to utilize waste resources responsibly, aligning business performance with circular economy principles and long-term environmental sustainability.

From an engineering and economic perspective, the feasibility of green technopreneurship initiatives is commonly evaluated using techno-economic analysis (TEA) and engineering economic analysis (EEA). TEA involves systematic cost–benefit comparisons of alternative process technologies to determine economic competitiveness and scalability [22], while economic analysis evaluates whether a given industrial system is financially viable under specific operational and market conditions [23]. Engineering economic analysis, in particular, provides a structured framework for decision-making by considering capital investment, operating costs, the time value of money, and key financial indicators such as net present value (NPV), internal rate of return (IRR), payback period (PBP), and break-even point (BEP) [24-29].

Several studies have applied engineering economic approaches to waste-based conversion systems, demonstrating their potential to transform low-value residues into economically viable products. Examples include the production of consumer goods from waste materials [12], the processing of agricultural and food industry by-products [13-14], and waste-to-energy systems that emphasize capital recovery and long-term profitability [17-18]. These studies consistently highlight that economic performance is strongly influenced by process efficiency, raw material availability, and the integration of engineering design with market-oriented analysis.

Process optimization is a critical element in improving the feasibility of waste-to-food conversion systems. Optimization efforts typically focus on enhancing material yields, reducing energy consumption, and minimizing losses across key unit operations, including raw material preparation, thermal treatment, and product finishing. In food-based waste valorization, integrating mass balance analysis with economic evaluation allows for more accurate assessment of operational robustness and scalability. However, despite the growing body of literature on waste valorization, limited studies have explicitly combined detailed process flow analysis with comprehensive engineering economic evaluation for food products derived from agricultural waste, particularly within a home-industry or small-scale production context.

Based on the reviewed literature, a clear definition of unit operations and material flow is essential for reliable process optimization and economic assessment. In this study, the durian seed chip production system is structured into sequential processing stages, from raw material preparation to final packaging, as illustrated in Figure 1. The process flow diagram serves as the engineering basis for mass balance calculations, cost estimation, and the subsequent engineering economic analysis of the waste-to-food conversion system.

The production of durian seed chips from waste durian seeds consists of a sequence of integrated unit operations designed to ensure material quality, process efficiency, and product consistency, as illustrated in Figure 1. From an engineering perspective, the overall process can be grouped into four main stages: raw material preparation, pretreatment, conversion, as well as finishing and packaging.

i. Raw material preparation includes the collection and initial sorting of durian seeds to remove foreign materials and unsuitable fractions. The selected seeds are subsequently washed to eliminate adhering impurities and ensure hygienic processing conditions. This stage establishes feedstock quality and uniformity for downstream operations.
ii. Pretreatment operations involve thermal and physical conditioning of the durian seeds to improve processability. The seeds are boiled in a saline solution to soften the structure and reduce undesirable compounds, followed by peeling and size reduction through slicing to achieve uniform thickness. The sliced seeds are then soaked in a treatment solution containing turmeric and lime, which functions to improve color stability, reduce bitterness, and enhance product acceptability. Excess moisture is removed through draining prior to conversion.
iii. Conversion is carried out through thermal processing, where the pretreated durian seed slices are fried in cooking oil to produce chips with the desired texture and sensory properties. This unit operation represents the primary value-adding step, in which heat and mass transfer govern moisture removal, oil uptake, and structural transformation of the product.

iv. Finishing and packaging operations include cooling, seasoning, and final sorting to ensure product quality consistency. The finished chips are then weighed, packaged, and labeled for distribution. These downstream operations are essential for quality control, shelf-life stability, and market readiness of the final product.

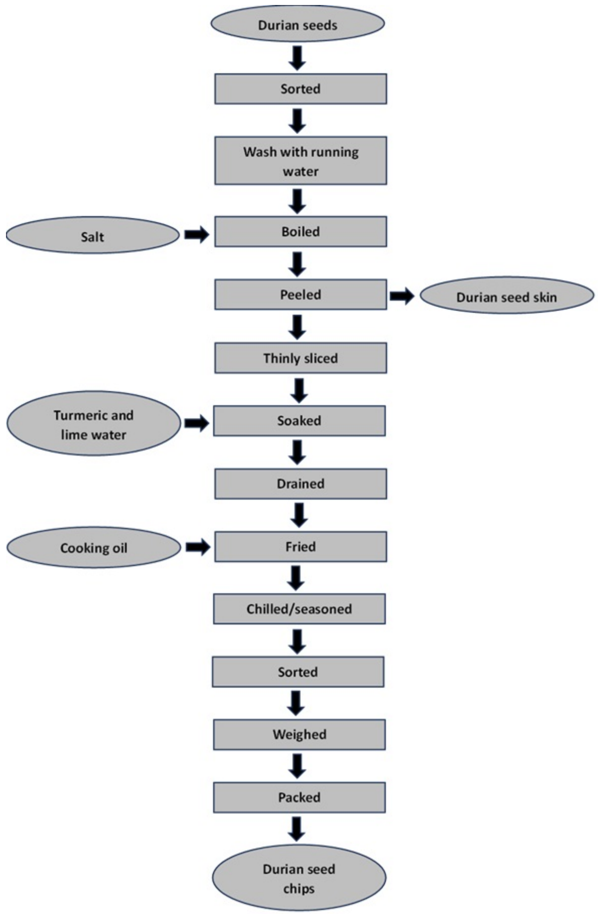

Fig. 1. Flowchart of durian seed chips production

By consolidating the processing steps into unit operations, the durian seed chip production system can be systematically analyzed using mass balance, energy consumption, and cost estimation methods. This structured approach enables process optimization and supports a comprehensive engineering economic evaluation of the waste-to-food conversion system.

3. Methodology

This study applies an engineering economic analysis combined with process-based evaluation to assess the feasibility and scalability of converting durian seed waste into value-added food products. Detailed information for this method is explained elsewhere [30].

The methodological framework integrates process description, mass balance estimation, cost analysis, and financial performance evaluation, which are commonly used in engineering feasibility studies for waste-based production systems. The method can be simply described as follows:

i. Process Boundary and System Description. The system boundary of this study covers the conversion of durian seed waste into packaged durian seed chips at the production site. The process includes raw material preparation, pretreatment, thermal conversion, and finishing and packaging operations, as illustrated in Figure 1. Upstream activities, such as durian cultivation, and downstream activities, such as product distribution, are excluded from the analysis. The process flow diagram serves as the basis for material flow identification, cost allocation, and economic evaluation.

ii. Data Collection and Assumptions. Technical and economic data were obtained from market-based observations, small-scale production practices, and average prices of raw materials and products available on online commercial platforms to reflect current market conditions. This pricing approach is commonly used in preliminary engineering economic evaluations to ensure realistic cost estimation. Several assumptions were applied to simplify the analysis, including steady-state operation, constant production capacity, and uniform product quality throughout the operational period.

iii. Engineering Economic Analysis. The economic evaluation was conducted using standard engineering economic indicators to assess project feasibility. Capital expenditure (CapEx) includes investment in production equipment and supporting facilities, while operational expenditure (OpEx) consists of raw materials, utilities, labor, and other operational costs. Financial performance was evaluated using Internal Rate of Return (IRR), Return on Investment (ROI), Payback Period (PBP), Break-Even Point (BEP), and Cumulative Net Present Value (CNPV). These indicators provide insight into profitability, capital recovery, and long-term financial sustainability of the waste-to-food conversion system.

iv. Production Capacity and Revenue Estimation. Production capacity was defined based on the designed daily output of durian seed chips and the assumed number of operational days per year. Annual revenue was estimated from the product selling price and annual production volume. Cost and revenue calculations were used to determine manufacturing cost, net profit, and break-even conditions under the assumed operating scenario.

Analytical Approach. All calculations were performed using deterministic mathematical formulations based on mass balance and discounted cash flow analysis. This approach ensures transparency and reproducibility of the results and allows comparison with other engineering economic studies on waste valorization and green technopreneurship systems.

4. Results

Table 1 summarizes the raw material requirements and associated costs for the production of durian seed chips under the scaled-up production scenario. The analysis is based on a processing capacity equivalent to one large-scale batch, with an estimated material shrinkage of approximately ten percent during processing due to moisture loss and trimming. Durian seeds constitute the primary raw material, while supporting ingredients include turmeric, lime betel, cooking oil, spices, fuel, and packaging materials, all of which contribute to the overall production cost.

Among the cost components, durian seeds, cooking oil, spices, and seasoning ingredients represent the dominant contributors to raw material expenditure, reflecting their significant usage volumes in the production process. Packaging materials and labels also account for a notable share of the total cost, indicating the importance of downstream finishing operations in food-based waste valorization systems. The total raw material cost is estimated at IDR 326,500,000 per day, which corresponds to an annual raw material expenditure of IDR 97,950,000,000 under continuous operation. This cost structure highlights that raw materials constitute the largest portion of operational expenditure, emphasizing the importance of efficient material utilization and process optimization to improve overall economic performance of the waste-to-food conversion system.

Table 1
Raw material calculation

Raw material	Requirements per small scale production (kg/h)	Large scale production requirements (scale up)	Price (IDR)	Total (IDR)
Durian seeds	100	1000	20,000	20,000,000
Turmeric	4	1000	30,000	30,000,000
Lime betel	3	1000	30,000	30,000,000
Cooking oil	15	1000	25,000	25,000,000
Garlic	2	1000	45,000	45,000,000
Candlenut	1.5	1000	40,000	40,000,000
Red chili	2	1000	60,000	60,000,000
Sugar	2	1000	20,000	20,000,000
Salt	0.5	1000	7,000	7,000,000
Gas 3 kg	9	1000	10,000	10,000,000
Plastic packaging	10	1000	35,000	35,000,000
Packaging labels	100	1000	4,500	4,500,000
Price/day				326,500,000
Price/year				97,950,000,000

Table 2 presents the estimated capital investment for production equipment required in the durian seed chip processing system. The listed equipment represents essential tools and small-scale processing units used across the main unit operations, including slicing, drying, frying, weighing, and packaging. From an engineering perspective, the selected equipment reflects a home-industry–scale production model that prioritizes simplicity, affordability, and operational reliability rather than high automation.

Table 2
Equipment calculation

Tool name	Unit price (IDR)	Amount	Total price (IDR)	2026 price (IDR)
Slicer	80,000	1	80,000	
Tablespoon	4,000	4	16,000	
Measuring cup	20,000	2	40,000	
Gas stove	600,000	1	600,000	
Wooden spoon	12,000	2	24,000	
Paring knife	25,000	3	75,000	
Drying table	350,000	4	1,400,000	
Drying oven	4,000,000	1	4,000,000	
Scales	150,000	1	150,000	
Plastic basin	20,000	3	60,000	
Wok	60,000	3	180,000	
Frying spoon	30,000	3	90,000	
Frying pan	30,000	3	90,000	
Copycat	40,000	3	120,000	
Gas cylinders	200,000	2	400,000	
Total				7,325,000

The total equipment investment is relatively low compared to operational costs, indicating that capital expenditure is not a major barrier to entry for this waste-to-food conversion system. The largest portion of equipment cost is attributed to the drying oven, which plays a critical role in moisture reduction and product stability, followed by supporting thermal processing and handling tools such as gas stoves, woks, and drying tables. Other equipment items, including slicers, scales, and basic utensils, contribute marginally to the overall investment cost but are essential for ensuring uniform processing and product consistency.

The estimated total equipment cost of IDR 7,325,000 demonstrates that durian seed chip production can be implemented with minimal initial capital investment. This characteristic supports the scalability of the process through a distributed home-industry or small-enterprise model, making it suitable for green technopreneurship applications and community-based waste valorization initiatives.

Table 3 presents the profitability and break-even analysis of the durian seed chip production system based on the estimated fixed and variable cost structures. Fixed costs consist of capital-related expenses and asset depreciation, representing long-term investment obligations that remain constant regardless of production volume. Variable costs, which include raw materials, utilities, labor, and sales-related expenses, dominate the total manufacturing cost and are directly influenced by production capacity and operational intensity.

Table 3
Calculation of profit and BEP

Component	Parameter	Cost (IDR)
Fixed cost	Loan interest	
	Capital related cost	2,260,705,237.50
	Fixed cost+depreciation	
	Depreciation	197,067,937.50
	Fixed cost less depreciation	
	Total fixed cost	2,457,773,175.00
Variable cost	Raw material	115,350,000,000.00
	Utilities	360,000,000.00
	Operating labor (OL)	198,000,000.00
	Labor related cost	59,400,000.00
	Sales related cost	9,240,000,000.00
	Total variable cost	125,207,400,000.00
% profit estimated	Sales	132,000,000,000.00
	Manufacturing cost	127,468,105,237.50
	Investment	2,112,298,125.00
	Profit	0.03
	Profit to sales	2.15
BEP	Unit	3,000,000
	Fixed cost	2,457,773,175.00
	Variable cost	125,207,400,000.00
	Sales	132,000,000,000.00
	BEP	1,085,492.967
	Percent profit on sales	0.034332536
	Return on investment	2.299661132
	Pay out time	0.416725506

The analysis indicates that raw material costs constitute the largest share of variable expenses, confirming that material efficiency plays a critical role in determining overall profitability. Based on the projected annual sales and manufacturing costs, the system generates a positive net profit margin, indicating that the waste-to-food conversion process is economically viable under the assumed operating conditions. The ROI value demonstrates strong investment efficiency, reflecting the relatively low capital requirement compared to annual profit generation.

The BEP analysis shows that the system reaches financial equilibrium at a production level significantly below the maximum designed capacity. This result suggests that the operation does not require full-capacity utilization to cover fixed and variable costs, providing flexibility under fluctuating market demand or raw material availability. Furthermore, the estimated payback period confirms that initial capital investment can be recovered within a relatively short operational timeframe, supporting the attractiveness of the project for small-scale entrepreneurs.

The profit and break-even analysis confirm that durian seed waste conversion into chips is financially robust and suitable for scalable implementation within a home-industry or small-enterprise framework, particularly when supported by efficient material utilization and stable market access.

Table 4 presents the estimation of annual revenue for the durian seed chip production system based on the designed production capacity and selling price. The system is designed to operate at a consistent daily output, which translates into a stable annual production volume under the assumed operational schedule. Revenue estimation is derived from the multiplication of annual production capacity and the unit selling price of the finished durian seed chips, reflecting the gross income potential of the waste-to-food conversion process.

The results indicate that the production system is capable of generating substantial annual revenue, demonstrating strong market potential for value-added food products derived from agricultural waste. This level of income highlights the economic attractiveness of durian seed chip production, particularly when implemented within a home-industry or small-enterprise model where operational flexibility and localized market access can be leveraged. From an engineering economic perspective, the high revenue relative to capital investment further strengthens profitability indicators such as return on investment and payback period.

The annual revenue analysis confirms that durian seed waste valorization into chips is not only technically feasible but also commercially promising, supporting the scalability of the process and reinforcing its suitability as a green technopreneurship initiative aligned with sustainable development objectives.

Table 4
Calculation of income per year

Sale		
Capacity	10,000	pcs/day
Capacity	3,000,000	pcs/year
Selling price of board	44,000	/pcs
Income per year	132,000,000,000	pcs/year

Figure 2 illustrates the cumulative net present value (CNPV) normalized by total investment cost (TIC) over the project lifetime, providing insight into the long-term financial performance of the durian seed chip production system. In the initial operational years, the CNPV/TIC curve shows a relatively slow growth trend, reflecting the impact of capital investment and early-stage operational adjustments. This behavior is typical for small-scale processing systems that require an initial stabilization period before achieving optimal production efficiency.

As the project progresses, the CNPV/TIC value increases steadily, indicating that cumulative discounted revenues consistently exceed cumulative costs. The positive and increasing trend demonstrates effective capital recovery and sustained profitability over time. The absence of significant declines in later years suggests that the system maintains financial stability once steady-state operation is achieved. From an engineering economic perspective, the upward trajectory of

CNPV/TIC confirms that the waste-to-food conversion process is not only profitable in the short term but also economically sustainable in the long term.

The CNPV analysis supports the feasibility of scaling durian seed chip production within a green technopreneurship framework, as the project generates increasing economic value throughout its operational life while utilizing agricultural waste as a primary resource.

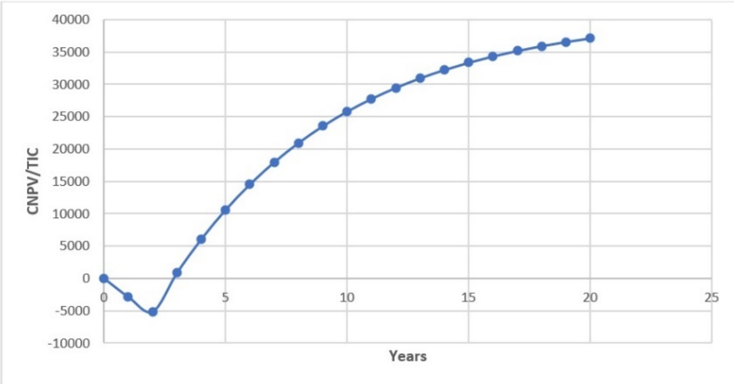

Fig. 2. CNPV/TIC graph per year

The results of the engineering economic analysis demonstrate that the conversion of durian seed waste into value-added food products is both technically feasible and economically attractive within a home-industry production framework. The cost structure analysis indicates that raw materials and operational inputs dominate total manufacturing costs, highlighting the importance of process optimization and efficient material utilization in improving overall profitability. The relatively low capital investment required for equipment further enhances the accessibility of this waste-to-food system for small-scale entrepreneurs and community-based enterprises.

From an engineering perspective, the structured unit operations (from raw material preparation to finishing and packaging) enable systematic mass balance evaluation and cost allocation. This process configuration supports scalability by allowing production capacity to be increased through parallel operation rather than high-cost automation. The favorable break-even characteristics and short capital recovery period suggest that the system remains financially resilient even under partial capacity utilization, which is particularly relevant for agro-waste processing systems subject to seasonal raw material availability.

Beyond economic performance, the proposed waste-to-food conversion system contributes directly to multiple SDGs. The valorization of durian seed waste into edible products supports SDG 12 (Responsible Consumption and Production) by promoting circular resource use and reducing organic waste disposal. By creating income-generating opportunities and supporting small-scale food enterprises, the system aligns with SDG 8 (Decent Work and Economic Growth). The utilization of locally available food resources also contributes to SDG 2 (Zero Hunger) by enhancing food availability and reducing post-consumption waste. In addition, minimizing waste disposal and associated emissions supports SDG 13 (Climate Action). This adds new information regarding SDGs as reported elsewhere [31-35].

The integration of process engineering, engineering economic analysis, and sustainability considerations demonstrates that durian seed chip production is not merely a financial venture but a practical green technopreneurship model. When supported by appropriate market access and operational management, this system offers a scalable pathway for transforming agricultural waste into economic and social value while advancing sustainable development objectives.

4. Conclusions

This study confirms that converting durian seed waste into value-added chips is technically feasible and economically viable within a home-industry production model. The integration of process-based unit operations and engineering economic analysis demonstrates strong profitability, efficient capital recovery, and long-term financial sustainability. Low capital requirements and flexible operating capacity support scalability through small and community-based enterprises. Beyond economic performance, the waste-to-food system promotes circular resource utilization and green technopreneurship, contributing to the SDGs, particularly SDG 2 (Zero Hunger), SDG 8 (Decent Work and Economic Growth), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action). Overall, this research provides a practical engineering framework for sustainable agro-waste valorization.

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Conflict of Interest Statement
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Author Contributions Statement
Author A conceptualized and designed the study, supervised the project, and reviewed the manuscript. Author B conducted the experiments and data analysis. Author C contributed to data interpretation and wrote the initial draft of the manuscript. All authors contributed to manuscript revision, read, and approved the final version.

Data Availability Statement
All data generated or analyzed during this study are included in this published article. Additional datasets are available from the corresponding author upon reasonable request. Where applicable, publicly available datasets used in the study are cited in the references.

Ethics Statement
This study was conducted in accordance with the ethical standards of the institutional and/or national research committee. Ethical approval was obtained where required, and informed consent was obtained from all participants involved in the research.

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